DOCTORAATSPROEFSCHRIFT

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Mental Maps and Daily Travel: Qualitative Exploration and Modelling Framework

Proefschrift voorgelegd tot het behalen van de graad van Doctor in de Verkeerskunde, te verdedigen door:

Els HANNES

Promotor: prof. dr. Geert Wets

universiteit hasselt

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D/2010/2451/16

Voor Peter,
mijn rots,
en voor Jan, Toon en Sien,
onze trots.

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Els

Diepenbeek, 25 juni 2010

SAMENVATTING

De negatieve gevolgen van het almaar stijgend gebruik van gemotoriseerde vervoerswijzen zijn genoegzaam bekend: files, verkeersongevallen, uitstoot van schadelijke stoffen, teloorgang van de publieke ruimte… Om het tij te keren, is beleid nodig dat de vraag naar vervoer zo beïnvloedt dat verplaatsingspatronen duurzamerer worden, met minder trips, kortere afstanden, milieuvriendelijke vervoerswijzen of andere tijdstippen om te reizen. Om het effect in te schatten van maatregelen om de vervoersvraag te managen, kunnen beleidsmakers gebruik maken van computermodellen die de vervoersvraag voorspellen. Bovendien kunnen dergelijke modellen ook de mobiliteitseffecten van meer algemene socio-demografische evoluties in kaart brengen. Ze zijn dus een belangrijke bron van informatie voor rationeel en efficiënt beleid.

Vooral in de wetenschappelijke wereld bestaat recent de tendens om de vervoersvraag in zo'n computermodel te benaderen als de afgeleide van een activiteitenpatroon; mensen verplaatsen zich omdat ze dingen willen of moeten doen op verschillende locaties. Bovendien zijn de huidige computers zo krachtig dat simulaties van het verplaatsingsgedrag van grote groepen mensen op gedesaggregeerd niveau mogelijk worden. Daarom wordt in de meest geavanceerde activiteitengebaseerde vervoersmodellen eerst de tijdsbesteding van mensen voorspeld: voor elk individu in de populatie wordt bepaald welke activiteiten uitgevoerd worden, waar, wanneer, met wie en hoe de verplaatsingen in die agenda georganiseerd zijn.

Om geloofwaardige voorspellingen te doen over het verplaatsingsgedrag in de toekomst, is het belangrijk dat deze modellen de mechanismen van het menselijke gedrag zo realistisch mogelijk nabootsen. Tot op heden is de meest gebruikte methode om beslissingen te genereren in vervoersmodellen gebaseerd op de rationele keuzetheorie en nutsmaximalisatie: mensen overwegen verschillende keuzeopties en de bijhorende eigenschappen en kiezen uiteindelijk voor het alternatief waarvan ze verwachten dat het hen globaal gezien het meeste nut oplevert. De andere aanpak voor het modelleren van de

vervoersvraag beschouwt het plannen van activiteiten en verplaatsingen als een proces van opeenvolgende keuzes die tot stand komen in 'als…, dan…'-redeneringen. Zo'n denkpatroon kan voorgesteld worden in beslissingsbomen. Het nieuwe FEATHERS-model voor Vlaanderen past deze laatste methode toe.

Dit doctoraatsonderzoek wil een bijdrage leveren aan de realistische voorstelling van het menselijk gedrag in activiteitengebaseerde vervoersmodellen. Deze algemene doelstelling wordt verder beperkt tot de weergave van de 'mentale kaart' voor dagelijkse verplaatsingen. Dit begrip duidt niet alleen de ruimtelijke kennis van mensen aan, maar het verwijst ook naar het tijdelijke complex van gedachten wanneer mensen beslissingen nemen. Aangezien het plannen van activiteiten en verplaatsingen, het nemen van beslissingen in ruimte en tijd met zich meebrengt, omvat dit concept deze twee belangrijke aspecten in het tot stand komen van individueel verplaatsingsgedrag.

Er zijn drie stappen in dit onderzoek: eerst wordt de rol van de mentale kaart in dagelijkse verplaatsingen verkend. In deze fase houden 20 mensen gedurende een week een gedetailleerd dagboek bij. Daarbij worden ze vooraf uitgebreid geïnterviewd over hun plannen en nadien over de uitgevoerde activiteiten en verplaatsingen. Op basis van de bevindingen uit dit kwalitatief onderzoek, wordt in de tweede stap een concept ontwikkeld voor het modelleren van de mentale kaart van één individu. Als voorbeeld worden de werkgerelateerde verplaatsingskeuzes van een moeder van 3 jonge kinderen gemodelleerd in een Bayesiaans beslissingsnetwerk. In de derde en laatste stap van het onderzoek worden normale werk- en schoolroutines van jonge gezinnen in kaart gebracht op basis van populatiegegevens. De op die manier ontwikkelde familiepatronen worden in dit onderzoek gebruikt als toetssteen voor de uitkomst van het FEATHERS model. Later kunnen deze patronen ingebouwd worden in het model om de weergave van het menselijke gedrag te verbeteren.

De belangrijkste bevinding uit de kwalitatieve interviews is dat de dagelijkse activiteiten en verplaatsingen van mensen meestal niet bewust gepland worden, maar dat ze voor een groot deel bepaald zijn door vaste routines en scripts die het gedrag automatisch sturen, al naar gelang de omstandigheden. In het dagelijkse leven zijn echte verplaatsingskeuzes eerder zeldzaam en de beslissingsprocessen zijn zeer kort. Activiteiten- en verplaatsingspatronen zitten verankerd in engagementen op lange termijn zoals het werk, de woonplaats, het gezin, de auto … Daarom kan de mentale kaart van dagelijkse verplaatsingen gedefinieerd worden als een individueel repertoire van vaste scripts van activiteiten en verplaatsingen waarin bepaalde ankerpunten in tijd en ruimte de krijtlijnen uitzetten voor de dagdagelijkse tijdsbesteding van elk individu.

In de daarop volgende casestudy van zo een *mentaal repertoire* van een werkende moeder van 3 jonge kinderen is aangetoond hoe werkgerelateerde activiteiten en verplaatsingskeuzes verband houden met allerlei contextuele factoren. Deze omstandigheden maken bepaalde activiteiten (op bepaalde plaatsen) noodzakelijk, omdat ze horen bij de sociale rol(len) die het individu heeft opgenomen. De onmiddellijke, subjectieve beoordeling van gepast gedrag in welbepaalde omstandigheden volgens het individuele beeld van de sociale rol kan tegelijkertijd ook het mechanisme vormen voor de waardering van keuzealternatieven in een rekenkundige vertaling van deze mentale kaart als een Bayesiaans beslissingsnetwerk. Hierin kunnen zowel de normale routines als het gedrag in uitzonderingsscenario's weergegeven worden.

Verder onderzoek van de normale werk- en schoolverplaatsingen in gezinnen met jonge kinderen in Vlaanderen bevestigt dat dergelijke verplichte activiteiten niet van dag tot dag gepland worden, maar dat ze deel uitmaken van patronen die een bepaalde standaard organisatie van het hele huishouden reflecteren. 10 typische familiepatronen zijn onderscheiden en verder geanalyseerd. Deze patronen zijn dan vertaald in een reeks van letters volgens de notatiemethode van DNA-strengen. Vervolgens zijn de posities van de karakters die school- en werktrips weergeven in deze strengen gebruikt om na te gaan hoe goed het huidige FEATHERS model deze familiepatronen voorspelt. Er is daarbij vastgesteld dat het FEATHERS model het aantal verplaatsingen met als motief 'halen en brengen' in jonge gezinnen onderschat, en dat interacties op het niveau van het huishouden nog onvoldoende in rekening worden gebracht. Op deze punten kunnen de ontwikkelde familiepatronen de toekomstige versies van het model verbeteren.

SUMMARY

The use of motored means of transport is continuously growing, and its negative consequences are clear: traffic-jams, road accidents, emission of noxious gases, loss of public space … To turn the tide, policy measures are needed to alter the demand for travel in sustainable travel patterns with a reduced number of trips, shorter distances, environmentally friendly travel modes or different travel times. To estimate the effect of such travel demand management measures, policy makers may use computer models to predict the population's travel demand. Moreover, these models make it possible to map out the mobility effects of general socio-demographic changes as well. This way, they are an important source of information in rational and efficient policy making.

In a scientific realm in particular, there is a clear tendency to approach travel demand in such a computational model as derived from an individual's activity pattern; people travel because they want or need to do things at various locations. In addition, the increase in computational capacity of the past decades enables to simulate travel behaviour of large groups of people at a disaggregate level. That is why people's time use is predicted first in most advanced activity based models of travel demand: for each individual in de population a daily schedule is determined, indicating the activities to perform, where, when, with whom and setting the organization of tours and trips in this agenda.

To make plausible forecasts about future travel behaviour, it is important to represent individual's actual behavioural mechanisms as true as possible in these models. To date, the most frequently used method to generate individuals' decisions in travel demand models relies on rational choice theory and expected utility maximization: people consider different choice options and their characteristics and eventually, they choose the alternative that is expected to yield the highest overall utility. Another approach to model individuals' travel demand considers planning of activities and travel to be a process of successive choices that come about in 'if…, then…' lines of reasoning. This way of thinking

can be represented in decision trees. The newly developed FEATHERS model of travel demand for the region of Flanders in Belgium applies the latter method.

This doctoral research aims at contributing to the true representation of human behaviour in activity based models of travel demand. This general goal is narrowed down to the interpretation of the 'mental map' in daily travel behaviour. This notion does not only indicate an individual's spatial knowledge base, but it refers to the temporary complex of thoughts when people make decisions as well. Thus, because planning of activities and travel involves decision making in space and time, this concept covers two important aspects in the formation of individual travel behaviour.

There are three distinct steps in this research: the role of the mental map in daily travel is explored to start with. In this phase, 20 respondents keep a detailed diary during one week. They are interviewed in depth about their plans before the registration week, and afterwards about their executed activities and travel. Based on the findings of this qualitative research, a concept is developed in the second research step to model the mental map of a single individual. As an example, the work-related travel choices of a mother of 3 young children are modelled in a Bayesian decision network. In the third and final step of this research, normal work and school routines of young households are mapped based on population data. This way, family patterns are developed that are used to benchmark the outcome of the FEATHERS model in this research. Later on, these patterns can be implemented in the model to improve its behavioural realism.

The most important finding from the qualitative interviews is that daily activities and travel are not planned consciously, generally speaking. Rather, they are largely determined by fixed routines and scripts that guide individual behaviour automatically, depending on the circumstances. Actual travel choices are rare and decision processes are very short. Activity and travel patterns are anchored in long-term commitments such as the job, the house, the family, the car, the social club… Accordingly, the mental map can be defined as a repertoire of fixed activity and travel scripts in which spatio-temporal anchor points chalk out the blueprint of individual schedules.

In the subsequent case study, such a mental repertoire of a working mother of 3 young children shows how work-related activity and travel choices depend on various contextual factors. These circumstances impel certain activities (at certain locations) because these activities are part of the engagements and social role(s) of the individual. At the same time, the immediate, subjective assessment of appropriate behaviour in specific circumstances according to the individual image of the social role can form the valuation mechanism of choice options in a computational translation of this mental map in a Bayesian decision network. Such a network is able to represent the normal activity and travel routines as well as behaviour in exceptional scenarios.

Further research of normal work and school travel routines in families with young children in Flanders confirms the finding that mandatory activities such as working or attending school are not scheduled on a daily basis. Rather, they are part of activity and travel patterns reflecting a particular standard organisation of the entire household. 10 typical family patterns are discerned and analysed further. Next, these patterns are translated in sequences of letters according to the representation of DNA-strings. The position of characters representing school and work trips in these sequences is then used to check how well the current version of the FEATHERS model predicts these family patterns. This benchmarking exercise reveals that the FEATHERS model underestimates the number of trips to 'bring and get' people in young households, and that interactions on the household level are insufficiently taken into account to date. In this respect, the family patterns developed in this PhD research can improve future versions of the FEATHERS model and better the true representation of human behaviour and decision making in this model.

LIST OF ABBREVIATIONS

AB	Activity-Based
ALBATROSS	A Learning-BAsed TRansportation Oriented Simulation System
API	Application Programming Interface
BIN	Bayesian Inference Network
BTM	Bus Tram Metro
CAQDAS	Computer Aided Qualitative Data Analysis Software
CNET	Causal Network Elicitation Technique
CPM	Computational Process Model
CPT	Conditional Probability Table
CUT	Conditional Utility Table
EUT	Expected Utility Theory
FCM	Fuzzy Cognitive Map
FEATHERS	Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS
GPS	Global Positioning System
IWT	agentschap voor Innovatie door Wetenschap en Technologie / Agency for Innovation by Science and Technology
OD	Origin Destination
PDA	Personal Digital Assistant
PM	Partial Municipality
PSSM	Position Specific Scoring Matrix
PT	Public Transport
RUM	Random Utility Model
SEE	Socio Economic Enquiry
SS	Statistical Sector
TDM	Travel Demand Management
UH	Universiteit Hasselt / Hasselt University

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1 INTRODUCTION

1.1 Problem Statement

Mass motorization has changed both the life and living environment in industrialized regions over the past century. Almost 100 years ago, Henry Ford did not only start one of the most influential economies in history to date, his 'cars for all' principle marked an era of welfare capitalism, widespread private car ownership, car-oriented land use schemes (sprawl) and ubiquitous motor traffic. After the post-war baby boom and rapid economic expansion, the sticker slogan: 'My car, my freedom' decorated a number of rear windows in Flanders in the 1970's and 80's. This motto expressed consumer's pride and deep-rooted conviction that his car would take him anywhere he wanted, anytime. In an era of early energy crises, economic recession and awakening environmental concern, individual mobility by car was an acquired right. However, with expanding action spaces and ever increasing car use, the dark downside of added individual choices became manifest in endless traffic jams, car accidents, monopolization and deterioration of public spaces, excessive consumption of land, oil depletion, air pollution, health issues… Society has grown into an untenable lifestyle. Modern citizens are captives of a car-way of thinking in a car-oriented environment (Goodwin, 1995; Peeters, 2000; Urry, 2004). 'Our cars, our prison', might reflect reality much better nowadays.

Originally, planning policies focussed on mastering the increasing post-war travel demand by expanding the supply of transportation infrastructure. These policies were adopted in an immediate response to the predicted growth in car ownership and use. Yet the rise continued steadily and additional infrastructural capacity even induced new traffic flows (Hansen & Huang, 1997; Noland, 2001), the so-called transportation rebound effects (Victoria Transport Policy Institute, 2009). Moreover, it enhanced urban sprawl (Handy, 2005). Maintenance and expansion of existing infrastructure made heavy demands on limited financial resources, and negative effects of vast amounts of motorized traffic gradually came to be policy concerns. The Club of Rome and its famous report, 'Limits to

Growth' (Meadows et al., 1972), introduced a general environmental awareness, whereas the Brundtland report, 'Our common Future' (World Commission on Environment and Development, 1987), added to the growing concern of managing the environment in the pursuit of economic wealth and pushed 'sustainable development' into the mainstream political agenda. Against this background, transportation policies shifted from mere facilitation to reduction and control (Dijst, 1997).

A general term for policy strategies that should result in more efficient use of transportation resources is travel demand management (TDM). Objectives of such strategies are to: (1) change travel behaviour to avoid massive infrastructure expansion, (2) exploit existing transportation facilities to the full and (3) avoid harmful effects of the uncontrolled growth of private car use (Krygsman, 2004). Victoria Transport Policy Institute (2009) offers a comprehensive overview of TDM measures, such as improving transport options, promoting alternative modes to reduce driving, managing parking and land use and reforming policy and institutions. A common theme in TDM is to persuade or force people to make sustainable travel choices.

Parallel to this swing in transportation policy, methodological changes could be witnessed in the scientific support of transportation planning in the second half of the 20th century. Since the early 60's, a rational process view of planning was widespread and faith in the application of scientific tools to inform policymaking and evaluate alternative plans was increasing rapidly (Taylor, 1998). In transportation, four-step models of travel demand constituted the dominant approach to estimate person travel (McNally, 2000; Ortúzar & Willumsen, 2001). These models dealt with trip generation, trip distribution, modal choice and route assignment successively. They were designed for the analysis of urban highway expenditure before all else, and the earliest versions were applied effectively at an aggregate space-time level (Bates, 2000).

However, four-step trip-based models generally simplified travel as an isolated phenomenon, irrespective of trip purposes, activity sequences or person characteristics. Although next generation tour-based models sought to overcome some of these shortcomings by taking sequential information in home or work-based travel tours into account, more flexible and detailed demand structures were required in the light of changing lines of policy. The need to effectively analyse, evaluate and implement a range of complex TDM measures and scenarios gave rise to the awareness that an improved understanding of individual travel choices and behaviour is essential to accomplish reliable and policy responsive forecasts. In order to reflect individuals' responses to a wide range of policy measures, advanced travel demand models needed to incorporate realistic representations of decision making processes and contexts (Bhat & Lawton, 2000). An important part of this call is answered in the current activity-based (AB) modelling framework. This approach is gaining importance in the design and evaluation of policies aimed at a growing list of concerns (Mahmassani, 2000; Vovsha & Bradley, 2006).

Building on ideas originally put forward by Hägerstrand (1970) and Chapin (1974), the AB approach is founded on the recognition of the derived nature of travel; individual mobility results from the need or desire to engage in activities at various locations. Therefore, AB modelling efforts concentrate primarily on modelling activity schedules that trigger and include travel participation, akin to time-use research objectives (Bhat & Koppelman, 1999). The aim is to predict which activities are conducted, where, when, for how long, with whom, as well as how to get to these locations. In addition to this shift from trip-based to AB models of travel demand, modelling techniques have evolved from aggregate approaches to micro-simulation of individual behaviour (Lemp et al., 2007) favoured by the vast increase in computational capacity during the last decades (Koskenoja & Pas, 2002).

Computational models of complex behavioural processes such as activity and travel scheduling and execution, typically rely on broad assumptions about human behaviour and developers' domain knowledge. Since its first applications the AB modelling theory and practice has been refined in numerous analyses, specific behavioural hypothesis tests and explorations of modelling methods. An overview of important aspects involved in AB analysis and modelling is provided by Ettema and Timmermans (1997), and further progress is reported by Timmermans (2005).

At the same time, the adequate representation of decision mechanisms of individuals and households underlying activity and travel scheduling remains a vexed question (Ben-Akiva et al., 1998; Timmermans & Zhang, 2009; Williams & Ortuzar, 1982), especially in the light of agent-based micro-simulation (Davidson et al., 2007). Moreover, a stronger behavioural paradigm is pursued by considering mediating constructs that can account for unexplained heterogeneity in travel choices by current models, such as an individual's perception and cognition of space (Walker, 2006). Only recently, Henson et al. (2009) identified spatial and temporal resolutions and cognitive-behavioural capabilities to be the main weaknesses of current AB modelling and simulation in a review of 53 AB models, limiting their range of application.

These two issues, i.e. space and decision making, are central in this PhD research. From an individual's point of view, planning and executing activities and travel entails decisions about time and space. In this context, both the mental representation of decision problems and cognition of space share a common denominator in the term 'mental map' (Hannes et al., 2009). These multiple meanings of mental maps and their representation in an AB model are the subject matter of this thesis. The background section of this chapter offers a concise introduction to mental maps and AB models, including the actual AB model under consideration (FEATHERS).

While the broad theme of improving the behavioural realism of AB travel demand models is narrowed down to mental map aspects in this PhD research, the initial and most important methodological approach is qualitative in nature. Current AB models are based on socio-economic variables and observed behaviour reported in standard activity-travel diaries and surveys. Although recent technological advances such as handheld computers and a global positioning system (GPS) have increased the level of detail and spatial accuracy of these surveys, e.g. Kochan et al. (2008), mainly outcomes of individual choices are registered. However, a diary-based monitoring process says little to nothing about *why* choices are made or *how* decisions take shape. Such questions generally call for a qualitative approach (Bradley, 2006). Even though this is not a mainstream method in transportation at all, understanding travel behaviour and the impact of TDM as opposed to simply measuring it, suggests the need for qualitative evaluation (Cohen, 2009).

The issue of behavioural realism of travel demand models and the representation of decision making touches an ongoing debate in transportation sciences (Shiftan & Ben-Akiva, 2008). On the one hand, pragmatic modellers believe that as long as the outcomes of the model fit observed or observable behaviour to a sufficient level, it can be assumed that the inner workings are implicitly captured by the model. In this 'black box' approach (Walker, 2006), there is no need to fully understand what goes on inside the model, let alone to increase its complexity for the sake of behavioural realism. On the other hand, Roorda and Miller (2005, p. 204) show that: "*It has been argued that understanding the underlying process of activity scheduling is crucial for a more accurate prediction of activity-travel patterns*". Indeed, behavioural purists adhere to the idea that better understanding of real decision processes will improve modelling forecasts (Algers et al., 2005). Their strongest argument concerns the use of the model to predict future behaviour; as future conditions are uncertain, at least the modelling principles should reflect empirically grounded, real-world behavioural mechanisms in order to produce plausible results (Reich, 2000).

In summary, the problem is that AB models of travel demand mainly rely on observed behavioural outcomes instead of empirically grounded domain knowledge about activity and travel decision mechanisms. Moreover, modelling paradigms and techniques from various fields are adopted without questioning its behavioural validity in a different context. Limited efforts are made to scrutinize the rationale behind activity and travel planning and execution within the actual field of AB travel demand modelling, and to develop modelling principles accordingly. Furthermore, although the output of AB models should reflect such domain specific theories, their presence is hardly ever verified in modelling results.

1.2 Research Objectives

Consequently, the main research question corresponding to the general objective of this doctoral thesis to improve the behavioural realism of AB models, can be formulated as follows:

How to establish a better representation of true behavioural mechanisms underlying activity-travel scheduling in AB models of travel demand?

Since future circumstances are uncertain, the behavioural principles grounding activity-travel planning and execution constitute the bond to empirical reality in forecasts of future behaviour. Hence, improving the behavioural realism of AB models will increase the credibility of impact assessments of complex TDM policies.

Decision making and the use of space are inherent to travel. Therefore, the integration of *mental map* characteristics related to *daily travel behaviour* is sought more specifically. This mental map notion covers both individual's mental model of decision problems and individual's cognition of space. Since daily travel constitutes the major share in an individual's activity-travel pattern, the focus lies on everyday activities such as working, going to school, etc.

In pursuit of this general objective, three successive research objectives and steps are distinguished: (1) explore how the mental map shapes individual daily activity-travel choices, (2) formulate a representative, computational mental map model, and (3) conceptualize the integration of the mental map in an AB model of travel demand and test its occurrence in the output of an AB model.

Figure 1 summarizes the main focus in each of these research steps, as well as the scope in the transition from one research phase to another. Furthermore, this figure indicates the method, the expected outcomes and the input in each research phase to meet these objectives.

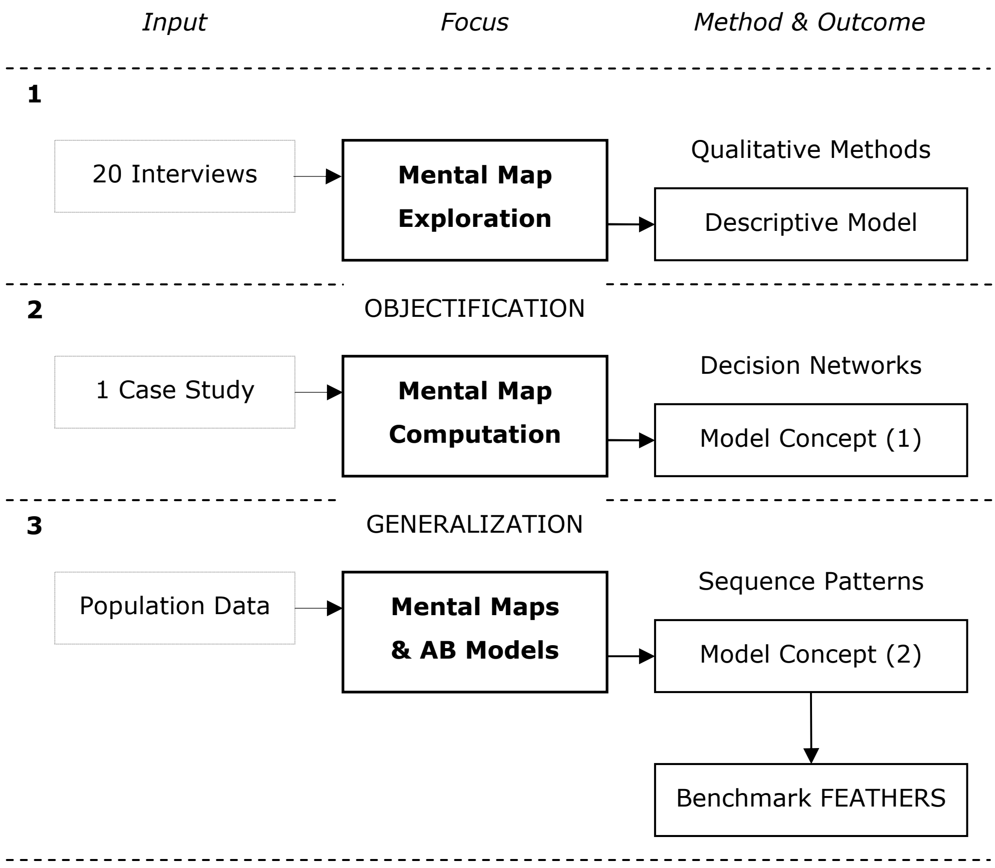


Figure 1 PhD Research Objectives

Methodologically, a qualitative approach characterizes the *first* research phase in which the mental map in daily activity-travel behaviour is explored to reveal relevant behavioural mechanisms and properties. In addition to the common registration of individual travel patterns, their behavioural grounds are examined in a series of in-depth interviews before and after planning and executing activities and travel. How and why questions are central in this type of inquiry, resulting in a comprehensive, descriptive model of the mental map in daily travel.

Bearing the final modelling goals in mind, the *second* step needs to objectify this descriptive mental map of daily travel in a computational application. This transition form qualification to quantification of the mental map is proposed on an individual level in a single case study of a mental map to start with. Although the computational representation of a mental map can take many shapes, a first conceptualization corresponding to the peculiarities of individual activity-travel execution and AB modelling is sought in decision networks.

Finally, in the *third* research phase, further generalization of these research findings is required in order to achieve a better representation of mental map characteristics in AB models of travel demand. Population data enable to scale up the representation of mental map aspects, while their second conceptualization as sequence patterns is supported by state-of-the-art modelling practice. In addition, the outcomes of this modelling exercise can be used to check whether the model output data reflect the developed mental map theory.

In meeting these objectives, the contribution of this research to the state-of-the-art is twofold from a scientific point of view. On the one hand, modellers are informed about cognitive mechanisms underlying daily travel, enabling a true representation of decision making in AB models. On the other hand, the application of qualitative methods in travel behaviour research is shown, specifically its significance to applied model development.

Besides this direct scientific use, the societal relevance of this research is mainly indirect. Assuming that increasing the behavioural realism of travel demand models will lead to better simulations and predictions, the ultimate interest is to improve informed policymaking based on a better AB model. However, policy makers too could benefit from the in-depth view on the mental map based on qualitative inquiry; simply knowing what drives people might help the design of effective policies to channel travel behaviour.

1.3 Background

To fully understand the research effort and outcomes described in the following chapters, mental maps and AB modelling of travel demand need some further introduction. Therefore, this background section positions the mental map to start with, highlighting its double interpretation related to travel behaviour. AB models and their representation of both decision making and space are discussed next. Finally the AB model at stake (FEATHERS) is presented, as well as its forerunner (ALBATROSS).

1.3.1 Multiple Meanings of Mental Maps

The term 'mental map' is commonly used to represent the internal knowledge base of a human data processor, i.e. notions and know-how in the mind concerning a certain issue or question. Most often, this concept is related to geographical or physical spatial aspects – hence the use of the 'map' metaphor (Kuipers, 1982) – but distinct interpretations exist in different scientific fields.

Ever since behavioural psychologist Tolman (1948) first put forward the original synonym 'cognitive map', this concept has been studied, adopted and adapted in various disciplines such as cognitive psychology, behavioural geography, computer science, engineering, neuropsychology, etc. For instance, our analysis of 305 references generated by entering the search term 'mental map*' in the ISI Web of Knowledge (Thomson Scientific, 2008) shows that present sources can be assigned to 83 different subject areas. Inevitably, this has led to the attachment of multiple meanings to the concept, and a proliferation of related terms such as: '(spatial) mental model', 'mental representation', 'cognitive image', 'cognitive collage', 'mind map', etc. Figure 2 illustrates the most commonly used terms linked to their top 5 related subject areas. Even within one field, various metaphorical expressions are used. For instance, Barkowsky (2002) lists several notions for spatial mental knowledge processing, and according to Montello and Freundschuh (1995), up to 200 combinations of adjectives and nouns referring to cognition and space for describing environmental spatial knowledge are conceivable.

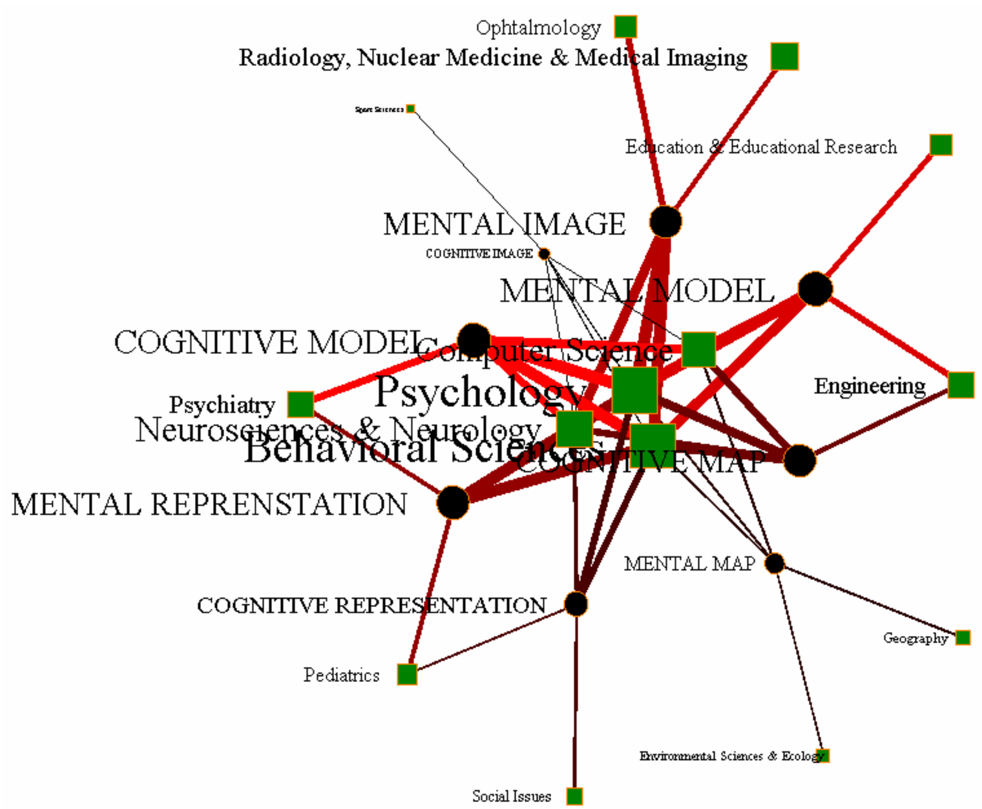


Figure 2 Force Directed Network Visualization (NWB Team, 2006) of Mental Map Synonyms (Circles), and Their Top 5 Related Subject Areas (Squares) in the ISI Web of Knowledge

Because of varying contents of the mental map and its applications across different contexts and conditions, as well as its lack of a fixed and precise meaning, it has become an outstanding example of a fuzzy concept. Yet using such ill defined constructs may lead to misunderstanding and misinterpretation. Moreover, its vagueness and ambiguity can hinder computational implementation. Although the mental map and its intuitive, virtual definitions might be sufficiently clear and self-explaining to use in human communication, definitions for the reconstruction of a knowledge universe require a far-reaching process of formalization in which mathematical logic plays a key role (Lucardie, 1994). During this process, the meaning of a concept often appears to become less clear.

This is exactly what happened to the mental map concept in the travel demand research community to date. Clearly, the expression will be intuitively understood by most travel behaviour researchers. However, there is no generally accepted definition in this field – each author basically defines the notion closely to the task at hand –, let alone a universally applied method to take the concept into account in computational applications such as travel demand models. Still its importance to understand travel behaviour is widely recognized (Chorus & Timmermans, 2009; Hannes et al., 2009a). Moreover, in theoretical accounts on travel demand models, the mental map is mentioned as a distinct behavioural factor, for instance: Arentze and Timmermans (2000, p. 76) mention the cognitive environment when drawing up the ALBATROSS concept; Golledge et al. (1991, p. 6) describe the cognitive map in the conceptual framework of their SCHEDULER model; Meister et al. (2005, p. 475) indicate the mental map and the mental repertoire in the framework of a dynamic genetic algorithm-based household scheduler; Salvini and Miller (2005, p. 220) refer to the mental map when discussing the state representation in their ILUTE model. However, measurement of this construct and putting the concept into operation in actual forecasting models proves to be problematic (Golledge & Gärling, 2004), to say the least, partly due to its fuzzy nature.

Mental map notions from two major areas of research are particularly relevant to travel demand modelling: spatial cognition and decision making. First of all, since travel involves movement in space and time, there is an obvious spatial component to the execution of travel plans. Thus, individual's perception and comprehension of geographical space is a key factor to understand travel behaviour; the mental map is human's spatial knowledge base, incomplete and biased, regularly updated by travel experiences and foundation of various travel decisions at the same time (Weston & Handy, 2004). This brings us to the second notion of the mental map stemming from decision theory and human reasoning: it conveys the mental representation of a decision problem; a temporarily generated mental model in someone's thought process including relevant choice factors and decision rules (Johnson-Laird, 2004). As planning and executing activity schedules involves different choices such as destination, travel mode and route choices, spatial knowledge is anchored in this broader, general decision process. Both meanings of the mental map, i.e. representation of individual's spatial knowledge (the *geographical mental map*) and mental model of personal thought processes related to travel decisions (the *decision making mental map*), are crucial to comprehend individual's travel behaviour. The conceptual diagram in Figure 3 illustrates these distinct interpretations of the mental map. In the next sections, relevant aspects of mental maps in both related research areas related to travel behaviour are summarized.

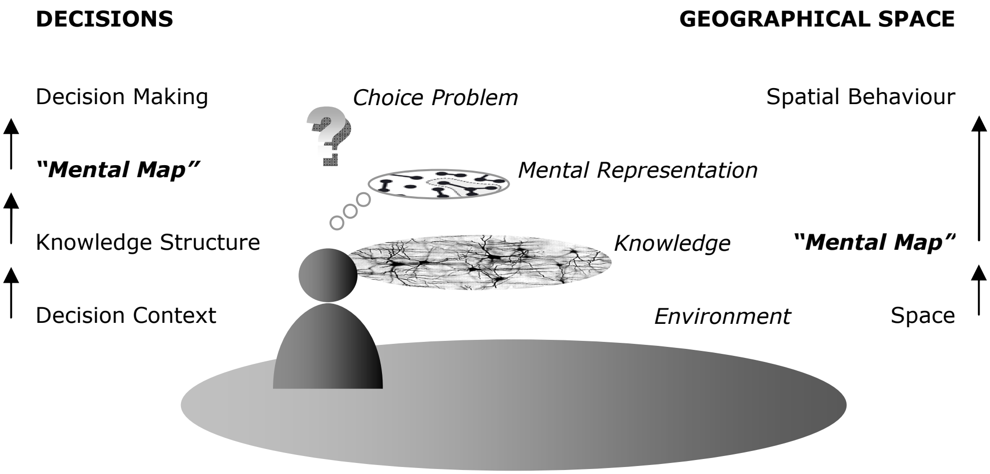


Figure 3 Multiple Meanings of Mental Maps Related to Travel Behaviour

1.3.1.1 Geographical Approaches

In geographical approaches, the 'mental map' usually reflects an individual's spatial knowledge base. This is all location-specific information about the world stored in memory (see Figure 3, right-hand side) in the *geographical mental map*. Some well-known techniques to explore people's knowledge about the environment are asking respondents to sketch a map of a certain area, to describe routes or to estimate distances. This way, content, structure and biases in geographical mental maps are defined, and individual differences are determined. Reviews are numerous: e.g. Mark et al. (1999) provide a historical overview, Gould and White (1986) show different examples and Golledge and Stimson (1997) highlight various research aspects.

Not all geographic knowledge is relevant in everyday travel behaviour. Daily activity spaces are small compared to the likely extent of the entire spatial knowledge universe of the individual, and relatively well-known. Yet, on the one hand, imperfect information – even about daily activity locations – may affect the knowledge and appreciation of the accessibility of an area, hence the considered destinations, transport mode options or route alternatives when planning a trip.

Executing travel plans, on the other hand, involves interactions with the environment. This entails updating, detailing or completing existing spatial knowledge. Spatial learning of large-scale environments is reflected in theories of spatial knowledge development. Siegel and White's model of evolving geographical mental maps from landmark over route to survey knowledge is the dominant framework, but its stage-like development assumption is contested (see Ishikawa & Montello, 2006).

Particularly interesting for travel behaviour is the 'anchor point theory' suggested by Golledge (1978), in which a hierarchical ordering of locations, paths and areas is based on the relative significance of each of these to the individual. Important elements of the daily activity space such as home, work, and shopping serve as initial primary anchor points for further spatial knowledge acquisition. Anchor points of the daily activity space form the basis of a skeletal mental map structure. Additional anchor points may include commonly recognized elements of the environment, such as well-known landmarks, nodes, routes, edges and districts which generally constitute the 'image of the city' (Lynch, 1960). Travelling between these places adds to the development of area concepts such as neighbourhoods, regions, etc.

There are some specific theoretical accounts with regard to travel behaviour and the geographic notion of the mental map, e.g. Golledge and Gärling (2003) and Weston and Handy (2004). Related empiric research mainly focuses on way finding and navigation. The impact of the geographical mental map on travel decisions prior to route choices such as transport mode decisions, destination choices and activity scheduling is less well documented. Two recent examples can be found: based on distance estimates and estimates of the relative distance to pairs of commonly known destinations, Mondschein et al. (2008) show that individual differences in spatial knowledge (hence individual differences in accessibility) are related to previous travel experiences and differences in transport mode use; Chorus and Timmermans (2009) examine stated and revealed geographical mental map quality and find similar evidence of better spatial knowledge for people who travel by car or bike (active transport modes) than people who travel by bus (a passive mode).

1.3.1.2 Decision Making

The second meaning of the 'mental map' relevant for individual travel behaviour is its notion of temporary mental representation of a decision problem (see Figure 3, left-hand side) or the *decision making mental map*. This specific meaning builds upon the seminal work on cognition and planning of Hayes-Roth and Hayes-Roth (1979), and it is related to the general research area of mental models of deduction, e.g. Johnson-Laird (2004). Faced with a decision problem such as in activity and travel scheduling, individuals explore and evaluate alternative courses of action, taking personal contexts, means and goals into account. Therefore, a temporary and situation-specific reduction of reality is created in mind. Obviously, the decision context in which people operate and the knowledge they rely on, exceeds mere spatial characteristics. Most common techniques to elicit mental representations are thinking aloud methods (Someren et al., 1994) and laddering (Neimeyer et al., 2001). The latter technique links thought processes to core values and beliefs of an individual. However, Fujii and Kitamura (2004) elicit mental representations of travel time in a survey using written questionnaires.

In decision theory in general, the predominant paradigm is expected utility theory (EUT) founded in von-Neumann and Morgenstern's utility theorem (McFadden, 2001). Here, a decision is considered to be a choice out of certain options, depending on the probability of occurrence and a valuation of alternatives. This implies a considerate, informed decision maker, prone to a high degree of rationality, as opposed to approaches that account for bounded rationality (Simon, 1990), intuition (Plessner et al., 2008) or uncertainty and lack of information of the decision maker (Frederick, 2002; Tversky & Kahneman, 2002). Most often, the decision making mechanisms in the latter behavioural approaches are referred to as fast and frugal heuristics (Gigerenzer et al., 1999). For a theoretical account on behavioural decision making in travel behaviour, see Svenson (1998).

This dichotomy (rational versus behavioural) in theoretical approaches of decision making applies to the different types of decisions that characterize individual travel as well. On the one hand is the repetitive nature of trips (such as commuting, chauffeuring kids to school, grocery shopping) likely to render (once) conscious decisions into script-based or habitual behaviour (Gärling & Axhausen, 2003). On the other hand is activity scheduling (including choices of destinations, travel modes and routes) likely to entail the coordination of competing goals and intentions (e.g. amongst household members) in a complex environment (e.g. traffic-jams, opening hours), similar to complex planning problems (Gärling et al., 1997). The actual decision making mechanisms of daily activity and travel scheduling and execution are scrutinized further in this PhD research.

The decision making mental map of travel decisions can be modelled as a decision network such as a Bayesian Inference Network (BIN) or a Fuzzy Cognitive Map (FCM) (Hannes et al., 2009). Only recently, Arentze et al. (2008) have developed the Causal Network Elicitation Technique (CNET) method to elicit individual's mental representations of intertwined spatio-temporal travel decisions, and they have tested the method in a complex shopping-trip planning experiment. Kusumastuti et al. (2008) have applied this method on less complex travel decisions related to leisure shopping. These applications inspire the modelling efforts of daily activity-travel in this PhD research.

1.3.2 Activity-Based Models of Travel Demand

Since this research aims to acknowledge mental map characteristics in an AB model of travel demand, an explanation of these models is needed. First, the AB modelling framework and its scheduling component are introduced. In the next sections, specific attention is paid to their representation of decision making and their spatial characteristics, given the dual meaning of the mental map. Whereas Henson et al. (2009) provide a concise overview of general AB model paradigms and AB model spatial and temporal resolutions in 53 AB models to date, these sections highlight features and properties of AB models related to the content and properties of decision making mental maps in Section 1.3.2.2 and geographical mental maps in Section 1.3.2.3.

1.3.2.1 Activity-Based Model Framework and Scheduler

Generally speaking, an AB model of travel demand consist of various model components to streamline the process from population input to travel output (see Figure 4). A *population synthesizer* is required to generate population input data sensitive to demographic evolutions. The *scheduler* uses this input and additional data such as transportation and land use characteristics from other model components to generate detailed activity and travel plans. Subsequently, various components to model route choice, to assign traffic to the road network and to account for interaction between demand and supply can be added to establish a full AB micro-simulation model (Raney et al., 2003). In advanced AB models, these model components interact in a modular system design, e.g. MATSIM-T (Balmer et al., 2006) and FEATHERS (Bellemans et al., 2010).

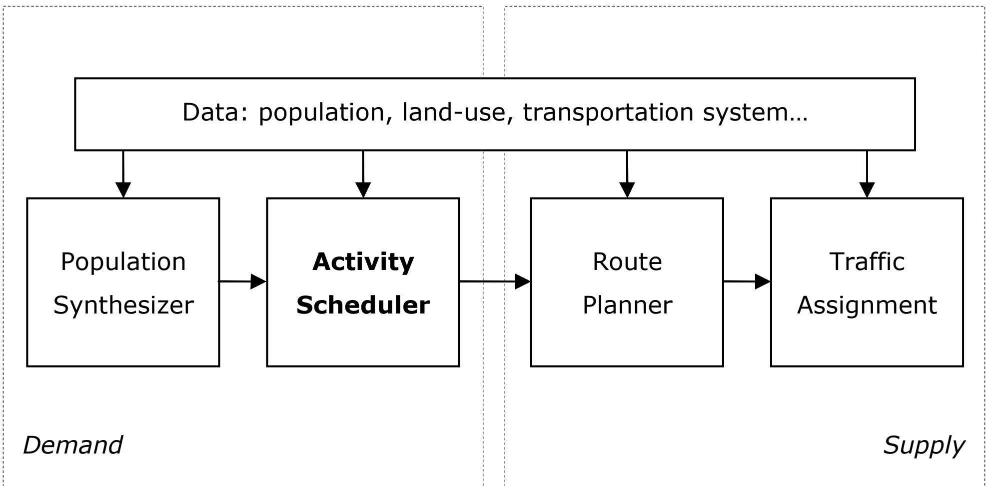


Figure 4 AB Travel Simulation Model Components

Clearly, the core of an AB model of travel demand is the scheduler since this model component produces a detailed calendar of activities and travel for each individual, indicating what to do, when, for how long, where and how to travel to that location. AB schedulers generally generate such a detailed activity calendar from scratch for each individual in de population based on their socio-demographic characteristics, although some schedulers use a predefined frame of activities depending on person characteristics, e.g. the CEMDAP model distinguishes workers from non-workers (Bhat, 2005) and the first version of ALBATROSS applied skeletons for fixed activities on a given day (Arentze et al., 2000). Such rich output data not only inform policy makers on important aspects of the travel demand of an entire population, they also provide essential information on tours and trips to feed a subsequent traffic assignment model and predict traffic flows on the road network.

Roughly speaking, building the scheduler of an AB model involves a 3 phase process (see Figure 5). Firstly, the actual model is learnt and its parameters or rules are estimated based on observed activity and travel behaviour in diary data (the training set). In the next step, the model performance is tested. Therefore, current population characteristics are used to generate individual activity and travel calendars, and this output is compared to actual travel behaviour as observed in travel surveys (the test set). Once validated, the model can be applied to forecast the impact of policy measures, such as road pricing, e.g. Arentze and Timmermans (2008), and general socio-demographic changes in so-called policy scenarios.

When using the model and evaluating policies and trends, changes in input data (e.g. an ageing population), model parameters (e.g. the value of time), rules (e.g. outcome changes due to increasing choice options) or constraints (e.g. opening hours of shops) lead to differences in simulations of the population's activity and travel choices. Thus, multiple estimations for varying levels of changes yield ranges of choice outcomes. Eventually, a comparison of these modelling results will show the variation and relative impact of different uncertain scenarios.

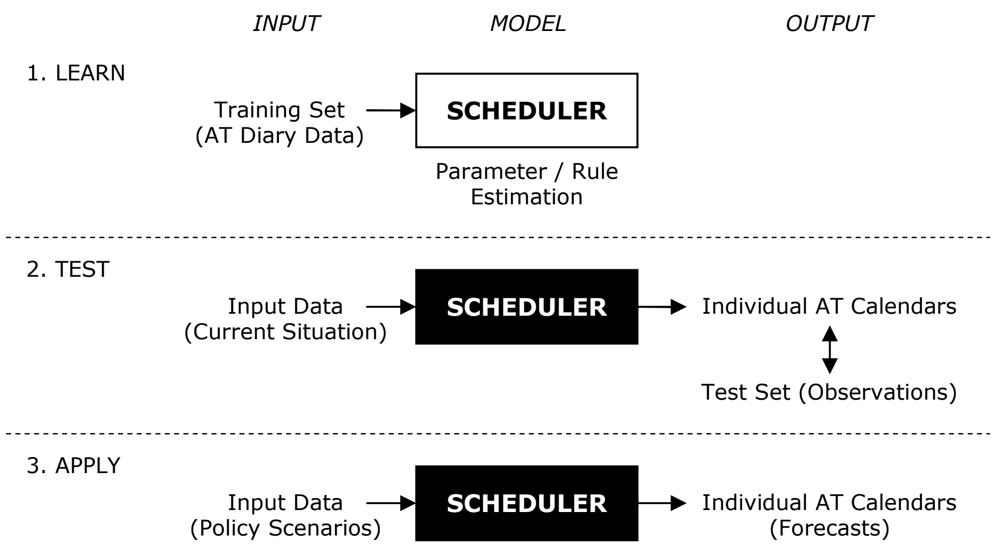


Figure 5 Three Phase Model Making Process

1.3.2.2 Representation of Decision Making in Activity-Based Models

Representation of decision making mechanisms in current AB models of travel demand can be divided into two distinct approaches (Algers et al., 2005), reflecting mainstream perspectives in decision theory. There are econometric, discrete choice models such as random utility models (RUM) based on rational EUT on the one hand (the predominant format), and computational process models (CPM) comprising a set of scheduling rules and decision heuristics on the other hand. While the former suggest a structural approach to travel demand modelling by simulating various choice aspects simultaneously, the latter framework emphasizes the scheduling process in a sequential model (Timmermans, 2001). The next few paragraphs show how the meaning of the decision making mental map is implicitly present in both AB modelling approaches.

Utility-Based Models

The majority of AB models of travel demand use RUM structures to simulate and predict various dimensions of activity and travel planning and execution. The use of RUM for disaggregate travel behaviour analysis is founded on sound principles of comparative choice developed in psychology by Thurstone in 1927 and adapted in economy in 1968 by McFadden (Manski, 1977). A detailed historical account is provided by McFadden (2001).

In brief, a RUM represents the outcome of a decision making process in which travellers compare the expected overall utility of each choice option by assessing their attributes. When applying the utility maximization principle, the alternative with the highest overall utility will be chosen. Put into operation, the utility functions consist of a measurable (deterministic) part, and a random (stochastic) part, as follows:

(1) $$U_a^i = V_a^i + \varepsilon_a^i$$

Where U_a^i is the utility that the individual i associates with alternative a; V_a^i is a function of observed attributes, e.g. travel time, cost or comfort, and the error term ε_a^i captures the uncertainty due to incomplete information from the modeller's perspective (Bierlaire, 1998), such as the individual's inclination to seek variety, e.g. Bhat (2005). Subsequently, in a rational, utility maximization framework, the probability P that alternative a is chosen by individual i within choice set C is defined by:

(2) $$P_C^i(a) = P\left[U_a^i = \max_{b \in C} U_b^i\right]$$

For both the deterministic and the stochastic model components, typical mathematical-statistical assumptions exist (translated into sub models), yielding different types of RUM, such as the multinomial logit model and the nested logit model. Further technical introduction is provided by Bierlaire (1998).

Proponents of the RUM approach praise its univocal theoretical foundation and its concomitant, clear mathematical interpretation enabling advanced statistical elaborations. However, even at the source of this theory, i.e. in economics, critics adhering to behavioural perspectives argue that although the rigid *homo economicus* assumption is useful in normative or prescriptive applications (as a model of how people ought to choose), people's everyday decision making does not meet perfect rationality (Camerer, 1998). Gärling (1998, p. 7) summarizes some behavioural assumptions overlooked in travel choice modelling and concludes: *"microeconomic theory is both an invalid and incomplete description of how people make choices. Therefore, it is not an appropriate theoretical basis of travel-choice modelling"*. Likewise, current RUM-based AB models have been criticized for lacking behavioural realism (Algers et al., 2005). An alternative behavioural approach is offered by CPM's.

Computational Process Models

A CPM or production system is a computer program that uses knowledge ('rules' or 'productions' and facts) in a defined sequence of actions to solve a problem. The birth of computers in the 1940's and the rapid progress in information theory in the following decades preceded the rise of cognitive psychology. Influenced by analogies to computers and conceptions of information processing, considerations of the role of mental processes that determine human behaviour became increasingly important in psychological research (Fuchs & Milar, 2003). Based on pioneering work of Newell and Simon (1972), CPM's were used to create expert systems and models of human behaviour, based on the idea that human beings solve problems in a step-wise process using heuristics and information (Jones & Ritter, 2002).

A typical rule-based system has three components (Konar, 1999): (1) the rule-base (a series of productions containing 'if'-statements or conditions and 'then'-actions); (2) the database; (3) and the inference engine, controlling the process of the system based on the interaction of the rule-base and the database. As a model of the human mind, the rule-base is equated with long-term memory, containing certain rules of thumb or heuristics that people tend to use, while the database contains the information in working memory or short-term memory, such as objects, attributes and values from sensory input such as observations, known facts and instant deductions, relevant for the task at hand (Jones & Ritter, 2002).

To develop a rule-based system of human behaviour, a knowledge engineer needs to learn the content, context, structure and hierarchy of 'if-then' heuristics that people use, i.e. the aspects and actions considered in these rules, the order of their decisions and likely conflict resolution strategies. Such knowledge can be provided by people (experts), in conversations or specific questionnaires, or by means of process tracing methods such as think aloud protocols and information board techniques (Crozier & Ranyard, 1997). However, manual knowledge acquisition can be cumbersome and difficult for both modellers and experts (Konar, 1999). Therefore, rule-based models are developed based on large datasets of observed behaviour as well. In such cases, rules are learned on the basis of examples, assuming that a set of instances of observed variables and outcomes can reveal relevant knowledge. In addition to examples, other knowledge may be used to put the production system into operation, such as mere common sense or developer's domain knowledge.

To acquire knowledge from large amounts of data with less involvement of a human expert, machine learning techniques can be used. The outcomes are classifications and rules with predictive power. The induction of decision trees is an example of these machine learning techniques. Decision trees form hierarchical structures by dividing a dataset according to the values of the most informative attributes. This process is repeated, and it leads to a predictive rule-based model (Medsker & Schulte, 2002). In such a CPM, the resulting decision trees are equated with individual decision making heuristics. Note that the output of such automated knowledge extraction doesn't necessarily equal individuals' conscious considerations in the decision making process; rather, they represent instances of meaningful associations and correlations in large amounts of available data. For instance, in a recent study, Kusumastuti et al. (2010a) show differences in condition variables of decision trees generated from activity-travel diary data for leisure trip decisions and actual considerations reported in qualitative interviews.

Forecasting rule-based models of travel demand are based on standard travel surveys and activity diary data, since it is very difficult to trace the activity scheduling process, especially on a larger scale. Indeed, observed activity-travel patterns can be the outcome of a series of long-term and short-term choices, many of which are subconscious (Roorda & Miller, 2005). Nevertheless, some critical voices argue that observation of cognitive processes underlying decision making and choice behaviour is a requirement to develop a credible rule-based model of activity scheduling (Golledge & Stimson, 1996).

The application of production systems to activity scheduling has been suggested and tested by Gärling et al. (1998) in the SCHEDULER project (and its further elaborations). Two other attempts are AMOS, a system that generates activities and trips within individual space-time constraints, and PCATS, a simulation system that replicates how travellers would modify their activities and travel when changes take place in the travel environment (Kitamura & Fujii, 1998). Later on, Arentze and Timmermans (2000) developed ALBATROSS (and its successors) and put it into operation to assess policy impacts in the Netherlands (Arentze & Timmermans, 2008). Only recently, the ALBATROSS approach was transferred to the region of Flanders in Belgium in the FEATHERS-project (Arentze et al., 2008). Since this PhD research aims at integrating characteristics of the mental map (both the decision making mental map and the geographical mental map) in this rule-based AB model of travel demand, the architecture of these models will be discussed in further detail in section 1.3.3, after explaining the representation of space in AB models in general.

1.3.2.3 Representation and Use of Space in Activity-Based Models

To date, only few researches attempt to take the geographical connotation of the mental map explicitly into account in AB models of travel behaviour. Golledge and Gärling (2004) review some early endeavour. In addition, Sivakumar and Bhat (2006) integrate causes of individual heterogeneity such as spatial cognitive factors (learning, preference…) in an econometric model of location choice for non-work activity in specific vector functions and the error term of a random utility-maximization-based model structure. An interesting separate computational conceptualization of the geographical mental map and spatial learning is developed by Arentze and Timmermans (2003). This model, based on Bayesian beliefs networks, is conceptually developed (yet not integrated) in the ALBATROSS CPM model system framework as part of the research effort to model various aspects of individual learning and adaptation in urban environments. So, similar to the representation of decision making mechanisms in AB models of travel demand, the representation of the geographical mental map is at best implicitly present in the considered spatial attributes.

To a large extent, spatial representations in of AB models of travel demand are determined by two practical issues: the availability of data and computational capacity concerns, e.g. Arentze et al. (2003). Since geographical space is a continuous variable yielding infinite choice options, discretization in zones (such as postcode areas or statistical sectors) and aggregation of spatial data is common practice. Clearly, such a zone-based approach tends to disregard individual differences emphasized on in disaggregate modelling. Moreover, existing zoning systems might not reflect spatial coherence, nor correspond to individual perception of opportunities.

However, advances in geographical information systems (GIS) since the 1980's have facilitated the integration of travel databases and spatial databases, and hence the potential quality of spatial inference in transportation applications in general (Waters, 1999) and in AB analysis of travel demand in specific (Wang & Cheng, 2001). Three theoretical constructs particularly relevant to AB modelling, can benefit from this integrated approach: *space-time prisms*, *accessibility* and *spatial attraction* measures.

First of all, in simulations of individual decision making with respect to activity participation and travel, information on choice alternatives is crucial, be it spatial or temporal choice options and opportunities. In compliance with Hägerstrand's definition of *space-time prisms* (1970), time windows available to engage in activities and potential destinations can be delimited since individuals' submission to physical limitations (capability constraints), joint arrangements (coupling constraints), and regulations (authority constraints) affect their travel options. Thus, this use of spatial characteristics in the constraint-based approach adapted from time geography indicates individual travel possibilities by making individual's decision context more explicit. Miller (1991) developed GIS methods to identify space-time prisms. Only recently, Buliung and Remmel (2008) developed *aspace*, a tool to visualize and describe spatial properties of individual and household activity spaces.

Second, the reach of an individual's space-time prism (i.e. the available opportunities given a certain time window) depends on the ease to access certain destinations. This can be represented in *accessibility* measures. The most straightforward ways to compute accessibility use the distance as the crow flies from the core of the origin zone to the core of the destination zone and a measure of average travel speed. More advanced measurements account for differences due to the travel mode involved, time of day (peak and off-peak), travelled routes or individual differences. Chen and Li (2006) describe the evolution of accessibility over time. Following Miller (1991), Kim and Kwan (2003) develop a GIS-based algorithm that better represents the space-time characteristics of urban opportunities and human activity-travel behaviour. Within an econometric modelling framework, Dong et al. (2006) develop an AB accessibility measure to all activities in which an individual engages, incorporating scheduling constraints and travel characteristics such as trip chaining.

Finally, the ease to access an area can be one of the characteristics constituting the *attractiveness* of a potential destination. According to Jonnalagadda et al. (2001) in destination choice models, the explanatory variables can be classified into two types: accessibility and attraction variables. The latter type captures relevant attribute values of alternative destinations (usually zones) indicating its magnitude (size variables) or characteristics (type variables). Examples are socio-economic data such as population density, employment by sector, enrolment in schools… and land use or transportation data such as housing density, presence of socio-cultural facilities, parking supply, transit services… In fact, similar operationalizations of attraction in terms of size date back to early macroscopic gravity-based models for trip distribution, in analogy with Newton's law of gravity in physics. However, while the gravity approach has proven to be successful in explaining choices of large numbers of individuals, the choice of any given individual may vary considerably from predicted values (Levinson, 1998). Indeed, attraction variables do not necessarily reflect individuals' knowledge and perception of potential destinations.

1.3.3 ALBATROSS and FEATHERS

In order to understand present efforts to integrate mental map characteristics in a CPM of travel demand, the final part of this chapter describes the layout of the AB model under consideration, and highlights some relevant properties.

ALBATROSS is an acronym for A Learning-BAsed TRansportation Oriented Simulation System. A prototype of this model is developed at the turn of the 21st century for the Dutch Ministry of Transport to predict individual activity-travel patterns and to assess transportation policy impact in the Netherlands. It is refined in numerous supplements since (Arentze et al., 2008; Janssens et al., 2007).

In 2005, the success of ALBATROSS has inspired a research programme coordinated by IMOB and funded by the Agency for Innovation by Science and Technology (IWT) in Belgium. The goal of this project is to reach a state-of-the-art AB micro-simulation model of travel demand for Flanders. Under the acronym FEATHERS (Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS) a framework is developed to accommodate various prototype sub-models involved in travel demand modelling such as a population synthesizer, a scheduler and a route choice and traffic assignment module. Moreover, the modular nature of the FEATHERS platform enables future implementations of innovative components and experimental extensions (Bellemans et al., 2010).

In its primary version, the scheduling component of FEATHERS is based on the ALBATROSS scheduler using Flemish data. This CPM estimates complete activity-travel patterns for every individual agent in the simulation. Table 1 presents some classifications and choice facets used in the scheduler, and gives an idea of the level of detail that is achieved.

Table 1 Classifications Used in ALBATROSS (FEATHERS Version)

ASPECTS & CLASSES	DESCRIPTION
Activity	
In-home	All in-home activities, including sleeping
Work out of home	Work or school
Bring/get	Drop off or pick up persons or goods
Single shopping	Grocery shopping to one store in one trip
Multi shopping	Shopping to multiple stores in a trip chain, window shopping
Service	Bank, post office, personal business, movie rental…
Social out of home	Social visits to family, friends, acquaintances…
Leisure out of home	Café, restaurant, concert, museum, sport…
Touring	Travel for pleasure, having a walk, bicycle trip…
Transport mode	
Car driver	Travel by car as car driver
Car passenger	Travel by car as car passenger
Slow mode	Walk, bike, moped…
Public Transport	Train, tram, bus, metro…
Start time (flexible activities)	
Before 10 a.m.	Start time of activity is before 10 a.m.
10 - 12 a.m.	Start time of activity falls in 10 – 12 a.m.
12 – 2 p.m.	Start time of activity falls in 12 – 2 p.m.
2 – 4 p.m.	Start time of activity falls in 2 – 4 p.m.
4 – 6 p.m.	Start time of activity falls in 4 – 6 p.m.
After 6 p.m.	Start time of activity is after 6 p.m.
Duration (flexible activities)	
Short	Relatively short activity duration
Average	Average activity duration
Long	Relatively long activity duration

Figure 6 shows the components of the CPM scheduler. The rule-base of this scheduler consists of 26 decision trees, accompanied by a set of dynamic constraints. For FEATHERS, the decision trees are trained on Flemish activity-travel diary data. The induction method used to derive a tree for each decision aims at finding the best fitting tree that explains the relevant observations best. This is done by repeatedly dividing the sample on attribute variables (Arentze & Timmermans, 2008), including available spatial characteristics. Time and space-time constraints are updated according to the current state of the schedule in the scheduling process thus limiting choice sets or choice ranges to the extent possible given available data. Hence, these dynamic constraints determine the use of spatial characteristics in the model and reflect geographical mental map properties.

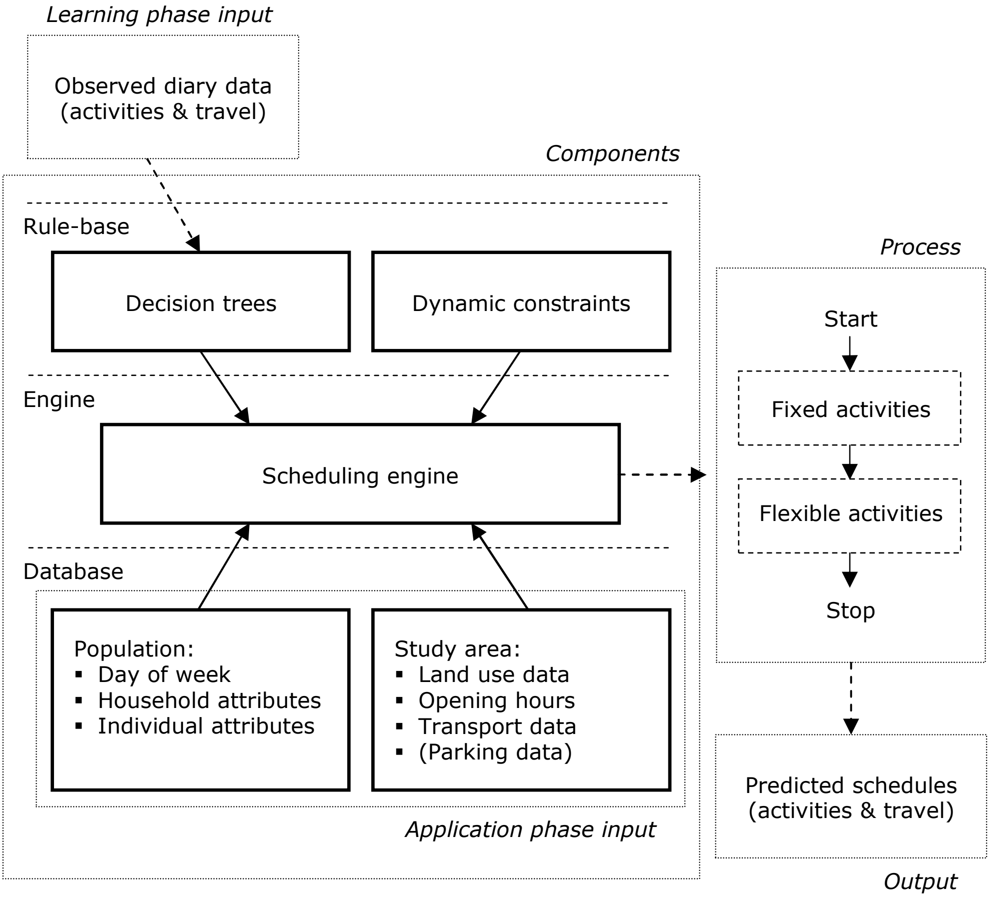


Figure 6 Scheduler of ALBATROSS (Based on: Arentze & Timmermans, 2008, p. 5)

The database holds all information with regard to the agents and their household (socio-economic data), and with regard to the study area, including available spatial land use data, transport data, opening hours and parking data. This reflects the available geographical mental map knowledge. According to (Bellemans et al., 2010), in Flanders, each inhabitant is represented based on census data from the most recent socio economic enquiry (SEE) in 2001. Missing data are sampled, and characteristics are updated to 2008. Flemish study area data are available in three geographic levels, i.e. municipalities (N=327), partial municipalities (PM) (N= 1,145) and statistical sectors (SS) (N=10,255). Table 2 gives an overview of available study area data with a geographic component.

Table 2 Available Study Area Data in Flanders

DATA TYPE	USE
Employment by sector (at SS level)	**Proxy for presence & attraction of**
Total employment	Work activities
Children in primary school	Drop off – pick up activities
Shops (daily goods)	Daily shopping activities
Shops (non daily goods)	Non-daily shopping activities
Services (bank, postal office…)	Service related activities
Catering industry (restaurant, café, bar…)	Leisure activities
Population (at SS level)	**Proxy for presence & attraction of**
Number of households	Social activities
Urban density	Social activities
SS size	Social activities
Opening hours	
Average & largest opening hours per sector	Authority constraints
Transport data (in OD matrices)	**Transport mode choice**
Road network (at SS level)	
Car travel time fastest route	
Car distance fastest route	
Slow mode distance fastest route	
Congested travel times (at PM level)	
Free floating car travel time	
Car travel time in morning peak as percentage of free floating car travel time	
Car travel time in evening peak as percentage of free floating car travel time	
Bus Tram Metro (at PM level)	
BTM travel time including access and egress	
BTM access and egress time as percentage of total BTM travel time	
BTM cost	
Train (at PM level)	
Train travel time including access and egress	
Train access and egress time as percentage of total train travel time	
Train travel distance including access and egress	

In the current version of FEATHERS, zone attributes such as employment and population data are used as a proxy for the availability and attractiveness of certain activities in each zone. Opening hours determine the authority constraints in the model. Transport data are attributes that belong to pairs of an origin zone and a destination zone (OD), stored in OD matrices. Since parking data are currently unavailable, the initial model runs without these inputs.

The information stored in both the rule-base and the database is used by the engine to produce an individual's activity and travel schedule. The scheduling engine assumes a sequential decision making process that intends to simulate the way individuals solve scheduling problems. This process and its components represent the decision making mental map. Although individual heterogeneity is likely to occur, the main lines of this scheduling process are predefined and invariable across cases to simplify the modelling task (Arentze & Timmermans, 2000). In this process, fixed activities such as work or drop off and pick up commitments are scheduled first on a day-to-day basis. Thereafter, flexible activities complete the schedule. The series of 26 consecutive decisions (hence 26 decision trees) are indicated in Table 3. Depending on the outcome of a decision, loops and shortcuts in this process may occur until a full schedule is reached. For instance, if there is no other fixed activity but work to include (decision 15), the engine switches to the decision whether to include a non-work flexible activity (decision 20).

The distinction between flexible and fixed activities refers to supposedly different scheduling strategies (Arentze et al., 2003). While flexible activities are likely to be scheduled on a daily basis, fixed activities are likely to be part of settled routines. That is why in the earliest version of ALBATROSS, a so-called skeleton of fixed activities was assumed given. The daily scheduler included nine decision trees, and completed this fixed, predefined framework with flexible activities. However, to increase policy-responsiveness of the model, the original ALBATROSS CPM was extended to include the generation of schedule skeletons of fixed activities. Thus, today, the first part of the model generates an activity skeleton of fixed activities and their exact time and duration (as continuous variables). Given this skeleton, the second set of decisions determines the part of the schedule related to flexible activities to be conducted during that day (as discrete choices). However, when multiple days are simulated, e.g. a whole work week, the scheduler models the fixed activities anew for each day.

Table 3 Scheduling Process of ALBATROSS (FEATHERS Version)

Nr	Activity Type	Decision
1	Work	Include a work activity?
2	Work	Duration of the work activity?
3	Work	Number of work activity episodes?
4	Work	Duration of the work activity episodes?
5	Work	Duration of the break in between the work activity episodes?
6	Work	Timing of the work activity episodes?
7	Work	Location work activity: same as location previous activity?
8	Work	Location work activity: same as home municipality?
9	Work	Location work activity: order of other municipality?
10	Work	Location work activity: nearest municipality of chosen order?
11	Work	Location work activity: distance band choice of municipality?
12	Work	Location work activity: order of zone in chosen municipality?
13	Work	Location work activity: distance band choice of zone?
14	Work	Transport mode choice to work?
15	Non-work fixed	Include a non-work fixed activity?
16	Non-work fixed	Number of episodes of non-work fixed activities?
17	Non-work fixed	Duration of the episodes of non-work fixed activities?
18	Non-work fixed	Are these non-work fixed activities chained to the work activity?
19	Non-work fixed	Timing of the non-work fixed activity episodes?
20	Non-work flexible	Include a non work flexible activity?
21	Non-work flexible	Duration of the non-work flexible activity?
22	Non-work flexible	Timing of the non-work flexible activity?
23	Non-work flexible	Chain the non-work flexible activity to other activities?
24	All non-work	Location of the non-work activities: same as previous location?
25	All non-work	Location of the non-work activities: distance-size class?
26	All non-work	Transport mode choice to non-work activities?

A final property of the model to be mentioned is the treatment of household interactions. While the decision making unit in most agent based AB schedulers is the individual, it is recognized that interactions and group decision making affect activity and travel decisions. As Bhat and Pendyala explain (2005, p. 444): "*Early activity-based models considered tours generated at the individual* *level, using household characteristics as explanatory variables, but without the direct consideration of the presence of other household members on the tour or the other activities undertaken by individual household members. It is only recently that models have begun to consider joint activity participation among, and activity (task) allocation between, household members. In particular, there is an emerging and substantial interest in the behavioural modelling community to examine ways in which decisions about joint participation in activities and allocation of activities among household members can be modelled in a rigorous behavioural analytical framework.*" In the current FEATHERS version of ALBATROSS, such household interactions take the form of constraints imposed by scheduling decisions of the household member whose activity and travel calendar is modelled firstly, on scheduling choice options of subsequent household members. Basically, if there is only one car in the household and this car is occupied by the first household member, other members of the household do not have this choice option in their transport mode decision.

The brief account on ALBATROSS and FEATHERS above shows that putting a model of complex phenomena such as daily activity and travel scheduling into operation, entails a substantial amount of simplifications, classifications and assumptions. In such an exercise, striking the balance between what is theoretically advisable (such as from a behavioural perspective) and practically feasible (for instance in terms of availability of data or computation time) is far from easy. Clearly, there is room for refinement and improvement of this model. The main challenge is to diagnose its most important weaknesses and to find cures that have the potential to improve the performance of the model in a substantial way and that indicate new modelling perspectives.

1.4 Outline

Besides summarizing the background of this research from a behavioural and modelling perspective, this introductory chapter clarifies the reasons and subsequent goals of this research. This is improving the behavioural realism of AB models of travel demand by: (1) exploring multiple meanings of mental maps in daily travel, (2) developing a quantitative model of the mental map of daily activity and travel decisions and (3) integrating mental map characteristics in an AB model of travel demand. The remainder of this thesis is organized according to these successive research steps. Furthermore, since each of these research phases involves a distinct methodological approach, each of the following chapters opens with a separate account of the applied research method.

The exploration of mental maps in daily travel behaviour in Chapter 2 highlights the use of qualitative methods in general and in travel surveys in specific to start with, based on (Hannes et al., 2009b), a chapter written for the online travel survey manual. What follows, is the report of a qualitative in-depth study into decision making heuristics and mental map properties in daily travel scheduling and execution, based on (Hannes et al., 2009a, 2008).

Chapter 3 builds on the qualitative script model of daily travel defined in the exploration phase. In an attempt to bridge the gap between qualitative research findings and quantitative modelling applications, an individual mental map of daily travel routines is proposed, defined as a BIN. The description of this application is based on (Hannes et al., 2009, 2009a, 2009b).

In Chapter 4, the script approach and the individual mental map model are generalized in a conceptual family skeleton model for households with young children. Based on an analysis of the SEE data of Flanders, flexible sequence patterns are defined that characterize the division of work and care commitments amongst household members, thus constituting a skeleton in daily activity and travel scheduling (Hannes et al., 2010). These patterns are used to benchmark the outcome of the scheduler of FEATHERS, and they can be integrated in the AB scheduler of FEATHERS to improve the representation of human behaviour.

In conclusion, Chapter 5 summarizes the main findings from this PhD research. Furthermore, this chapter runs a critical eye over the research efforts presented in this thesis, and concludes with some recommendations for future research.

2 QUALITATIVE EXPLORATION OF MENTAL MAPS IN DAILY TRAVEL

– HUMMINGBIRDS –

Heuristic Use of Mental Map INformation Gained from Behavioural Inspection of Routines in Daily activitieS

2.1 Introduction

This second chapter explains how the mental map shapes individual daily activity and travel choices, based on a qualitative exploration. Before detailing the actual qualitative study, qualitative research methods are introduced in the second section and applications in transportation research are reviewed. Subsequently, the third section in this chapter elaborates on the layout of the actual qualitative exploration of mental maps in daily travel, including specific objectives, data gathering procedures and sampling and analysis. Finally, the results and conclusions of the qualitative analysis are presented in the last chapter section.

2.2 Qualitative Research Methods in Transportation

This section explains the added value of integrating qualitative methods in travel behaviour research. After briefly framing some general aspects of qualitative research, distinct steps in a research process are highlighted to structure the remainder of this qualitative methods section. Firstly, questions and contexts most applicable for qualitative methods are addressed. Next, their actual use, role and timing in travel surveys are discussed. Sampling and data collection issues are treated subsequently, followed by a brief account on qualitative analysis and presentation of research outcomes. To finish, some quality questions in qualitative research are dealt with. Throughout the method section of this chapter, numerous references point at both valuable general methodological sources and specific examples of actual studies of this type in the field of transportation.

2.2.1 General Outlook on Qualitative Research

Originating from social sciences, the notion 'qualitative research' is an umbrella term, covering multiple data collection methods (e.g. in-depth interview, focus group conversation and observation), different analysis approaches (e.g. discourse analysis, content analysis and grounded theory) and a variety of research objectives (e.g. exploration, description, theory development and action research).

Nevertheless, these varying research practices share some common characteristics. First of all, research questions in qualitative approaches focus on an in-depth understanding of the subject at stake. 'Why?' and 'how?' are central in this type of inquiry, not the traditional, objective and quantitative 'what?' or 'who?', 'when?', 'where?', 'how much?' or 'how often?' Second, basic data are usually unstructured and rich in detail, such as verbal accounts, pictures and observational data, and sample sizes tend to be rather small. These types of data are necessary to describe the perspective of the participants based on qualitative analysis, intead of statistical data analysis. Thus, a third distinguishing feature in qualitative research is the inductive approach of data analysis and its different presentation of research outcomes.

In this doctoral research a pragmatic stance towards different methodological approaches is taken: since different methods produce different types of findings, researchers should simply use methods that suit their needs best. Still, it is important to mention that there is an underlying theoretical debate between positivist and anti-positivist camps influencing the acceptance or rejection of certain research methods. Goulias (2003) frames this discussion between positivist or quantitative, objective approaches and anti-positivist or qualitative, subjective human-centered outlooks in the context of transportation studies. Clearly, a fundamentalist attitude toward a specific scientific paradigm hinders the integration of research methods.

Compared to the amount of quantitative, positivist scientific research effort, qualitative research constitutes a rare phenomenon. This is especially true for the field of transportation research, originating from quantitative applied sciences such as engineering and economics. For instance, in the bibliographic database TRIS Online (NTL, 2009), search terms 'travel behavior' and 'travel behaviour' generated 4579 records. Further restriction using various search terms related to qualitative methods, and analysis of the listed results, shows only 114 unique references reporting on qualitative approaches to some extent.

A possible explanation of this limited use of qualitative approaches is that these methods are relatively unknown and neglected in mainstream transportation teaching and research practice (Clifton & Handy, 2003). If applied, quite often specialized teams treat qualitative research components separately (Grosvenor, 2000). Furthermore, despite small sample sizes, qualitative methods can be time consuming (thus costly), while research outcomes are much harder to define in advance compared to quantitative efforts. Moreover, quality in qualitative research is hard to measure. While quantitative methods can rely on objective statistical verification, qualitative research results rely on subjective interpretation and alternative (contested) readings of 'validity' and 'reliability'. Add these observations to usual tight research budgets and strict time locks, it is clear why convincing clients to invest in qualitative research can be a real challenge.

Still, qualitative methods are emerging in the growing amount of transportation research output. For instance, while the results list of the TRIS Online search covers 30 years of qualitative accounts on travel behaviour, two third of this output is generated in the last decade. This could reflect a shift in research needs caused by changing transportation policy questions related to travel behaviour. While measures of adjusting supply to increasing demand have long dominated both transportation policy and research agendas, growing environmental and health concerns have forced policy makers to make people change their travel choices. Thus, a deeper understanding of individual decision making with regard to travel behaviour is prompted to develop, understand and estimate the impact of travel demand management. As Bradley (2006) shows, in gathering such detailed, in-depth process data, qualitative methods definitely have a role to play.

2.2.2 Research Questions in Qualitative Inquiry

A clear distinction between quantitative and qualitative methods is the type of research questions that can be answered. Denzin and Lincoln (1998, p. 8) put it this way: "*The word 'qualitative' implies an emphasis on processes and meanings that are not rigorously examined or measured (if measured at all), in terms of quantity, amount, intensity, or frequency. Qualitative researchers stress the socially constructed nature of reality, the intimate relationship between the researcher and what is studied, and the situational constraints that shape inquiry. Such researchers emphasize the value-laden nature of inquiry. They seek answers to questions that stress how social experience is created and given meaning. In contrast, quantitative studies emphasize the measurement and analysis of causal relationships between variables, not processes. Inquiry is purported to be within a value-free framework*."

Which method to choose, depends on research objectives at stake. In travel behaviour research, this usually relates to increasing understanding of travel-related phenomena. In this respect Grosvenor (2000, p. 1) points at two essential virtues qualitative approaches can provide: depth and breadth. It brings depth, because underlying motivations and intentional meaning are revealed in its relevant context. It brings breadth, because related issues and their interactions are listed and framed.

Applied to travel behaviour, focusing on an in-depth explanation or revealing an inside perspective is appropriate if there is a need to know how people (or specific groups) experience travel. While traditional travel surveys using travel diaries and questionnaires focus primarily on outcomes of travel behaviour, here contexts, motivations and decision making processes are central. At the same time, a deliberate search for breadth will uncover the variety of factors, perspectives, characteristics, etc., influencing travel behaviour, regardless of their size. For example, think of different meanings adhered to travel, its potential significance in social conduct and various related attitudes or emotions…

Perhaps the best way to illustrate research questions that can be answered using qualitative methods is by pointing at specific examples in literature in the remainder of this chapter. Note that these instances do not provide an exhaustive overview of all qualitative research conducted in the field of travel behaviour. Rather, an arbitrary sample is provided of research in which qualitative methods played a substantial part in developing a better understanding of transportation related issues.

2.2.3 Timing and Role of Qualitative Methods in the Travel Survey

Qualitative methods can shape a complete research project, such as in in-depth travel studies of specific groups. These groups can be groups hard to reach with traditional travel survey instruments because numbers are small (e.g. the very rich), because specific skills to complete questionnaires are lacking (e.g. illiterates) or simply because they are the usual drop-outs in traditional travel surveys (e.g. the financially weak). In practice however, few comprehensive, in-depth qualitative travel studies exist. Some examples: Handy et al. (2008) explored travel behaviour of immigrant groups in California, USA, primarily by means of focus groups. In a similar way, ageing baby-boomers in typical suburban neighbourhoods in the Boston metropolitan area, USA, were targeted by Zegras et al. (2008) after segmentation using urban design analysis. Daley et al. (2007) explored barriers and enablers to cycling in inner Sydney, Australia, in in-depth focus group conversations. Hjorthol and Timmermans (2005) used in-depth personal interviews to understand motives and frequency of teleworkers in the Oslo region in Norway.

Qualitative methods can be combined with quantitative survey techniques. As to timing, three points in the research process can be distinguished: before, parallel to and after a large-scale survey. In each stage, qualitative methods play a specific role.

Firstly, qualitative exploration helps to define or refine research questions early on in the research process. This is mostly relevant for new topics or dynamic environments. For instance, Giglierano and Roldan (2001) study the effects of online shopping on motor travel based on in-depth interviews, after discovering a scarcity of prior research on this topic. Besides this, exploratory interviews and focus groups are often used to discover the range and wording of meaningful categories that need to be questioned in later, structured data collections. For example, Farag and Lyons (2009) developed an online questionnaire with regard to public transport (PT) information use in the UK, based on earlier exploratory interviews and group conversations (Farag & Lyons, 2008). In a similar vein, Loukopoulos et al. (2004) use focus groups to gauge adaptation strategies for car use before measuring their incidence in an internet-based survey.

Next, qualitative methods can be used at the same time as quantitative surveys. 'Mixed method' approaches such as including open ended questions in questionnaires have the advantage of enabling both qualitative and quantitative analysis, but they take up a lot of time. On the other hand, using interviews or focus groups parallel to large scale questionnaires offers a real voice to respondents. It is probably the best way to 'let the data speak'. For instance, in a two stage survey approach, Mackett (2003) examined why people use their cars for short trips. Firstly, respondents were asked to keep a two-day travel diary. Subsequently, short trips by car were identified from these diaries and used as focal point for detailed discussion in the second stage of the research.

Finally, qualitative post studies are helpful to clarify strange, illogical or unaccountable results of quantitative surveys. This can happen when predefined categories appear to reveal too little differentiation, or response rates in residual categories such as 'other' are too high. Also, results might show inexplicable differences with previous or comparable studies. For instance, when travel surveys in Northern California indicated substantial increases in long-distance interregional commuting, Lee (1996) further explored this type of travel using focus group conversations and found an explanation in respondents' housing preferences.

2.2.4 Qualitative Sampling

In quantitative research, random sampling is used in order to be able to generalize results. Qualitative researchers on the other hand, try to build a sample that includes cases selected with a different research focus: to gain in-depth understanding. Therefore, cases are usually carefully chosen. This is 'purposive sampling'. Depending on specific research goals, different strategies exist, but according to Maykut and Morehouse (1994), the most prominent and useful strategy might be 'maximum variation' sampling. Here, cases are sought out that represent the greatest difference in that phenomenon. In an account on qualitative survey techniques to explore travel related decisions, Mehndiratta et al. (2003) argue that the sample should be divers with respect to factors hypothesized to affect the travel decisions under investigation.

Furthermore, with regard to sample size, Mehndiratta et al. (2003) state that four or five individuals sharing each key characteristic should be included in the sample. According to these authors, this typically results in sample sizes that range between ten and twenty people. Indeed, it is a well known fact that sample sizes in qualitative research are smaller than in quantitative surveys. However, much less noted is the fact that in qualitative research data collection (thus building the sample) and data analysis can be intertwined in an ongoing process until 'saturation' in understanding is achieved. This is when typical 'breadth' and 'depth' goals of qualitative methods are met and when adding new cases stops leading to new information or additional insights. Ezzy (2003) calls this an integrated research process (see also Figure 7).

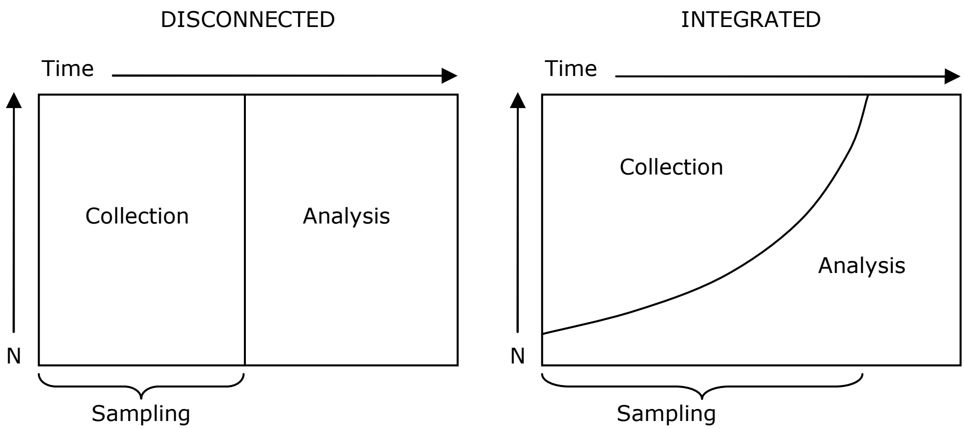


Figure 7 Relationships Between Data Collection and Analysis (Based on: Ezzy, 2003, p. 62)

Finally, to locate and address respondents, particularly for rare populations, qualitative researchers can use the 'snowball method' (Kalton & Anderson, 1986), where one research participant or setting leads to another. An actual application of this method (and previously mentioned purposive sampling) in the field of travel behaviour is detailed further in this chapter, since this sampling strategy is used to target respondents for the actual exploration of mental maps in daily travel.

2.2.5 Qualitative Data Collection Methods

In qualitative inquiry, primarily unstructured data are gathered: conversations, texts, pictures, etc. Generally speaking, three types of data collection methods can be distinguished: (1) collecting existing documents, (2) observing, (3) and organizing and recording interviews and conversations.

2.2.5.1 Existing Documents

Existing documents can be private diaries, blogs, internet forum conversations, news, commercial announcements and other media. On the one hand, some clear drawbacks are that important contextual information is lost, no additional in-depth information can be collected if necessary and the origin of the documents might be insecure. A clear advantage on the other hand is that data collection costs can be low because all material is readily available. Besides this, ten Have (2004) argues that these so-called 'natural' documents are produced as part of current societal processes and not for the purpose of the research project in which they are used. Therefore, such data are not affected, for instance by interview effects. In the search of examples of qualitative research related to travel behaviour, no cases relying on natural documents could be discovered.

2.2.5.2 Observation

Observation as data collection technique is rare in travel behaviour research as well. According to Clifton and Handy (2003) the observation of participants in the context of their daily lives could mitigate problems such as self-selection bias, recall and memory issues and behaviour modification. They explain that the approach has a rich tradition in ethnographic urban studies, but only one concrete example in the field of transportation is mentioned (ibid. 2003, p. 11): "*Niemeier combined surveys with participant-observer techniques to study the travel patterns of welfare mothers. She conducted surveys at Job Fairs, then followed-up by spending a day with each of a few of the survey respondents, travelling with them throughout the day*". A general methodological introduction on ethnography and field methods can be found at ten Have (2004).

A special case of observation is participatory research or action research in which participants and researchers work together to examine a problematic situation or action to change it for the better (Kindon et al., 2008). For instance in Flanders, the research group "Kind & Samenleving" (Child & Society) is specialized in qualitative research with children to give a voice to the child's perspective in society, and one of their projects involves a participatory 'experience research' into the travel independence of children aged 10-13 (Meire, 2005).

2.2.5.3 Interviews and Conversations

Without any doubt, interviews and conversations are the best known and most often used data collection methods in qualitative travel behaviour research. With regard to the actual interview questions, protocols can range from (semi) structured methods such as an ordered list of open ended questions, to unstructured free conversation about a certain topic. As far as the interview setting is concerned, this can be a one-to-one discussion between interviewer and respondent, or a so-called 'focus group'. The latter is a group conversation with several respondents, a moderator and an observing researcher. There are numerous general methodological accounts on interviewing and focus group research. For instance, Seidman (2006) offers a comprehensive guide to personal interviews. Bloor et al. (2000) discuss how to set up focus group research in practice and Puchta and Potter (2004) detail how moderators can guide the interaction in focus group conversations.

Related to travel behaviour, a discussion and examples of the use of open-ended interviews can be found at Mehndiratta et al. (2003). In the same field, Clifton and Handy (2003) offer a brief methodological account on the application of focus groups and personal interviews, together with a number of examples. One classic and influential model is explicitly pointed at: the HATS (Household Activity-Travel Simulator) developed by Jones et al. (1983). In their research, qualitative techniques such as exploratory interviews with households lead to the development of a semi-structured interview technique using a display board to assess the interaction and interdependencies amongst household members in scheduling and executing activity-travel behaviour. To date, this method inspires household travel surveys such as reported by Clark and Doherty (2009) and Stopher and Greaves (2007).

During face-to-face interviews or conversations, researchers can take notes to store elicited information. These notes can describe observations, such as contextual aspects, responses to questions, important statements and non-verbal communication. Methodological notes can reflect lessons learned from using the protocol, while theoretical or analytical notes represent emerging insights and preliminary ideas with regard to research outcomes. To relieve observation burden and keep as much information as possible, conversations are usually recorded by voice or video-recorders. Afterwards, audio-files are converted into text files in a process called 'transcription'. Typing out interview sessions word for word is a cumbersome task. According to Seidman (2006), it takes 4 to 6 hours to transcribe a 90 min. tape. However, such verbatim data files are necessary to enable coding and further qualitative analysis.

2.2.5.4 E-Research

In the past decades, technological revolution enabled the rise of new data collection methods or 'e-research' (Anderson & Kanuka, 2003), such as online focus groups (Rezabek, 2000) and e-mail interviews (Meho, 2006). Clearly, one of the advantages of such methods is the avoidance of time-consuming transcription because basic data are text files. However, a major drawback for qualitative research questions is that important contextual information is lost as well. Detailed methodological discussions can be found in the references mentioned here above. In general, it is clear that online research tools can complement traditional techniques rather than replace them. Therefore, chosen strategies should be geared to actual research goals and questions. To date, there are no genuine qualitative online or internet-based surveys in the field of travel behaviour, at least to the best of our knowledge. At most, some open-ended questions are included in traditional web-based questionnaires with predefined categorical answers, e.g. Klöckner (2004).

2.2.6 Qualitative Analysis

While data collection methods are usually quite well explained in reports on qualitative research, descriptions of data analysis often remain brief and hazy: interviews or focus groups are carried out, and subsequently, research findings are presented without elaborating on the actual method of analysis. In reality, the analysis process in qualitative research is one of the most difficult steps to undertake. Coding of unstructured data, classifying codes, connecting and synthesizing findings requires a lot from the researcher: creativity and knowledge to see the theory, meticulousness to manage a large amount of unstructured data, patience and persistence to systematically compare, check and double check, introspection and self-criticism to re-examine critical steps in an iterative analysis process, empathy to take the perspective of respondents and a verbal disposition and facile pen to show results and common findings.

2.2.6.1 Approaches in Qualitative Analysis

Roughly speaking, in methodological sources on qualitative analysis, e.g. Bryman and Burgess (1994), Dey (1993) and Ezzy (2003), two types of analysis are distinguished: discourse analysis and content analysis. Discourse analysis is concerned with texts and speech as social practice. It pays attention to content in talk, such as topics and meaning, as well as form, such as grammar, structure and cohesion. For further methodological details, see Wodak and Meyer (2001). An application related to travel modes can be found at Guiver (2007), but overall, this type of analysis is rare in travel surveys.

Indeed, the majority of qualitative analysis in travel behaviour is some sort of content analysis. Here too, two distinctive strands exist: grounded theory (an inductive approach) and the use of predefined coding schemes (a deductive approach). On the one hand, in analysis using a grounded theory approach, theoretical accounts with regard to the research object emerge from the data

(Goulding, 2002). Unlike deductive content analysis approaches, there is no pre-existing theory taken into account. Development of coding schemes is an ongoing process during the analysis. A travel-related example is the work of Gardner and Abraham (2007).

The use of coding paradigms on the other hand allows researchers to use a predefined scheme in the coding process, such as conditions, contexts and interactions (Strauss & Corbin, 1998), processes (Becker, 1998) or a table or matrix (Miles & Huberman, 1994). A concrete example related to reasons for driving a car is shown by Handy et al. (2005). They develop a framework for exploring the boundary between choice and necessity and then use this framework to guide in-depth interviews and characterize patterns of excess driving.

2.2.6.2 Coding Qualitative Data

In a case for qualitative methods in transportation research, Weston (2004, p. 2) states: "The key to analysis is coding the data". The process of labelling or annotating, categorizing and sorting data serves to summarize and synthesize observations into concepts and theories.

Strauss and Corbin (1998) distinguish 3 steps in the coding process: 'open coding', 'axial coding' and 'selective coding'. Initial 'open coding' means breaking down, examining, comparing, conceptualizing and categorizing data. 'Axial coding' refers to a set of procedures whereby data are put back together in new ways after open coding, by making connections between categories. Finally, 'selective coding' means selecting the core category, systematically relating it to other categories and filling in categories that need further refinement and development. Various aspects of analysis are presented sequentially as though analysis proceeds straight through the various coding steps. However, analysis is an iterative process that can be better represented by an iterative spiral (Dey, 1993), as shown in Figure 8.

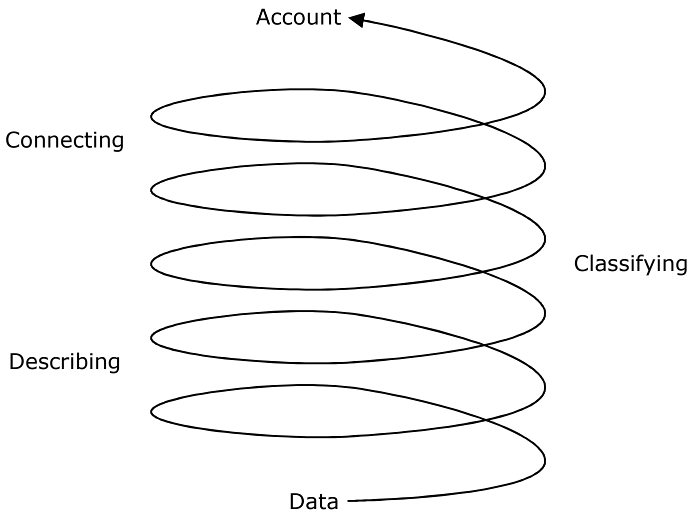


Figure 8 Qualitative Analysis as an Iterative Spiral (Dey, 1993, p. 55)

A similar process view of coding unstructured data is presented by Boeije (2006). She structures data, activity and result categories along an analysis spiral, see Figure 9.

To enhance the qualitative analysis process, specialized software is developed, so-called Computer Aided Qualitative Data Analysis Software (CAQDAS). This software does not automate coding and analysis processes per se, but it facilitates systematic coding, organizing and retrieving documents and presenting data to a large extent, be it texts, images, audio or video sections. A recent innovation in this computational support tool is the integration of GIS type functionality such as geo-referencing. Thus, the use of CAQDAS can improve both quality and pace of qualitative analysis. Lewins and Silver (2006) offer a concise overview and comparison of different available software packages. Besides this, specialized workshops such as organized by Lim (2009) can help to learn more about computer-aided qualitative research.

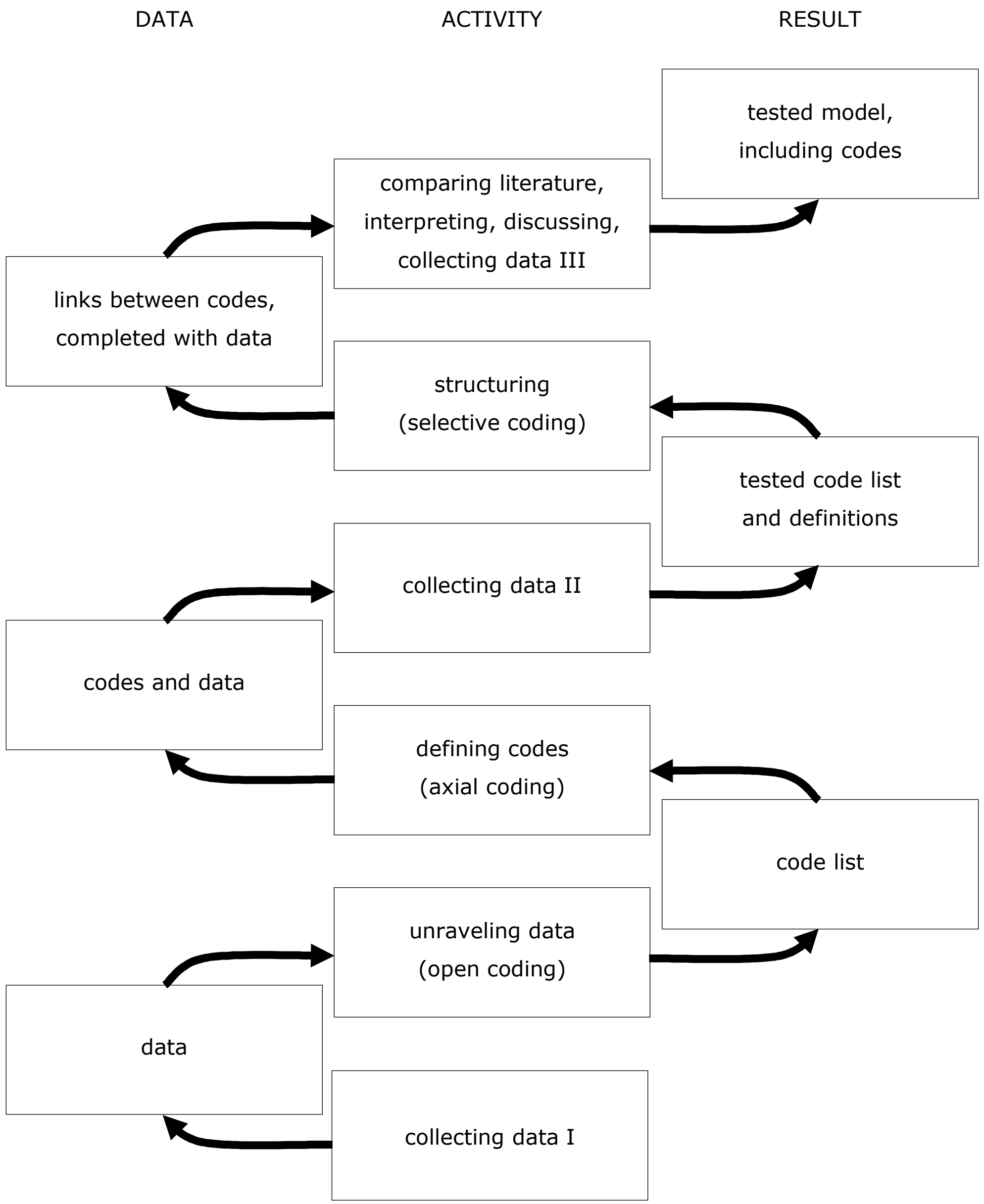


Figure 9 Qualitative Analysis as an Analysis Spiral (Adapted from: Boeije, 2006, p. 83)

2.2.7 Presentation of Qualitative Research Results

When qualitative methods are part of an exploratory pre-test, for instance to determine categories to use in large-scale instruments, the outcome of the research process can be a simple list of codes or categories. However, in case a written report is needed, it is important to carefully think through the presentation of research results. General methodological elaborations of this stage of the qualitative research process are offered by Margot et al. (2005) and Woods (1999), amongst others.

In general, typical exemplary verbatim quotes from interviews or conversations are used to demonstrate and illustrate findings. See Hine and Scott (2000) for an example in the field of travel behaviour research. Furthermore, developed theory can be presented in lists (usually coding lists), schemes, causal networks or matrices. For instance, Stanbridge et al. (2004) presented results of 11 in-depth interviews with regard to travel considerations in the residential relocation process in a 'residential relocation timeline', complemented by typical quotes. According to Dey (1993), causal networks or diagrammatic displays constitute powerful means in both analyzing and presenting qualitative findings. Several CAQDAS offer specific tools to map these graphical representations of coding schema (Lewins & Silver, 2006). This technique is applied in the actual qualitative exploration reported further in this chapter.

2.2.8 Quality in Qualitative Research

The assessment of quality in qualitative research is the topic of an ongoing debate. Obviously, traditional scientific objectivity and quantitative measures such as validity and reliability are untenable in this context. Therefore, Lincoln and Guba (1985) propose distinct standards for qualitative research such as credibility, transferability, dependability and confirmability. Yet opponents argue that such a wilful secession is harmful for the acceptance of qualitative approaches. A third, moderate view stresses the fact that qualitative researchers should aim at objectivity, but procedures for checking validity and reliability can be adapted to the specific character of the research. Important points of attention in this respect are: thick description (i.e. researchers should detail all the aspects of the research, including sampling and method of analysis); reflexivity (i.e. give an account on personal and theoretical perspectives and detail researchers' role); triangulation (i.e. test by multiple methods or data sources) and member validation (i.e. feedback results to respondents). In addition, checklists for quality or validity of qualitative research such as developed by Seale (1999) or Maxwell (1996) offer useful points of attention when considering qualitative approaches, applicable to travel behaviour research as well (see Weston, 2004). Moreover, such systematic checks can help to judge the value of qualitative accounts.

2.2.9 Concluding Qualitative Research Methods in Transportation

In summary, the application of qualitative research methods in transportation is scarce compared to quantitative approaches. Nevertheless, they can be critical complements to traditional quantitative travel survey methods, including:

- exploration of new, emerging or underreported research topics;
- identification of categories and multiple choice options to provide in closed-ended questions;
- assessment of user-friendliness of survey instruments and development and pre-tests of different survey designs;
- analysis and categorization of answers to open-ended questions and specifications of residual categories;
- analysis of additional, specific surveys targeting groups that tend to drop out in traditional surveys;
- in-depth understanding of unusual, unexpected or inexplicable results.

Besides these applications, qualitative research methods are very useful on their own, for any research question starting with 'why?' and 'how?' or whenever an in-depth understanding of phenomena is required.

For each phase in a qualitative research process, specific techniques are available and guidelines or handbooks can be found. Of course, their optimal application depends on the study objectives. The crux in all qualitative research, however, is to build a rich, convincing story based on large amounts of conscientiously analyzed, unstructured, real life data.

The next chapter sections show how some of the qualitative research methods framed above are applied in this thesis to explore the mental map in daily travel behaviour. Specific techniques used in subsequent research phases are: purposive sampling and snowballing, semi-structured in-depth interviews, qualitative analysis using CAQDAS, the use of graphical schemes and quotes, thick description and triangulation based on literature.

2.3 Exploring the Mental Map in Daily Travel

2.3.1 Objectives

The aim of the first phase of this PhD research process is to explore the behavioural framework of daily activity and travel scheduling in order to integrate the mental map concept into an AB model of travel demand, notably FEATHERS. Therefore, spatial cognitive factors as well as decision making mechanisms in activity and travel scheduling are scrutinized, considering the framework detailed in section 1.3. and methodological issues discussed in section 2.2.

The prime objective is to explore this framework breadthways and to make some preliminary observations related to spatial cognition and travel decision making based on variety in the data. In addition, an in-depth understanding of behavioural mechanisms in activity and travel scheduling is strived for by adding qualitative methods of data collection and analysis to the traditional travel survey process. The attention is focussed around typical qualitative 'why' and 'how' questions such as: why do people participate in activities at various locations and why do they travel to these locations the way they do, and how do these decisions come about?

With regard to the AB scheduler, the following research questions are at stake: (1) are the choice heuristics as assumed in a CPM of travel demand apparent in individual's daily activity and travel, in particular with regard to destination and mode choice decisions? (2) which elements in general occur in this propositional reasoning, i.e. to be conditions, restrictions, justifications or otherwise? (3) which spatial components in specific can be identified within these heuristics?

2.3.2 Method

To obtain a better understanding of spatial cognitive factors within general travel choice processes, the context of daily activity patterns needs to be taken into account to start with. To record daily activities and travel, a one week activity and travel survey consisting of a written questionnaire and an activity-travel diary was used, based on survey instruments traditionally used to gather revealed data in quantitative research such as the Flemish travel surveys (Ministerie van de Vlaamse Gemeenschap, n.d.). The survey length was extended to one week as opposed to the traditional two days Flemish travel survey. This prolongation enhanced the focus on variety in decision patterns on both a general and individual level, and enabled to reveal and question a typical sample of an individual's daily activity space taking a weekly rhythm of life into account (Axhausen et al., 2002). In addition, travelled routes were recorded by a GPS-enabled personal digital assistant (PDA) in order to enable a comparison between revealed and stated route information (e.g. distance estimates, route descriptions).

To model individuals' daily activity schedules, a CPM such as the FEATHERS scheduler utilizes if-then heuristics derived from traditional travel survey data and activity diaries. Another, more direct method to gain insight in the knowledge and methods of human decision making is to use think aloud protocols (see 1.3.2.2). However, an application of this method in the strict sense is cumbersome if not virtually impossible for the investigation of daily activity-travel patterns established during a week; the respondent would literally have to be followed everywhere by a researcher, continuously expressing his thoughts about his plans and actions. Therefore, this method is approximated in this PhD research phase by conducting a structured pre- and post-interview with open-ended questions about the activity and travel scheduling and execution in the chosen week. A one-hour pre-interview took place before the start of the survey and consisted of an inquiry into the activity space and travel plans for the following week. A 45-min post-interview or feedback interview occurred after finishing the survey and included a comparison of the executed activities and travel to the former planning.

Two major interview sections aimed at eliciting if-then destination and travel mode choice heuristics: the description of activity spaces on the one hand and the explanation of activity and travel planning and execution on the other hand. The first interview part consisted of questions about the perception and the extent of the individual's activity space. During this part of the interview, two main sets of open ended questions served as guidelines. The first set refers to the destination choice and the perception of distances in the activity space: "*Where do you perform [activity type]? Is that far away? How far is it? In distance? In time?*" Activity types taken into consideration are work, school, social visit, daily shopping, non-daily shopping and services. The second set of questions concerns the activity-related reach of respondents using different transport modes: "*Which activities do you execute by [transport mode]? Regularly? Occasionally? How far is that? In distance? In time?*" Transport modes questioned are foot, bike, bus, train, motorcycle and car. It is important to note that in this interview section no explicit questions were asked to reveal decision heuristics; rather a spontaneous elicitation of references to circumstances and reasons for certain destination and travel mode choices was strived for. Moreover, there was room to hold forth on particular subjects, if respondents wanted to explain particular topics in greater detail, of in case the researcher felt that further explanation was needed. Besides this, the major research paradigms for investigating spatial cognition, such as distance estimates, sketch maps and route descriptions, were covered in the interview questions of this pre-interview part.

In contrast with this first activity space interview section, during the interview sections regarding the scheduling (pre-interview) and evaluation of scheduled activities (post-interview), the motivations, circumstances and choice options for destination, mode choice and route choice were interrogated explicitly. With regard to activity locations away from home, respondents were asked to specify the activity location, the distance to that destination both in qualitative and in quantitative terms, the reasons for choosing that location, the frequency of selecting this location and the consideration of other choice alternatives. With regard to travel mode choices, respondents were asked for their motivations for choosing a particular mode of transport, the frequency of using this transport mode to reach that destination, the availability of other transport mode options and their consideration of alternatives, and their general appreciation of the accessibility of that activity location. Again, a list of open ended questions (see Appendix A) served as a guideline in these conversations.

2.3.3 Sample

The whole data collection procedure was tested twice before the actual sample was addressed in late spring 2005. To reveal as many determinants as possible and enable theory building, a selected sample of respondents was contacted. Consistent with Trost's (1986) recommendations for strategic non-representative sampling aimed at exposing variety, important revealed explanatory characteristics for activity and travel choices were taken into account: age, sex, education, occupation, driving licence, possession of car, marital status, household size, parenthood, residential location and mainly used transport mode. For each feasible value of these key characteristics, at least 4 to 5 respondents were pursued while avoiding clusters of characteristics as much as possible (e.g. both men and women without a driving licence are present in the group of respondents). This resulted in a total sample of 20 respondents, which is a typical sample size for qualitative research in the field of transportation, as stated by Mehndiratta et al. (2003). Similar sample sizes can be found in related research such as Beirão and Sarsfield Cabral (2007) and Gardner and Abraham (2007). Table 4 shows the final sample characteristics.

As for sampling strategy, respondents were first selected from the wide circle of acquaintances of the researcher and then, according to the 'snowball method', attracted from the circle of acquaintances of acquaintances. The degree of motorization in Flanders is rather high; 1.18 private cars per household and 487 private cars per 1,000 inhabitants in 2007 ensure the region of Flanders a top 10 position amongst 27 European countries (Studiedienst van de Vlaamse Regering, 2009). Therefore, respondents without a driving license and households without private cars were selected to start with.

Table 4 Sample Characteristics

CHARACTERISTIC	N	CHARACTERISTIC	N
Sex		**Driving Licence**	
Male	10	Yes	14
Female	10	No	6
Age Category		**Marital Status**	
< 30 years old	3	Married	13
30 – 39 years old	9	Living together	1
40 – 49 years old	5	Divorced	1
+ 50 years old	3	Unmarried	5
Place of Residence		**Work Schedule**	
(A) Central, good PT access	7	Full time	12
(B) In between, moderate PT access	7	Part time	4
(C) Remote, limited PT access	6	No paid work	4
Number of Cars in the Household		**Car Availability**	
0	5	Yes, always	6
1	8	Yes, confer with household members	6
2	5	Yes, confer outside household	2
3	2	No	6
Household Size		**Net Monthly Household Income**	
1	1	1,000 to 1,499 Euro	1
2	4	1,500 to 1,999 Euro	3
3	5	2,000 to 2,999 Euro	6
4	6	+ 3,000 Euro	9
5 and more	4	Unknown	1
Degree		**Net Monthly Individual Income**	
Secondary school (lower level)	1	< 750 Euro	3
Secondary school	7	750 to 1,249 Euro	3
College	7	1,250 to 1,749 Euro	9
University	5	1,750 to 2,249 Euro	5
Occupation		**Transport Mode (Work or Shop)**	
Student	1	Car driver	4
Housekeeping	2	Car passenger	3
Retired	1	Moped	1
Worker	1	Bike	5
Employee	10	Walk	1
Employee (management)	2	Bus	4
Self-employed	3	Train	2

Income proved to be the most difficult variable to account for. All respondents can be situated in the lower or upper middle class, leaving an in-dept view on travel behaviour of specific groups such as the financially weak and the very rich as a subject of further research.

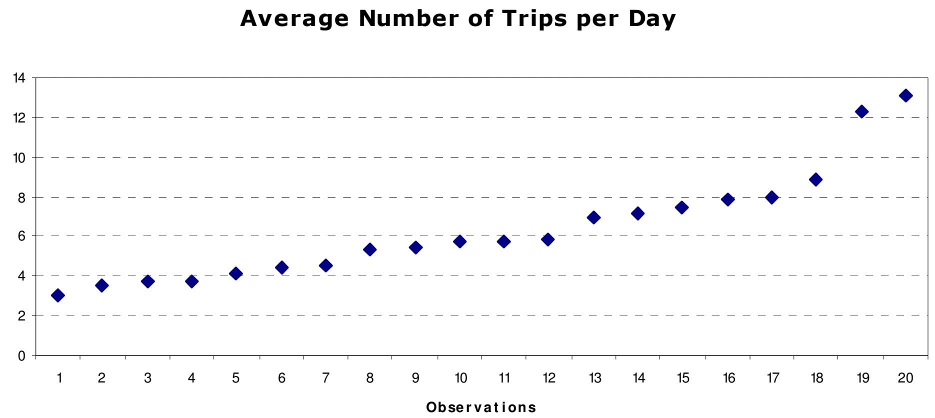
Although data collection and data analysis were performed consecutively, the initial sample of 20 respondents proved to be sufficient to reach saturation in understanding from a qualitative analysis point of view (see 2.2.4.); all 20 interviews were analysed but as from the interview analysis of the 16th respondent, no new code labels and categories were added.

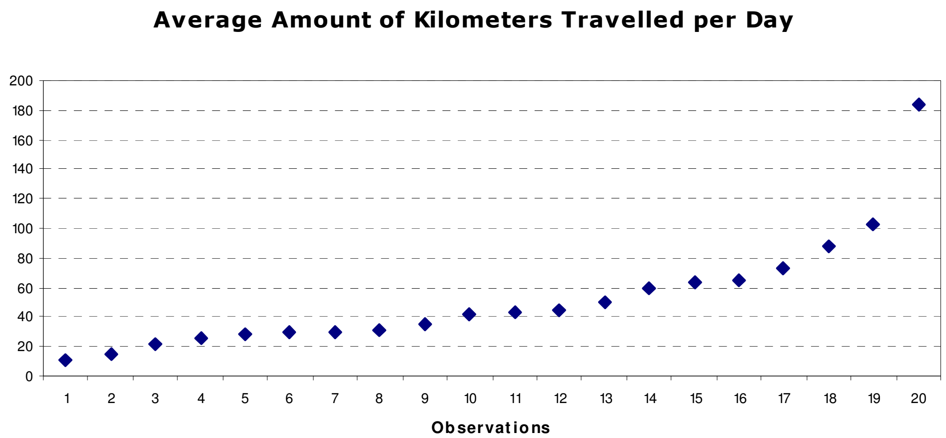
2.3.4 Analysis

2.3.4.1 Travel Diary Data and GPS Logs

To frame the in-depth analysis, some general statistics were drawn from the travel diaries. Compared to Flemish travel behaviour indicators, they provide insight in the degree of activity and travel of the sample of respondents. However, divergence from Flemish averages is not problematic since statistical representation is not aimed at. Rather, a wide spread in activity patterns and travel characteristics is sought.

On an aggregate level, the 20 respondents reported 888 trips and 1691 activities during 140 registration days. Activities were registered round the clock, both at home (67%) and outdoors (33%). 6.34 trips per person per day were reported (excluding travel during work or travel as work), with an average travel time of 18 minutes per trip and an average estimated travel distance of 8.2 kilometre per trip. The average amount of travelled kilometres per day is 52. Figure 10 shows some graphs of observed travel characteristics to indicate the spread observed in the sample. In the average number of trips per day, two respondents have very high averages: a home nurse, mother of 4, with 3 short work tours on each working day, and a postman working in two shifts and walking his dog twice per day. The outlier in the average amount of kilometres travelled per day is a respondent who went to visit the Champagne region in France for the weekend at the time of the survey.





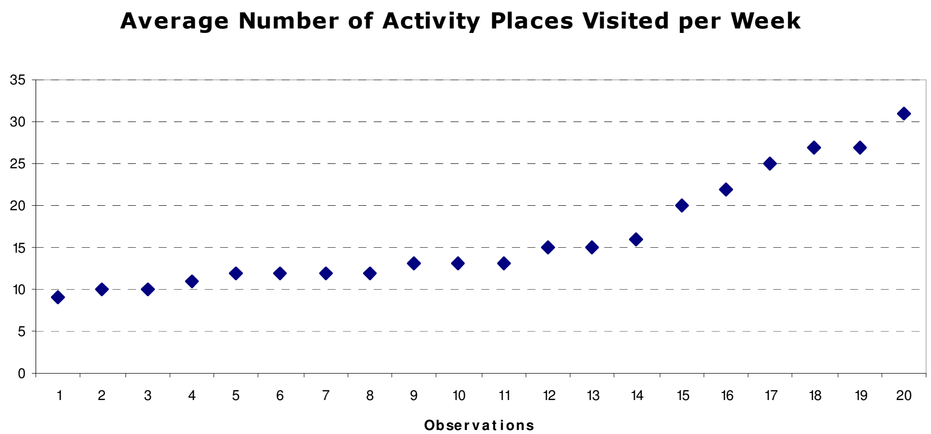


Figure 10 Travel Characteristics of the Respondents

The observed averages are considerably higher than Flemish travel indicators; Flemish travel surveys report an average of 3.14 trips per person per day and an average of 41.64 kilometres travelled per day (Janssens et al., 2009). This difference reflects a bias in the sample towards the more active part of the population. Moreover, the respondents in this qualitative survey paid a lot of effort to complete the activity and travel diaries and showed a lot of commitment, probably due to the personal relationship with the researcher and the planned before and after contact. Whereas in traditional, large scale travel surveys, survey fatigue often manifests itself in a steadily decreasing number of reported trips (Axhausen et al., 2007).

As to the activity spaces revealed in the diary data, the average amount of different activity places visited during one week is 16 per respondent. A number of these locations were visited more than once within one week (e.g. work, school). Several activities were performed at different destinations. Highest scores can be found for daily groceries (3.45 locations per person per week on average), and social life (4.25 locations per person per week on average).

Respondents were divided into 3 types of residential location (A, B and C) according to their proximity to PT services and the town centre. In this sample, the residential location has no or little influence on the amount of activities performed, on the amount of different activity places visited or on the amount of trips reported. The average travelled distance per day as estimated by respondents however, increases with increasing distance between dwelling and PT and town centre. It increases slightly when comparing A (33.36 kilometres) to B locations (42.01 kilometres), and it doubles on C locations (85.41 kilometres). Average travel time per day increases as well, yet more moderately, indicating that respondents in this sample living in A and B locations use slower modes of transport or slower parts of the transportation network compared to respondents living in C locations.

Weekly activity spaces were also observed by means of a GPS-logging. These georeferenced data can be visualised on a map of the road network by means of the GIS software TRANSCAD, as is shown in Figure 11. Unfortunately, the logging procedure failed for some respondents and in particular trips. For instance, in PT vehicles (trains and buses), the GPS signal was lost. At the same time, when moving slowly (walking speed) or in densely built-up areas, the recordings were inaccurate. Although this information with regard to the performance of the logging system proved to be valuable for the development of the planned large-scale data-collection in the FEATHERS project (Kochan et al., 2008), the actual GPS dataset gathered by the sample of 20 respondents was not used for further analysis in this PhD research.

One of the intentions was to use the revealed trip distances in the GPS-logs with respondents' distance estimates in their travel diaries and in the interviews. Not only is estimating distances a common technique in spatial cognitive research, e.g. Ishikawa and Montello (2006), the reliability of reported distances in travel surveys has been questioned as well (Witlox, 2007). Due to the biased GPS data and the limited sample size to start with, too little useful instances prohibited extracting meaningful results.

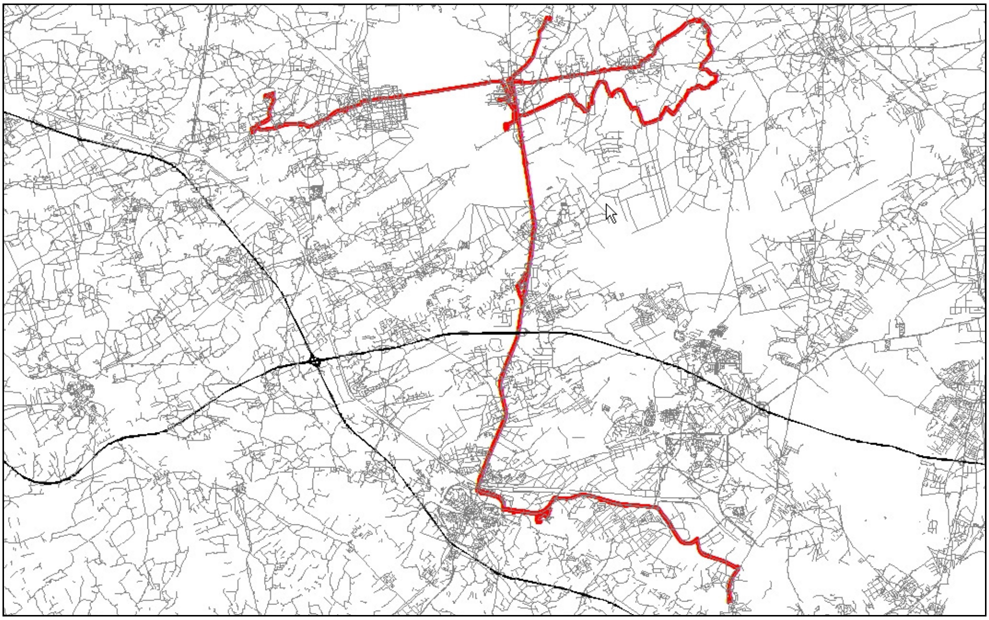


Figure 11 GPS-Logged Weekly Activity Space of a Respondent

2.3.4.2 Interview Analysis

The interviews were audio-taped, transcribed verbatim and processed with ATLAS.ti version WIN 5.0 (Scientific Software Development, n.d.). Such a specialized CAQDAS package is considered to be a useful instrument to improve not only the pace and flexibility of textual data management in specific, but also the consistency and internal reliability of qualitative research in general (Maso & Smaling, 1998; Seale, 1999), at least as long as basic prerequisites of interpretative qualitative theory building are taken into account (Kelle, 1997).

A cross-case analysis was undertaken for the interviews. Initial reading and re-reading was followed by indexing and free coding the texts, which involved assigning conceptual labels to topics and refining them through repeated inspection. Bearing the research questions in mind, all mentioned travel decisions were indexed manually in ATLAS.ti according to their activity, mode and destination type. References to choice processes and if-then heuristics were indicated and coded. For every new instance, similarity with previous cases was considered according to the constant comparative method (Glaser & Strauss, 1971). ATLAS.ti facilitated selecting, retrieving and displaying coded quotations to a great extent. If no proper existing label could be assigned, a new code was created and previous interview passages were checked anew for missed cases.

While coding progressed, ideas about different perspectives and relationships between codes and overarching categories developed and these were provisionally conceptualized in memos, codes and overarching code families. Secondary coding involved the elaboration of these preliminary ideas, further code classification, and examination of relationships between labels and categories. Final inspection and selective coding of the data led to an understanding of interrelationship between categories and their properties, and integration into central categories with regard to the activity-travel decision process. Finally, this data-driven analysis resulted into the descriptive phase and the construction of the analytical networks (see the results in 2.4).

Thus, the developed framework emerged directly from the data, while theoretical sensitivity was shown in the initial selection of the respondents (as discussed above) and in the classification of the assigned codes. In addition, these theories (i.e. the classified concepts and ideas that individuals associate with daily activity and travel choices and their relationship) were represented in 'script network views' using the graphic tool of the software. These results from the interview data analysis of respondents' discussion about their daily activity spaces are presented in the next section. Besides the use of networks to display data (Miles & Huberman, 1994), selected typical verbatim quotations (translated from Dutch to English as naturally as possible) are added for the sake of argumentation and illustration – a common practice in qualitative social research (Corden & Sainsbury, 2006).

2.4 Results

2.4.1 Daily Activity and Travel Decisions

Looking at the pieces of cognitive processes involved in destination choices and travel mode choices that were revealed in the discussion of daily activity spaces and activity and travel scheduling, two main observations dominate the analysis of the general form and structure of these decision processes: (1) the execution of daily activity schedules is principally automatic and seldom preceded by much deliberation; (2) the individual's daily activity-travel execution seems to start from a default setting, and is completed with additional heuristics.

A clear finding during the interview administration was the fact that, generally speaking, the different dimensions of the daily activity and travel planning and execution in general and the destination and mode choices in specific do not appear to be sequential stages within the decision process. Although often modelled that way, the travel related decisions in an everyday activity schedule are in fact perceived of and handled as being part of an integrated problem, in which certain interconnected solutions are triggered simultaneously without much consideration, not to mention the systematic weighing of different alternatives by its attributes, which is assumed in most classic utility based choice models (see 1.3.2). Activity, destination and travel mode are set in fixed mental scripts that are cued by certain situations. It is highly automated routine behaviour, often performed mindlessly. This was so stated spontaneously by a respondent:

17: "*Now I'm giving it some thought. That is not what one normally does.*"

This hypothesis is also shown by the fact that respondents often stated travel times to certain locations without even mentioning travel modes or having referred to them before in the interview. This shows the implicit presence of certain relations between decisions.

The script network view in Figure 12, which has been constructed based on the interview data, shows that within these *activity-destination-mode* scripts, both destination and travel mode appear to have some sort of standard norm or default setting for most of the everyday activity episodes. This default setting can be completed by some additional exceptions, expressed as if-then heuristics. However, there are some situations where either the destination or the transport mode or both attributes have no default setting and where two or more choice options are considered until the point of departure. In these cases, if-then heuristics appear to explain the circumstances or reasons for the consideration of choice options. The content of these default settings and these if-then heuristics is discussed further.

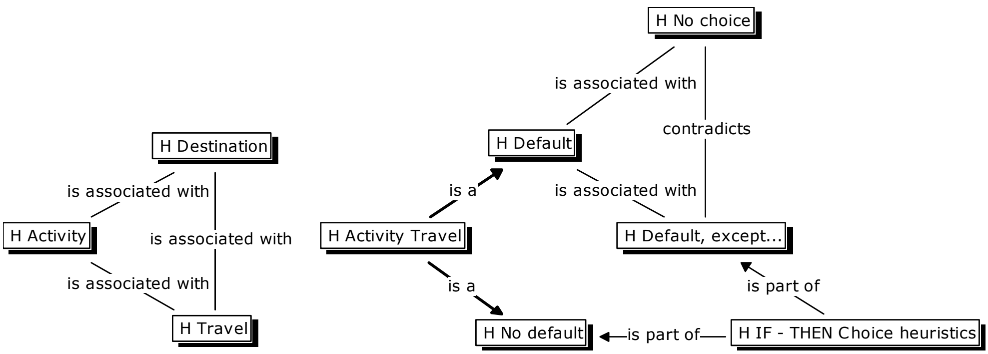


Figure 12 ATLAS.ti Script Network View of the General Activity-travel Decision Process

2.4.1.1 Default Settings in Daily Activity Spaces

In the case of a default setting, it is often referred to as a no choice situation in two ways: either there is no actual choice within the daily activity context or there are no perceived choice options (see Figure 13). The first situation can be caused by the fact that the choice at stake was part of a long-term decision, by the fact that others made the decision or by the fact that there was actually only one single choice option (within existing and accepted constraints such as space-time constraints, coupling constraints or institutional constraints). Besides the occurrence of no actual choice, there can be no perceived choice options as well. Respondents attribute this to the logic of the solution (again, within given constraints), the fact that it is a habit or they expose some opinion, which relates to attitudes and beliefs. Finally, a feedback effect can be identified between constraints in daily life and long-term decisions. The categories in Figure 13 will be detailed for the destination choice to start with. Afterwards, the travel mode choice will be dealt with.

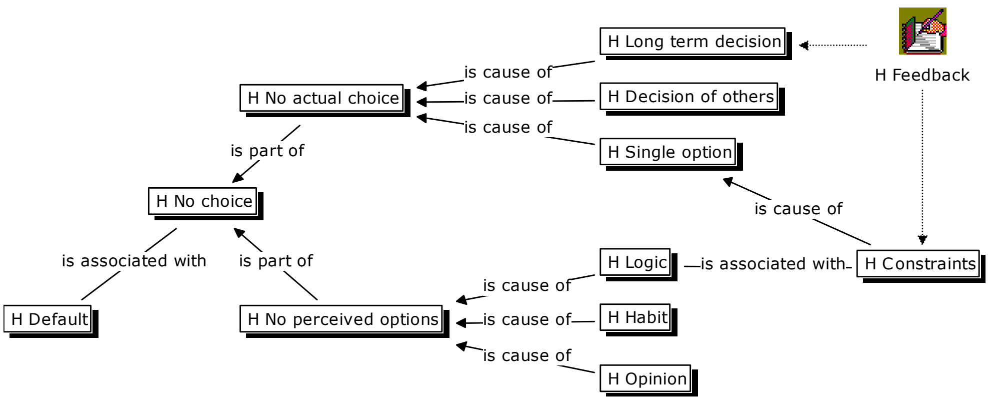


Figure 13 ATLAS.ti Script Network View of Defaults in Daily Activity Spaces

Destination Choice Default Settings

In daily travel patterns, destinations are fixed for many activities. There is no actual choice at the time of everyday activity and travel planning and execution. Long-term decisions such as where to live, where to work and where to go to school, determine travel destinations of mandatory activities such as work and education, e.g. Krizek and Wadell (2002). Leisure activities such as sports or other hobbies are generally considered to be discretionary activities and thus flexible in time and space. The long-term decision to join a club, however, can fix destinations of leisure travel in everyday life. As a result, such activities become much less flexible in activity schedules. Therefore it can be concluded that long-term decisions add to the constraints of daily life.

The daily destination choice of travel to execute social activities such as visiting family and friends is obviously determined by a (long-term) decision of others.

11: "*And going to friends, well, it is in fact indeed… A lot of people did actually move outside [respondent's hometown], now I'm giving it some thought, yes.*"

Besides that, for all sorts of discretionary activities where others are involved, activity location decisions can be made by others as well. These 'others' usually are members of the household, but destinations can be chosen by people outside the household too, for example when going out with friends. A special example of this 'decision of others' situation is 'bring and get' activities in which the driver has to chauffeur someone to a particular destination.

Finally, destination choices can be determined by the fact that there is actually only one option. When there is only one post office in the area, for instance, parcels to send by mail must be taken there. Remarkable in these cases is not only the fact that the amount of destinations available in the choice set is defined by the specificity of the wanted product or the specialization of the needed service, but also by the fact that there is a commonly accepted spatial assumption present in the statement 'in the area'. Theoretically speaking, more options can be available (e.g. post offices in the neighbouring areas), but in case of a large difference in (actual and perceived) distance between two equally valued alternatives, proximity within the space-time settings of the daily activity schedule can restrict the actual choice set.

Of course, the latter is also related to the default settings in daily activity destination choices where there are no perceived choice options. Daily grocery shopping, shopping for non-daily goods, consulting services, and real discretionary leisure activities all have multiple destination possibilities. Nevertheless, even when there is no official commitment to certain destinations and there are a number of possible activity locations (objectively speaking), attributions that can be categorized as 'logic', 'habit' and 'opinions' are mentioned as driving forces in establishing and maintaining default destination settings.

Logical arguments refer to the position of actual destination in the entire activity schedule and various applicable constraints. This finding is clearly related to literature in which the ratio between stay time and travel time for different types of activities is addressed, such as travel time ratios or travel time prices, e.g. Chen and Mokhtarian (2006) and Dijst and Vidakovic (2000). Such constructs could be considered as 'norms' that help people reach acceptable solutions without much deliberation. Given circumstances, some places are just the most logical place to go. Time and distance minimization in specific and cost minimization in general are important driving forces.

07: "*She [daughter] also does everything there, so, um, her hobby's are there too, so um. And currently I go to the gym, the Horizon [name of the gym], to use the 'power plate' but that is currently also when driving back from um, from school. Generally. I try to.*"

I: "*Do you still do your groceries in your former hometown? Yes?*". 19: "*I'm am working in Turnhout [town], that's why.*" I: "*So, that's on your working tour?*". 19: "*yes. Besides, the Cash [supermarket] is closed over lunch and it is a lot more expensive.*"

Besides logic, 'habit' can be a strong driving force as well, even overruling the logic of distance minimization. Built-up personal relations over time or semi-official commitments for services such as a bank or family doctors enhance such choices. Moreover, it is considered rather unusual to change certain activity locations once a choice is made and results proved to be satisfying, even under changing circumstances.

12: “*Our doctor, he used to live in Elsum [parish], and now he is living in the Dokter van de Perrestraat [street], so that is a bit further away now, so…*”

14: “*Our doctor, he lives in Hove [municipality] actually and there... When we still lived in Boechout [municipality] we chose him. But, yes, today that is in fact a remainder of that time.*”

18: “*The hairdresser is in Vosselaar still [previous place of residence]… Yes, yes, yes, so, that is those five kilometres again*… *That’s an old habit, I shall say.*”

Due to the interpretation of habitual forces by respondents, the concept of ‘habit’ in this theoretical framework differs from the usual meaning of habitual travel choice behaviour in transportation literature, in which the term ‘habit’ is often used to indicate all travel behaviour without explicit intention and no or little deliberation (Gärling & Axhausen, 2003). Here, ‘habit’ is but one force mentioned as a cause of maintaining certain default settings within a set of daily activity and travel scripts that can be performed mindlessly.

Finally, opinions about destination choices in general and about attributes of theoretically available options in particular can shape default settings. The first type is related to general problem-solving strategies and attitudes. The second sort of opinions about attributes of choice options is related to preferences, often shaped after unsatisfactory experiences. There is a default setting because (all) other options are perceived as being insufficient. This can overrule the logic of distance minimization.

09: “*But say, we buy everything here in the vicinity… If something is broken, we can go back there immediately… And the service is good as well, so it is stupid wanting to buy it somewhere else, even if it’s a little bit cheaper.*”

08: “*And in Leuven [town] I always, um, I always walk to cover distances, so in principle I could leave the bus in Leuven at the station and change to another bus that stops right in front of my office doors, but that is not what I do*… *That is* *a matter of principle again because it gives me some exercise (laughter). Because I have a sedentary job, so I think it's important.*"

14: "*You have got a small supermarket over here, but we don't like to shop there. Most of the times, we go to the Delhaize [supermarket].*"

Travel Mode Choice Default Settings

The impacting factors for the default settings of mode choices are similar to those of destination choices. First of all, long-term decisions with regard to the possession of vehicles (purchase of a bike, motor or private car) and the ability to drive them (learning how to drive a bike, passing one's driving test) is an important predictor for the use of individual modes of travel. This also applies to the acquisition of PT season tickets and reduced fare passes for the use of bus or train. Moreover, people seem to organize their lives from the perspective of the available modes of transport as well: They buy a car to get somewhere but the fact that they have a car, makes them choose destinations that they would not have considered otherwise.

08: [Bus] "*But in in Antwerp [city] or in um Ghent [city], and… That might be good to mention, I actually own a bus season ticket for the entire regional bus network from 'the Lijn' [bus company] and that also partly constitutes an argument to catch the bus or tram more easily in Antwerp or in Ghent or the like because I, yes, I have a PT season ticket, so…*"

In certain circumstances the default setting of travel mode choice that is experienced as a no choice situation in the daily activity-travel pattern is explained as a mere consequence of the decision of others in favour of a certain mode of transport.

06: [Car] "*Um, yes, going to the shop. But, hey, I don't drive in that case but I go along with my parents.*"

14: [Moped] "*Every Friday my collegue gives me a double (laughter)… Yes, from one school to the other school, you see. He has this Vespa, and both a helmet…*"

A third ‘no actual choice’ situation occurs when the modal choice set is limited to only one choice option. This is obviously the case for activities such as ‘walking the dog’, ‘run around the block’ or ‘making a bicycle trip’. This situation also arises when there is a limited individual modal choice set to start with (no car, no bike, inability to walk due to a physical problem), when PT supply does not fit the spatial or temporal demand, or when destinations are chosen that can only be reached one way within a reasonable period of time.

05: [Car] “*But at night, there are no buses and then they bring me back to Hasselt that way, so. Otherwise, I don’t drive along with a car. But it is the case when I have no alternative.*”

11: “*Now, suppose I miss the bus to Geel [town], so, then I still have one other option. Then I can take the train to Geel station, and the shuttle bus service… So if I miss my usual bus, I still have a chance to arrive at school on time. That is not the case with Vorselaar [second workplace], that is only one connection.*”

In addition to ‘no actual choice’ situations, ‘no perceived choice’ situations also occur in default mode settings. The first type of arguments for the existence of certain default mode settings appears to be logic within situational constraints. Because different modes of transport have different properties (speed, flexibility, cost, needed physical effort, availability, loading capacity…), they all have a different perceived logical use: walking is associated with very small distances and greater time consumption. Riding a bike is faster and appropriate for short and medium lengths. It shares its flexibility in space and time with walking, but both travel modes leave the traveller rather unprotected. Beside this, they force physical effort and offer limited loading capacity. Public transport services are bound in space (bus and train lines) and time (service schedules). Busses are considered suitable for short to long distances, trains for medium to very long distances. Cars finally, are found to be suitable for all distances (except very small ones) and can be used at any time, anywhere (except in areas that suffer from congestion or heavy parking restrictions), they offer protection and loading capacity for people and goods.

07: [Car] “*If you walk out the hairdresser’s door, your hairdo is fine, and then I think, if it rains then or the like or in the winter, I think in fact, I think it’s a shame, so.*”

11: [Train] “*Friends, very close friends live in Brussels [city].*” I: “*Is that far?*”. 11: “*To my opinion that is far, yes… We usually take the train to go there…*”

15: [Car] “*The Aldi [discount supermarket] is eum… Yes. Well, most of the times with my wife, because you can stuff the car you see.*”

As mentioned before, activity, destination and mode are intimately tied in everyday activity-travel scripts. Because a lot of destinations in the activity space are fixed or appear to have a strong default setting (e.g. work, school, residences of friends and family), the resulting distances that have to be travelled are fixed as well. Therefore, certain distances and destinations are automatically associated with certain suitable transport modes. Choosing the fastest travel mode out of the options is the most common logical choice strategy serving the benefit of time minimization, unless there is some clear other benefit experienced from travel with a slower mode.

I: [Walking] *“Is it just the distance? Or is there another reason as well? Why would you never take the car to go there?”.* 13: *“For parking as well. Sometimes you’re a lot quicker by foot than by bike or by car.*”

08: [Bus] *“Time, sure, that surely plays an important part for me… because I with regard to my job, um, I experience it as loss of time… but I do carry on… because I, just because I take the bus and on the bus I can do something else then when I’m behind the wheel myself, um, and can do nothing else but, um, minding the traffic.*”

Similar to destination default settings, habit is of strong influence in the maintenance of default travel mode settings. Moreover, a (chosen or forced) habit to use a certain transport mode to reach certain activity locations can be so strong that it becomes a general default travel mode setting for nearly all travel in everyday life. In that case, activity scheduling follows the functional logic of the travel mode at stake.

I: [Car] "*Yes. And how do you go to the station?*" 07: "*By car… (laughter) everything by car.*" I: "*and what is in fact too short as distance for you, to travel by car?*" 07: "*Yes, what, what actually… The village centre… But I still do that anyway… Regularly, um during the summer, um, we try to make it a habit to, to go to SACHICO [sports centre] for instance by bike.*"

I: [Walking] "*Do you consider other options?*" 17: "*No, in fact... I am used to walk to the locations you mention… We keep it that day then.*"

Finally opinions about travel modes and the properties of the environment in which they are of use influence the fact that certain modes are not perceived or considered as choice options in everyday life. General attitudes, beliefs, bad experiences, lack of knowledge, or a sufficient degree of satisfaction achieved with other travel modes feed this category.

03: [Car] "*To the sports hall. I don't do that 10 minutes by bike.*" I: "*Yes. And why not by bike?*". 03: "*Because it's in the evening and so you see eum…*"

08: [Bike] "*What is within Geel [town], is not far. I know a lot of people would take the car… But in my case it is the bike on principle grounds.*"

10: [Walking] "*Walking? Not really… The street is not suited to do so.*"

13: [Car] "*But like the Alma [supermarket], things like that. The Aldi [discount supermarket] I would walk to if it wasn't such a busy road, but it is far too busy so… I think it's even dangerous by bike.*"

18: [Bus] "*I'd rather not use it and that just has to do with… Because there are a lot of students on the bus then. And that's not OK really… I'd rather cycle through the rain in that case.*"

A final remark about observed appearances of 'logic' for the development and maintenance of both default travel mode settings and default destination settings regards the fact that this 'logic' in itself could be transferred into logical decision rules or if-then heuristics. It might be clear that in the mentioned quotations, such rules were often implicitly present. To make them more explicit, stated data from a thorough questioning of destination and mode choice in default settings could elicit such logical decision rules – at least, as far as people are aware, which is often not the case for default settings, as is shown above, and as far as they are able to articulate complex relationships among influencing factors. In addition, 'logic' does not have to be a synonym for rationality in human reasoning. Further analysis of the interviews will illustrate this.

2.4.1.2 If–Then Heuristics in Daily Activity Spaces

Besides clear default settings, if-then choice heuristics occurred in the interviews in two ways: they were either used as an expression of existing exceptions to default settings, usually linked with specific constraining circumstances, or they were used to express choice options and considerations when an activity-travel default setting was lacking. Quite remarkable is the fact that these exceptional situations and perceived choice sets plus their subsequent choice outcomes as they are, seem to be part of fixed scripts. This reasoning shows the existence of an 'activity-travel repertoire' or 'mental map' that comprises a set of standard alternative solutions for everyday life.

Within these heuristics, the classes of occurrence (circumstances, specifications, hypothesis, mode first, and choice set) indicated in Figure 14 below, can be recognized. In the following sections, destination choice heuristics and travel mode choice heuristics in each class are detailed subsequently. Travel mode decisions are elaborated per vehicle type.

If–Then Destination Choice Heuristics

Destination choices appear to be fixed for most daily activities. Some few explicit if-then heuristics occurred. As explained above, the activity categories of 'work', 'school' and 'social visits' are fixed because of long-term decisions or decisions of others. The activity categories 'services' and 'leisure' usually comprise some fixed locations because of certain commitments. For other destinations related to 'services' and 'leisure' and for destinations related to 'grocery shopping' and 'shopping for non-daily goods', few if any options are perceived or considered in everyday life.

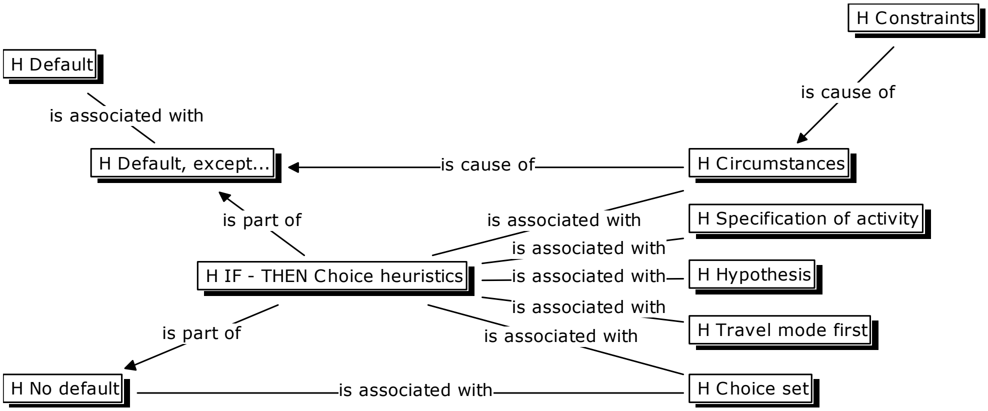


Figure 14 ATLAS.ti Script Network View of If-Then Choice Heuristics

Figure 14 shows that a first set of heuristics was used to explain specific circumstances or situations in which other-than-usual choices appear. Certain situational constraints, such as exceptions resulting from institutional constraints, household task allocation and space-time constraints, can cause deviations from the destination default setting. Quite remarkable is the fact that these exceptional problems and subsequent solutions in itself seem part of certain scripts. Thus, the mental map of destinatons comprises a set of standard alternative solutions for rather exceptional situations in everyday life.

12: [Groceries] "*that's not my duty really… And if I do it, if I do it, then it is really close, to the Vewo [small supermarket] for instance or to the Cash [small supermarket], or to the butcher.*"

13: "*If it is really urgent and the kids are very ill, then we go to another doctor.*"

17: "*If, by any chance, the department store here nearby is not open, and, then we go somewhere else. Sometimes to the GB [supermarket] or to… What is it called? The Delhaize [supermarket] or so.*"

A second appearance of explicit heuristics has to do with the categorization of activities. Apart from work and attending school, which usually comprises only one destination, each activity category is an aggregation based on presumed similarities in behaviour within the activity category. However, most respondents spontaneously mentioned meaningful specifications and typical subcategories, expressed as: "*if [activity subcategory] – then [destination and/or mode choice]*". Conditional on subcategories of daily and non-daily shopping, destinations are either defined in terms of generalized activity location areas (e.g. small daily groceries) or exact locations (e.g. comprehensive weekly groceries). When a certain activity subcategory only occurs infrequently (e.g. shopping for furniture), possible destinations are not fixed and referred to in general terms. Within the quite diverse activity category of leisure, a distinction between daily and weekly routines with principally fixed and near destinations on the one hand, and seasonal activities (e.g. cycling in summertime, or a trip to the seashore) and occasional leisure trips on the other hand, seems possible. The occurrence of 'leisure shopping trips' also shows that a mere functional categorization of activities has its limitations.

08: "*…For what shopping is concerned, if I need clothing or something like that, then I always try to buy that in Geel [town], um, in the centre of Geel, um, so I go, I travel very little distances for shopping elsewhere.*"

Apart from specifications of the activity categories, some of the relevance of perception of distance in the destination choices within different activity-travel categories was also illustrated. However, the travelled distance seems more related to frequency of activity performance and attractiveness of destinations than to the actual activity-related purpose of the trip; the further away, the less frequent the visit or the more attractive the destination, irrespective of the activity category.

Besides actual occurring choices in daily activity space, respondents have mentioned hypothetical choice situations in the interview conversation. Because these heuristics do not reflect actual performed travel behaviour of the past but only reflect speculations about possible future behaviour, they are not discussed further.

03: "*Yes… If tomorrow a new department store opens in the neighbourhood, then I will shop in the vicinity…*"

A fourth sort of heuristics illustrates the fact that mode choice can precede destination choices. Apart from that, all travel modes are associated with a certain reach. In a no-travel-mode-choice situation, destinations are obviously chosen within the possibilities of the available travel mode.

05: *"Sometimes it is the other way around as well, when I choose a destination to go based on the train."* I: *"Yes. Can you give an example?".* 05: *"Yes for instance next summer holiday I go eum explore our country a bit with my daughter, like that, and then I look where we can get by train and then I look for something interesting to see, so I do it based on where I can get."*

09: "*Um, if the destination is within half an hour [by bike], let's say, within an hour then…*" I: "*Then it is feasible, yes?*" 09: "*Let's say, for me, yes.*"

Finally, in the no-default-choice situation, destination choice sets in everyday life comprise several considered opportunities. In these cases, destinations are valued equally, and actual established choices appear to depend on scheduling logic, situational circumstances and coincidence.

18: [daily groceries] "*Yes yes. But hé, I never have to make a long detour here. Really, I pass by at least four bakeries.*"

16: [non daily goods] "*Eum in Lier [town] in the centre, by foot. So that is 500 meters, at most… eum or else I go eum shopping in Antwerp [city] and then I go by train.*"

IF–THEN Travel Mode Choice Heuristics

In contrast with the IF–THEN destination choice heuristics, mode choice heuristics were far more numerous in the interviews. This might be caused by the interview questions, but it also indicates that people appear to perceive more choice options with regard to mode choices than with regard to destination choices and that variety in mode choice occurs more frequently than variety in destination choice. Within these heuristics, the classes of occurrence shown in Figure 14, can be recognized for each travel mode. They are discussed for each vehicle type consecutively.

WALKING – First of all, walking as a travel mode is a choice in exceptional situations when circumstances are optimal and general space-time constraints are relaxed: nice weather and a lot of time are typically mentioned as favourable conditions. Relatively short distance to the activity location proved to be a prerequisite. However, in exceptional situations with constraining circumstances, walking can also be a (perceived) single remaining option. Examples of this are weather (snow), incidents, kids, cargo, and so on. Moreover such conditions can result into different destination choices.

04: "*And to church, sometimes I walk, in the summer. But then I walk, well… at least a quarter of an hour, let's say.*"

06: "*Um, sometimes to the bakery, if it has snowed or something like that, then I do go by foot to the bakery or…*"

15: *"It depends. If I'm alone then I would take my bike more easily. But if our son was here, then I would take him".* I: *"In a pram and than walk, you mean?".* 15: *"Yes, that happens sometimes."*

Similar to destination choice heuristics, if–then mode choice heuristics for daily walking occasions are used in the interviews to specify mode choice options within certain further specified activity categories. Again, distance is an important factor, together with practical constraints such as the company of children and the transportation of purchased goods.

05: "*Services, yes. Shopping as well if I take the shop across the road, then I often walk*."

18: "*Yes, you know, if I um, take for instance, go to buy drinks. Bottles, but that is by foot as well. And I think that is not as convenient by bike… yes that is in fact, those are practical concerns… and such a crate with bottles…*"

Walking can be chosen previous to the destination because of the benefit of walking as pastime or as part of a leisure activity. These cases are less distance sensitive.

08: "*Um, take a walk with the kids after school or something like that, through the city center sometimes or if we walk to the playground with the kids.*"

19: "*Yes, what happens is that we walk to den Bruun [village pub] on a Sunday afternoon, drink something and walk back.*" I: "*But that is if you have a lot of time then?*" 19: "*Yes.*"

Walking and cycling are sometimes considered equal alternatives in the choice set to cover short distances. Revealed decisive factors are time constraints and practical concerns; the bike is faster, but reliable storage is desired.

08: [Walking] "*Um, well, it could be the trip to the station, because I'd rather not leave my bike over there, and it could be just… It depends on the time, um, so at the beginning I did it far more often by foot, but um, now it is very often because of the kids and the lot that, let's say the fuss in the morning and so on that I am sometimes obliged to take the bike to get to the train on time, so…*"

A final remark about walking is the fact that more than one third of the respondents indicated to hardly ever walk to any activity location. Besides the noted reasons of time saving and health reasons, the main explanatory factor is the fact that they tend to live in low-density sprawled dwelling areas where distances are larger and walking facilities are poor; walking is not a perceived option in these areas.

CYCLING – Like walking, here too circumstances related to weather conditions and time are often mentioned as favourable preconditions. However, more often than walking, cycling is used to replace car travel for short to medium distances because of its speed and reach.

02: "*It's just, now, in summertime we do ride the bike.*"

08: "*In time, by car, it is about a quarter of an hour… But that is something I do sometimes, if the weather is nice, I go by bike and then it is about half an hour."*

12: "*To go to the bank um… To the bakery, um, yes… Such things. If the weather is nice and I've got some time, then I use my bike.*"

16: "*So that's about eight kilometres. So if we have time during the weekends or on a free day, we bike, but of course, not just like that… If you have time, or then, you know…*"

Specifications of if–then bike heuristics also appeared in the interviews. In this case the breakdown does not only occur on the level of the activity but also on the level of destination type, travel time, and travel distance, illustrating the close coherence of activity, destination and travel mode choices.

08: "*Services, yes, yes, of course if I have to go to the post office for instance I won't take the car, there I always go by bike. Yes. That's the same radius of action, in fact, because that is all grouped in the centre, you know, um. Regularly travel further away, yes, it depends on where exactly I have to be, um. If it, if it is Geel [town], then it is by bike, so and then it is possibly a bit further away, you know, because, um, it's like, I say, if I have to go to Bel [parish], Yes, then I go by bike, you know, or to Zammel [parish] or whatever…*"

14: "*Biking… Yes, to the bakery store, the supermarket, the newsstand, the station.*" I: "*Yes. And, the weekly groceries at the supermarket as well?*". 14: "*No, not the big groceries really, but, if we need something urgently, you know.*"

For some daily activity routines, there is a standard mode choice set. Respondents answered the question: "*How do you go to [activity]*" with at least two possible travel modes. Again, revealed decisive factors are time constraints and practical concerns.

02: "Well, it's just a matter of, like the weather, yes, then I will take um the bike, but if I go shopping, yes, then I usually take the, um, the car you see. You've got a lot of stuff with you in that case, you see... Like to the butcher or something like that. Yes, every time I can, I go by bike, you see." I: *"Yes, if you don't have to bring too much."* 02: *"To park over there, where I go to the butcher, well, there is no parking place and then I rather go by bike."*

Quite remarkable is the fact that a quarter of the respondents did not possess a bike at the time of the interview. Moreover, the majority of them are living in built-up areas near PT services and have no direct access to private cars or have no driving licence. However, income levels show that this is not a matter of poverty. Those respondents prove to live close enough to various facilities to fulfil their daily needs by foot or PT.

BUS – Buses are often used by daily cyclists to replace the bike in exceptional situations, such as bad weather conditions. Buses can also replace certain train trips, especially late at night when accessibility by train in certain areas drops. Buses are far less likely to be an alternative for car travel because of their association with longer travel times and their (equal) sensitivity to traffic chaos. Only if time constraints permit and if no other option is available or another benefit is experienced from travelling by bus, people will opt for the bus instead of the car.

05: "*But, shopping and work, to the academy of music and the like, we always go by bike. Except when it's raining heavily, then we do take the bus.*"

11: "*Yes… Now and again even, I have a friend living, who lives in Noorderwijk [village], then I can take the bus from Leuven [town]. I've done that before… And other friends of us moved close to a busstop somewhere, so it could occur* *that I will do that… But most often, I go there together with my partner by car during the weekend… But it could occur, during a holiday for instance…*"

I: "*yes. And to Turnhout [town]. Sometimes bike, sometimes by bus. When?*" 20: "*Mostly by bike and sometimes by bus.*" I: "*When by bus? Can you…*" 20: "*If we don't feel like…*" *(laughter).* I: "*Yes?*" 20: "*After a night out it could happen or if it's bad weather it could occur as well.*"

Some specifications of the situations in which buses are used in terms of activity type and distance or area also appear as if-then mode choice heuristics.

08: "*Um… Not easy, or at least… Now I really have to think carefully. I, um, what happens now and again is, for instance if I um have to be in Ghent [city] because of business, then it could happen that I take a bus over there...*"

For some trips, buses are part of the standard choice set. High transportation supplies with frequent buses to various destinations at low cost are favourable conditions for the occurrence of this choice situation.

I: "*Is it to the station by bike then?*" 09 (husband): "*If it is for one day only, then we leave the bikes over there, but if we go for a bit longer…*" 09 (wife): "*Then we take the bus.*" 09 (husband): "*Or somebody brings us by car or we take the bus.*"

15 [Chess club]: "*sometimes walking, sometimes by bike and sometimes by bus.*" I: "*o, yes, by bus. That's easy from here?*" 15: "*Yes, because there are buses, I think, every 10 minutes.*" I: "*And, when, when would you go by bike and when by bus? And when would you walk? It depends on what?*" 15: "*Um… How I um… by um… my bike was not fixed yet that time, you know… Otherwise I have to walk then, but you have to be there at a certain time, if not, you loose the game anyhow… But my wife has to work then, so I have to take care that she arrives home and that I can leave immediately then, and if that just doesn't work out, well, then I have to catch the bus, because in that case it is quicker than walking.*"

TRAIN – Only one typical 'if [activity] – then default [other mode], except [circumstances] then train'- heuristic could be recognized in the interviews. Trains are not often used as a travel mode to replace default travel modes in exceptional situations in daily activity-travel. It is however a vehicle that is mostly associated with specific activities to certain typical destinations at a medium to far distance such as occasional leisure trips to the seashore or to city centres, and occasional work trips to the Central Business District of large cities.

02: "*Just once a year, to the seashore, with my sister. That's just once a year.*"

03: "*Um… if I have to be in Brussels [city], for instance… On a worksop or…*"

04: "*To Antwerp [city], that is.*" I: "*regularly or?*" 04: "*No! Now and then. If there is a, you know, a musical.*"

05: "*If we go a bit further away or if we go to a big town or something like that. To some places that you can easily reach by train, then I take the train*."

07: "*To grandpa and grandma to, at least to Bruges [town] when grandpa and grandma give a party in Bruges (laughter). Because, because we don't have to mind the alcohol then.*"

18: "*Um, but for all far travel I take the train, actually. To Ghent [city], Brussels [city], yes, like going to Antwerp [city]… I will do that more easily by train in the future.*"

20: "*So, if I have to take classes in Brussels [city], I go by train. Actually, that happened not so long ago.*"

Sometimes, principally for leisure trips, the choice of this travel mode occurs before the destination choice (as discussed above). In the interviews, trains were never mentioned to be part of a travel choice set in a no-default mode choice situation. Moreover, for more than half of the respondents both busses or trains are simply never considered in daily activity-travel.

CAR – Cars are typically used for all distances. In exceptional cases, they are believed to replace rather short trips that can be executed walking or by bike whenever weather conditions are considered too bad. Furthermore, cars are used to replace another default travel mode when time constraints are high or when PT is not longer available, for instance during the night.

02: "*Yes, um, in this weather [sunny] I will take the bike more easily, but if it's cold or or if it rains, yes, then I take the car, usually.*"

08: "*Normally, normally I take the bus, if I, so, if I, if I can be flexible with my working hours, that is to say, if I haven't got in the morning, let's say about nine or something like that, if I haven't got a meeting or don't have to teach or the like, um, then I just take the bus, if I, if I can't afford it to, let's say, arrive at work at 9:30… In other cases if I have to start earlier or if I stop um later, if I have something to do in the evening that overruns it's time, and then I take the car. But mostly I take, um, the bus.*"

19: "*No, about half past midnight or one at night. But… what often happens, yes, if there is no bus, then we hitchhike, you know.*"

Distinctive specified activities that are most likely to be undertaken by car are activity-travel tours and weekly or monthly grocery shopping. Even most respondents who didn't own a car nor had a driving licence indicated that they would execute grocery shopping that way. They either borrow a car for these occasions or drive along with members of the household, relatives or friends. Only respondents from very small households stated not to need a car for shopping purposes; they simply increase the frequency of their shopping.

11: "*Um, now and again, um, to go to the shop, if we have to do a lot of groceries… the Colruyt is very near, but then we do take the car… to buy drinks and stuff.*"

20: "*Um, once every 6 weeks to 2 months we do big grocery shopping, and then we borrow the car from my mother, usually, else from my father in law.*"

2.4.1.3 *Long-Term Decisions and Daily Constraints: Feedback Effect*

A final point of attention in the analysis of individual activity spaces is the feedback effect related to long-term decisions and daily constraints that influence both default settings and if-then choice heuristics in daily travel. This effect is indicated schematically in Figure 15, in which a general overview of the developed theory of scripted daily travel behaviour is shown. The feedback effect is further explained in this last section of results.

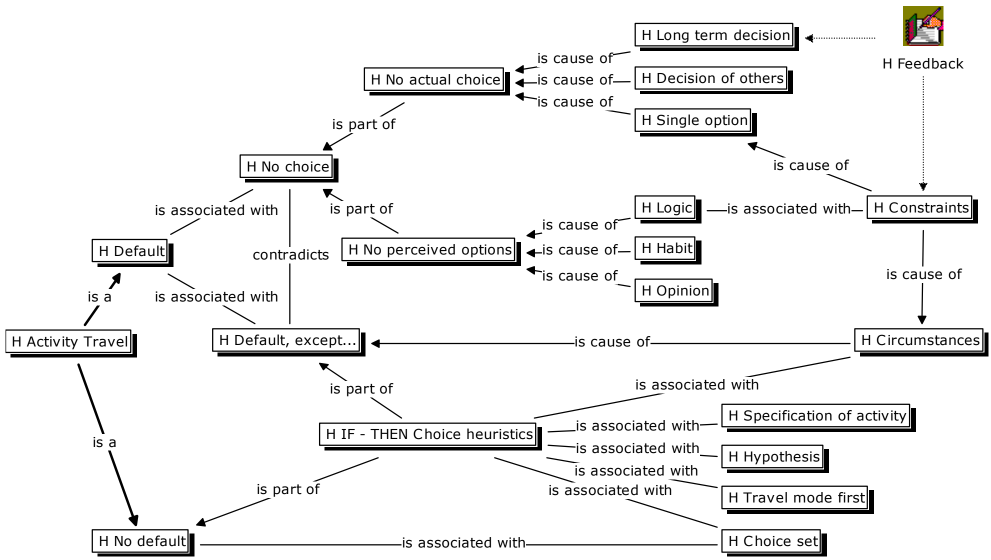


Figure 15 ATLAS.ti Script Network View of Scripted Daily Travel Execution

With regard to the if-then heuristics, it is shown in this qualitative inquiry that the weather clearly is a variable environmental factor that is able to trigger the execution of different scripts in people's mental maps. On an aggregate level, a similar weather effect on travel mode choices in Flanders is shown by Cools (2009). For people who are used to cycling a lot, bad weather conditions are typically mentioned as an exceptional situation. In these cases, they usually take the bus. However, for people who are used to travel by car, bad weather is often used as an excuse for not choosing cycling and nice weather is typically seen as an exceptional situation; perhaps cyclists are born optimists, unlike car drivers?

The explanation of such difference lies within the long-term organization of daily life based on the availability and accessibility of travel modes and in the feedback mechanisms between long-term decisions and daily activity constraints. On the one hand, car drivers have (unconsciously) chosen daily activity destinations in a habitual activity and travel schedule from the perspective of cars; their daily activity and travel schedules are space extensive and time intensive. As a consequence, only few destinations can actually be reached by other modes, unless their usual daily schedule is thoroughly reconsidered. They have developed a car dependent lifestyle. Their mental map, full of automated car-related scripts, is unimodal and biased.

On the other hand, individuals without a driving licence or private car have probably organized their lives in short-term and long-term decisions bearing a necessary spatial proximity and temporal deceleration in mind.

20: "*So it was our intention not to buy a car… And we thought, if we want to do that, we will have to live near the village centre. Otherwise, that is not feasible.*"

Surprisingly, their reflected repertoire of daily activity scripts typically shows a great variety of travel modes, and they use public transport, they walk and bike. Even cars are used, but only after conferring with others outside the household. Although their radius of action might be more limited in distance, they surely show more flexibility regarding travel mode choices. In a prevailing car-oriented society, these respondents also proved to be very aware of their somewhat unusual way of life.

09: "*For us nothing is far away. But for those who have cars, everything is far away. That is in fact really strange, no?*" I: "*yes, you will have to explain that a bit, because…*" 09: "*We are used to the fact that it always takes a long time before we get anywhere, for us it is not far away…*"

Spatial determinants (density, functional mix, presence of PT services) are thus more important in the occurrence of travel poverty than vehicle ownership; people who are living in mono-functional areas or far away from potential activity destinations typically have no choice but to use the car. Those who have a mix of activity opportunities available within a small distance range usually have a number of suited travel mode options.

Of course, these images of car drivers versus those who are not car drivers are quite extreme. In reality, several mixed situations occur. Driven by attitudes and opinions, some people deliberately choose to use the car more consciously. This way, they are less dependent on this travel mode. Others can only be forced to make other travel mode choices, if habitual daily activity and travel schedules become untenable (e.g. due to external conditions such as congestion).

16: "*But that is just because we have no alternative in that case, that is to say, just because we consciously avoid the car. But then there is the bus and I do think it takes long, but hey, that's something like OK, so be it.*"

2.4.2 Spatial Cognition and Daily Travel

Within destination and travel mode decisions, the influence of space and spatial cognitive factors is at most apparent in the perception of distances and subsequent distance-minimizing strategies. Besides that, generalization of possible activity destinations into functional areas is significant. For example, for shopping activities (small groceries, clothing, and the like), the default setting is often a general area that still holds a few possibilities instead of one specific activity location. From the point of view of mental maps, this spatial generalization of destination choice sets into functional areas is related to Lynch's (1960) concept of 'districts'. A third element of spatial factors influencing destination and travel mode decisions is the appreciation of the suitability and accessibility of travel environments with certain travel modes. For slow modes this can involve the presence of suitable infrastructure and motorized traffic. For car driving, respondents refer to congestion levels and parking facilities.

Next to spatial cognitive aspects in the discussion of travel decisions, some typical tasks from spatial cognitive research were adopted in the interviews. For instance, for every destination mentioned, the respondent was asked to estimate the distance in kilometres and in time. The metric distance questions were generally answered with great reluctance and apologies. Even for well-known, daily travelled routes, most respondents were insecure about the exact distance. Clearly, such detailed factual knowledge is not necessary to travel or schedule activities successfully in daily life. As mentioned before, due to the limited sample size and a bias in observed travel, these distance estimates could not be compared to actual distances (see 2.3.4.1). As for the knowledge of travel times – a requirement to schedule daily commitments –, such estimates were made with greater ease, albeit solely for the travel mode used frequently. Perhaps such lack of knowledge hinders modal shift too? Moreover, all daily travelled distances are most often categorized as: *"not far"*, sometimes followed by an excuse-like statement such as: *"I am used to it."*

Route descriptions and sketch maps were combined in the pre-interview: each respondent was asked to draw the route to a familiar destination (work, school or supermarket), while explaining the route aloud. An example of such as sketch map is shown in Figure 16. There was a general dislike of the drawing task. A lot of apologies for bad drawing skills and criticism on the end result were recorded; the drawings just didn't seem to reflect what the respondents had in mind. Due to the limited sample and heterogeneity of sketched routes, these drawings were not analyzed in further detail in this PhD research.

Nevertheless, route descriptions show that daily travelled routes are relatively well known. All respondents could travel the route mentally and recall a number of features to explain the route, such as crossings, landmarks and edges of areas, reminiscent of Lynch's (1960) mental map components. However, while answering and processing the route in their mind, respondents often made mistakes, immediately followed by likely corrections. This does not only indicate that people are not bothered with similar questions in daily life. It also shows that depicting a route does not correspond to actually driving it.

Generally speaking, once people have settled in their activity space and daily-life routines have been accepted, they become relatively unaware of their familiar environment and quite uncritical towards their travel behaviour. Building on Goffman's (1959) dramaturgical theory of everyday life, the theatre metaphor can be extended: space is but the décor of people's life; an apparently unnoticed and unimportant background in the scripted daily life's performance.

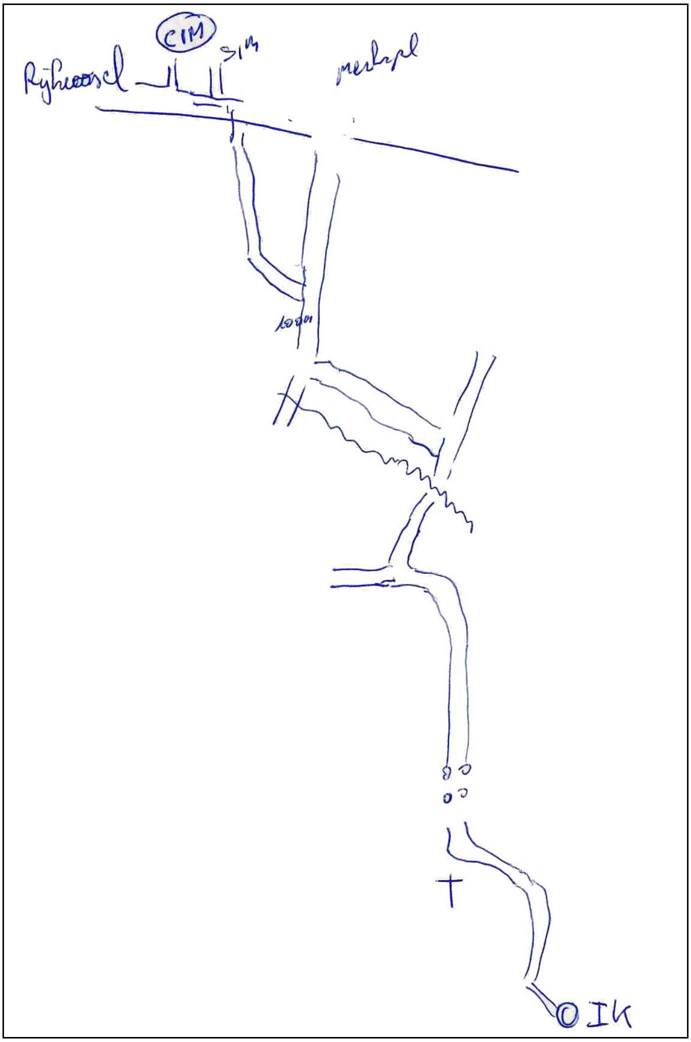


Figure 16 Sketch Map of the Route to Work

2.4.3 Conclusion and Discussion

In this qualitative exploration of mental maps in daily travel, decision processes in general and spatial factors influencing travel choices in specific are addressed. The context of daily activity patterns is taken into account explicitly. Results are descriptive and suggest an analytical perspective, useful for further research. In this particular case, the qualitative, explorative, contextual and descriptive research outline leads to the formulation of a 'script theory' of individual travel choice behaviour.

In summary, specific findings from this research show that in daily life, activity, destination choice and travel mode choice are mainly fixed, interconnected decisions, triggered simultaneously without much deliberation. Within these fixed scripts, strong default settings for mode choice and destination choice are apparent for most of the daily travel routines. In addition, if-then choice heuristics cover a wide range of specific or exceptional situations in which both travel mode and destinations are fixed as well given certain preconditions are met.

Actual and perceived choice sets are very limited, and choices are typically restricted and justified by long-term decisions, decisions of others, logical reasoning, habits and opinions. Driving forces behind the logical reasoning are various conditional constraints experienced in everyday life. Within these heuristics, reasoning concerning accessibility in general and distances in time and space, play an important role. Thus, the individual's mental map comprises a repertoire of possible activity and travel scripts, including travel modes and activity destinations. Elements in this option set are connected to an often imperfect perception of accessibility with various transport modes that influences daily scheduling.

While long-term choices such as residential location choice or vehicle ownership largely determine conditional constraints experienced in everyday life, a clear feedback effect is shown as well. Using (and getting used to) certain modes of transport enhances the organization of daily activity patterns from the perspective of the travel mode. For instance, typical car drivers develop a space-extensive or time-intensive lifestyle, leaving no or little choice options to organize their daily schedule.

Additional research in this area is needed to refine the way in which daily activity and travel scripts are formed, how they are preserved, and how they can be changed. Formation and adoption of scripts could be a matter of conscious, and even rational reasoning, but other learning strategies such as experimentation or imitation could occur as well. To understand the preservation of scripts, it could be useful to asses their strength in terms of establishment (e.g. is it the result of a choice or a no-choice situation) and additional forces such as habituation, opinions, and so forth.

Moreover, circumstances in which particular parts of an individuals' repertoire are applied and conditions causing variety in activity and travel behaviour deserve future attention, as well as circumstances and conditions that can cause (un)sustainable changes in scripted activity and travel behaviour (Fujii & Gärling, 2003) such as moving house (Bamberg, 2006), obtaining a driver's licence (Fujii, 2007) and various life course events (Verhoeven, 2010). Besides this, the effects of TDM should be studied, e.g. Fujii and Kitamura (2003), Fujii and Taniguchi (2005). In this respect, the merits of qualitative research approaches are shown, for instance by Harms (2003) who identifies the shift of car-use routines in favour of car-sharing initiatives based on a qualitative pre-study, and Loukopoulos et al. (2004) who study the choice of adaptation alternatives for car-using households based on focus groups and a subsequent internet-based questionnaire.

In addition, future research could address individual heterogeneity in mental repertoires (such as the number and strength of scripts) and decision making styles (e.g. rigid or flexible, conservative or adventurous) in order to elaborate and refine future implementations of scripts or mental repertoires in an AB model of travel demand.

Accordingly, no concrete mathematical model is derived from the results of this qualitative research yet. However, this qualitative approach in its own right represents an important way to improve modelling experts' domain knowledge. The descriptive or semantic model developed here, informs quantitative, mathematical modellers with regard to several modelling assumptions, including the structure of the model (e.g. different decisions are triggered simultaneously), activity categories to use (e.g. small daily grocery shopping versus weekly groceries), and the parameters involved (e.g. the existence of default settings). In general, descriptive results of this qualitative exploration can help to develop empirically grounded modelling hypothesis that – without any doubt – need further quantitative testing and validation. The next chapters of this thesis, follow this line of thought.

3 AN INDIVIDUAL'S MENTAL MAP MODEL

– ROBIN –

Routines Objectified as Bayesian Inference Networks

3.1 Introduction

In the previous chapter, a descriptive model of daily activity and travel decision making was developed based on a qualitative exploration. Generally speaking, everyday activity routines, such as sleeping, eating, work or school, and related travel decisions, such as destination choices and travel mode choices are not planned consciously on a day-to-day basis. Moreover, domestic routines such as grocery shopping, and even discretionary activities such as practising sports and visiting relatives can be anchored in a routine weekly pattern. Such repetitive episodes constitute a rather fixed frame of reference or 'skeleton' (Arentze et al., 2003) in an individual's daily activity and travel schedule in which spatio-temporal characteristics are anchored. On the other hand, the flexibility of this skeleton is shown in the description of specific or exceptional situations and their standard behavioural responses.

Based on these observations, the individual's mental map can be conceived in a repertoire of fixed scripts of daily activity and travel routines, and their scripted exceptions. Geographical mental map aspects, such as typical activity locations, are anchored in these fixed scripts. These automated scripts are triggered by representative situations. Actual and perceived choice sets are very limited and choices are typically restricted by various conditional constraints experienced in daily life situations. Therefore, an important part of the decisions in an AB scheduler of a travel demand model (see 1.3.2) seem to establish mindlessly in everyday life.

Since this PhD research aims at improving the behavioural realism of an AB travel demand model by integrating the mental map concept, a transition from this primarily descriptive, verbal model to a computational simulation model is needed. Therefore, this third chapter details an exemplary case study in which an important part of an individual's mental map (i.e. the work-related travel repertoire) is objectified as a BIN.

This chapter is structured as follows: firstly, the actual point of departure in the development of the computational mental map model is presented. This is an individual's verbal description of compiled daily life routines with regard to the work activity, the work locations and the transport modes used for commuting. Next, the modelling approach is presented from a theoretical perspective: the topic is positioned in decision theory, decision networks and BIN's are introduced and their application in transportation sciences is reviewed. This is followed by a detailed account of the actual application, the construction of the network and the estimation of the parameters. Finally, the results are discussed and conclusions for further research are drawn.

3.2 The Verbal Mental Repertoire

The text in the panes on the left hand side of Figure a and Figure 17b show a typical example of a verbal work-related mental repertoire of a full-time working mother of three children. Scripts with regard to the usual work routines, alternative work locations and travel mode choices are discussed, as well as exceptions that could occur, based on previous experiences. The nature of the description is based on interview practices in the qualitative exploration phase of the PhD research in Chapter 2 in general and the discussion of daily schedules in these interviews in specific, in which similar statements are recorded. The account reflects the actual daily life organization of the researcher at the start of the second phase of the PhD research, late 2007. This case is primarily meant to illustrate the abilities of the proposed model framework.

An integration of such verbal scripts into an AB model of travel demand can only be realized if a formal computational model is developed that mirrors the behaviour in this description. Based on the research objectives and qualitative findings, following preconditions for this model can be formulated: (1) the model has to reflect the existing repertoire of heuristics and relationships between influencing variables in a comprehensible, concise way; (2) the model has to enable the generation or the prediction of certain outcomes (choices) as a consequence of specific combinations of situations, attributes and preferences; (3) changing values of these model components should automatically (according to certain – preferably quantifiable – rules) lead to certain observed or observable combinations of choices.

One type of model that seems to meet these criteria in a self-evident way is a specific type of decision network, notably a Bayesian inference diagram or BIN. The next section clarifies this modelling approach by briefly reviewing decision models in general, and decision networks and BIN in specific.

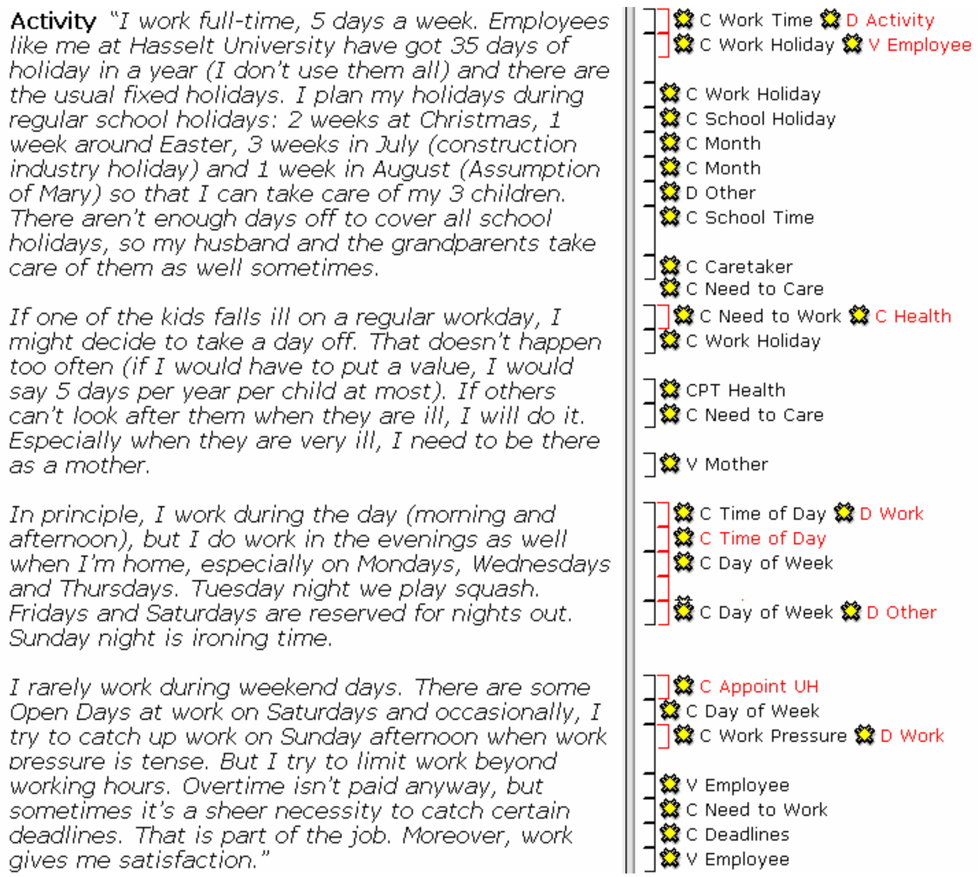


Figure 17a Verbal Description of a Work-related Travel Repertoire and Assigned Codes with Decisions (D), Contextual Chances (C) and Valuation Perspectives (V)

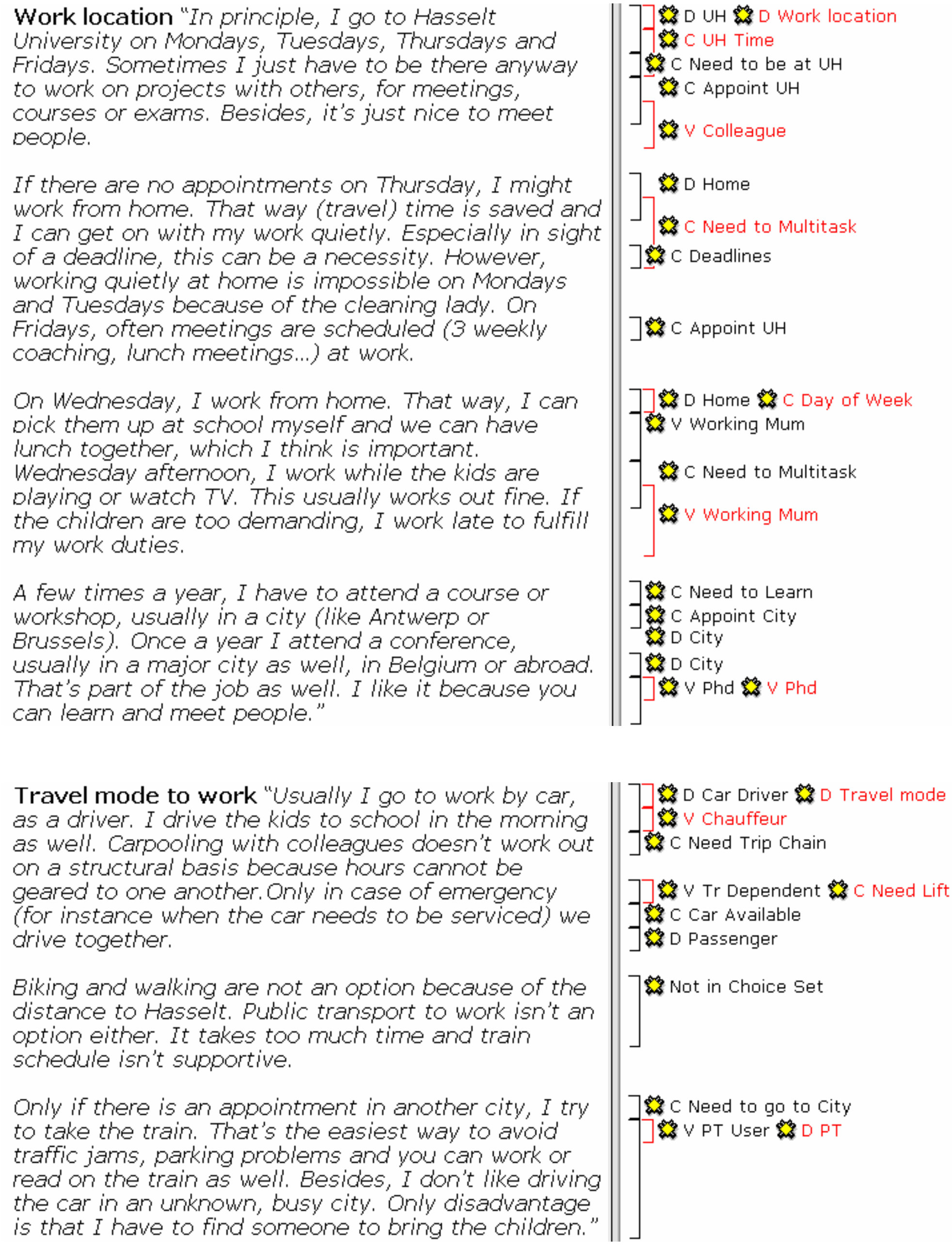


Figure 17b Verbal Description of a Work-related Travel Repertoire and Assigned Codes with Decisions (D), Contextual Chances (C) and Valuation Perspectives (V)

3.3 A Modelling Approach

3.3.1 Decision Models

In essence, AB models of travel demand are decision models in which different choice facets of activity and travel behaviour are modelled, e.g. which activity to perform, where to do it, how to go there, etc. (see 1.3.2). In the field of decision theory, decision models in general can be categorized according to different dimensions: their objectives, their structure and the type of decisions.

Hansson (2005) distinguishes different *objectives* of decision models to start with: on the one hand, 'normative' or 'prescriptive' models are used to compute how people or organizations should behave in order to obtain the best results. In these models, a rational, fully informed decision maker is typically assumed. On the other hand, 'descriptive' or 'positive' models try to model how people actually behave, taking issues of uncertainty, lack of information and bounded rationality into account. According to the same author, in both normative and descriptive applications, expected utility theory founded in von-Neumann and Morgenstern's utility theorem constitutes the major paradigm. Quite obviously, the objectives of the model proposed in this chapter fit best into the descriptive realm.

A second dimension characterizing decision models is the model's *structure*. Decision making can be studied in structural and process approaches (Svenson, 1996). In structural modelling approaches, choices and ratings are related to input variables, while in process approaches, the psychological process involved in decision making is assessed, highlighting different stages from problem presentation to final decision, and even implementation and evaluation. However, structural elements and sub-models can be found within process approaches. For instance, it is a generally accepted idea that a mental representation of the decision problem at hand is generated in the expert's mind (or working memory) when faced with a certain choice situation. This cognitive map or mental model as such a temporary representation is also referred to, for instance by Dellaert et al. (2008), can be formalized in various (structural) ways. Following the work of Johnson-Laird (2001) on mental models, it is considered to be the cognitive basis of the actual decision (see 1.3.1.2). The modelling approach presented in this research follows this line of thought.

Thirdly, the *type of decision* that is modelled and its according decision process characteristics constitute an important distinguishing dimension of decision models. Here, a range of decision types starting from conscious, slow, deliberate, complex decisions on the one end to automatic, fast, thoughtless, simple choices on the other end can be found (Ben-Zur, 1998; Frederick, 2002). Comprehensive multi-attribute analysis models dominate the former decision type. Partial dimensional analysis and decision heuristics constitute an intermediate modelling approach for fast, simple, yet controlled decisions representing a conscious decision strategy, e.g. Tversky and Kahneman (2002). Similarly, models of automatic judgmental heuristics, for instance choosing by liking or choosing by default, or compound pattern matching models account for routine decision making, e.g. Klein and Calderwood (1991). In the latter mentioned models, recognition of specific situations (context, goal) is of vital importance to trigger automated choice behaviour. Most often, decision trees are used to model this type of decisions computationally. However, since decision trees tend to suffer from exponential growth in the number of branches with each variable modelled, decision networks are believed to offer a valuable alternative approach. Based on the qualitative exploration reported in Chapter 2, it is clear that daily activity-travel choices are an outstanding example of automated routines. Therefore, the conceptual and arithmetic modelling attempts described below, are mostly tied up with research related to this decision type.

3.3.2 Decision Networks

A decision network or influence diagram is a compact graphical structure in which decision maker's problems can be formulated and knowledge of experts can be incorporated (Shachter, 1986). Because decision networks enable to describe decision problems in one graph, both intuitively understandable for human beings and formally specified to be treated by computers, Howard and Matheson (2005, p. 127) consider the influence diagrams to form: "*a bridge between qualitative description and quantitative specification*." In decision networks, decision problems are analyzed by mapping all related considerations (represented as nodes in the graph) and their relationships (represented as directed arcs).

Figure 18 shows a basic example of a decision network and its components, representing a situation where a decision maker is prompted to engage in a work activity. Three types of nodes can be distinguished: decision nodes (rectangles), chance nodes (ovals) and utility nodes (diamond shaped boxes).

The states of the decision nodes represent the choice options available to the decision maker (e.g. work or another activity).

Chance nodes represent all aspects that the individual takes into account when making the decision. These aspects can be elements of the decision context, as shown in the example (e.g. is it the regular time to work or not, is there a need to work or not), or other attributes of the decision alternatives that are able to influence the decision in a certain direction. Their states represent different ways of occurrence. Various terms are used in literature to characterize this type of nodes such as 'chance nodes' (Pearl, 1988) or 'nature nodes' (Verhoeven et al., 2006).

The third type of nodes in a decision network, the utility nodes, represents the different dimensions or meanings of utility that people pursue, which is linked to certain attributes of the decision. In the example shown in Figure 18, this situation and its related activity specific utility is defined as professional 'fulfilment'. Unlike chance nodes, utility nodes are not characterized by discrete states, but they have a defined utility (function). They represent some situation-specific goals, expressed as values or benefits. Arentze et al. (2008, p. 7) describe the distinction between attributes and benefits as follows: "*Attributes relate to the states of the system that are directly observable, whereas benefit variables describe outcomes on a more abstract level, standing closer to the need dimensions of the subject*".

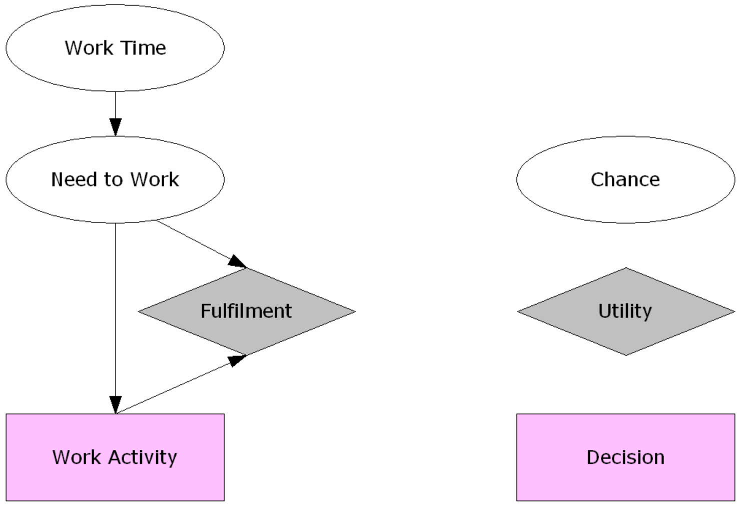


Figure 18 Basic Example of a Decision Network and its Components

The arcs in the graph have different meanings, based on their destinations. In his seminal work, Pearl (1988, p. 307) defines this as follows: *"Arcs pointing to utility and chance nodes represent probabilistic or functional dependence... They do not necessarily imply causality or time precedence, although in practice, they often do. Arcs into decision nodes imply time precedence and are informational, i.e., they show which variables will be known to the decision-maker before the decision is made"*. In our example in Figure 18, when making an activity choice, the contextual node 'work time' leads to the consideration of the 'need to work'. The node 'work time' is called the parent node of the node 'need to work'. (Beliefs about) these elements are known prior to the decision, and are hence the links arriving in the decision node. On the other hand, given a certain context, specific evaluative aspects are taken into account (e.g. having the professional 'fulfilment' of 'working' when there is a 'need to work'). In such a decision making process, each choice option is evaluated in terms of their contribution to the specific value that is desired.

The basic example in Figure 18 can be expanded with relevant contexts and utilities. Moreover, different interrelated decisions, including relevant chance nodes and utilities can be represented in one decision network. In such a complex network, the link between decision nodes represents time precedence in the decision making process. This will be illustrated further in this chapter (see 3.4).

3.3.3 Bayesian Inference Networks

One possible computational implementation of decision networks are BIN. Adding numerical values to each node, and the technique of Bayesian propagation through the network enable calculating the overall utility of each choice option (Winkler, 1972). Furthermore, by changing the values of different chance nodes, the outcome of various scenarios can be inferred.

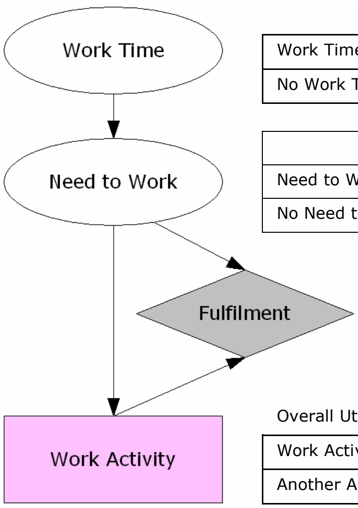
Based on literature with regard to Bayesian networks, there is a lot to be said for the use of BIN to model individual activity and travel repertoires. BIN can provide a simple yet powerful visual reproduction (Shachter, 1988) of a cognitive map (Arentze et al., 2008). It enables reflecting experts' subjective point of view on a decision problem, including complex relationships between influencing factors and experts' reasoning (den Hartog et al., 2005; Shachter, 1986). BIN's are intuitively understandable and therefore they are very well suited to communicate (Shachter, 1988). They enable the quantification and examination of certain relationships, and the impact of interventions can be simulated (Jensen, 2001). This way, predictions can be made (Glymour, 2001).

However, some initial drawbacks can be mentioned as well. In general, Bayesian networks are found suitable to model complex decisions, e.g. den Hartog et al. (2005). They are mostly used to model reasoning under uncertainty (concerning the actual state of the world), and hardly ever applied to model unconscious decisions in which knowledge or assumptions about the state of the world are not questioned (Winkler, 1972). Nevertheless, textbooks on Bayesian inference use rather simple daily life decisions to explain the model, such as whether or not to take an umbrella given a certain weather forecast (Winkler, 1972). Besides this advantage, it is argued that an important role for Bayesian models is its use as a benchmark for evaluating fast and frugal heuristics (Martignon & Blackmond, 1999). Furthermore, Winkler (1972) states that decision making under certain circumstances is not as simple as it seems either.

3.3.3.1 *Calculation of Bayesian Inference Networks*

Another, more fundamental drawback for the use of BIN to model individual decision making concerns its calculation. The arithmetic elaboration to calculate conditional probabilities in the light of evidence, i.e. Bayes theorem, is rather complex. People do not use such advanced mathematics in daily life, although Sternberg (1999) argues that such calculations are essential to evaluate scientific hypotheses, form realistic medical diagnoses, and analyze demographic data and many other real-world applications.

Figure 19 shows the elaboration of the basic decision network of the previous example in Figure 18 as a BIN. Here, numerical values are added to each node, and the technique of Bayesian propagation through the network enables the calculation of the overall utility of each choice option. There are two different types of parameters in a BIN: probabilities characterize chance nodes, and utilities define both value nodes and states of decisions. Furthermore, by changing the values of different parameters, the outcome of various scenarios can be inferred. The calculation of the simple example in Figure 19 is explained step-by-step further in this chapter section.



	No Evidence	*Scenario 1*	*Scenario 2*
Work Time	0.25	1	0
No Work Time	0.75	0	1

	Work Time	No Work Time
Need to Work	1	0.2
No Need to Work	0	0.8

	Need to Work		No Need to Work	
	Work A.	Another A.	Work A.	Another A.
Fulfilment	100	-150	50	0

Overall Utility	*No Evidence*	*Scenario 1*	*Scenario 2*
Work Activity	70	100	60
Another Activity	-60	-150	-30

Figure 19 Calculation of a Basic Bayesian Inference Network

Each node in the BIN has some defined states. These states correspond to classes or options of the variable. Each chance node (oval) has a related conditional probability table (CPT) describing the probability of occurrence of each state of that specific node for each possible combination of states in the parent node. The values in a CPT represent subjective probabilities. They define quantitatively how an outcome variable is impacted by its parents' nodes (Verhoeven et al., 2006). Probabilities quantify uncertainty in a subjective way and they are valued by a number between 0 and 1 that represents the extent to which a person believes a certain statement to be true (Edwards, 1982). The sum of all probabilities of each individual state of a variable must equal 1. Probabilities can be assessed in various ways, ranging from well-founded theory over frequencies in a database to subjective estimations (Jensen, 2001).

The CPT of a node without parents is simple. It only contains the probability distribution across the states of this node. For instance, the table 'no evidence' of the node 'work time' in Figure 19 shows estimated chances that it is regular 'work time' at 25%, and 'no work time' at 75%, based on the occurrence of working hours in a regular work week of 40 hours. The CPT of a node with one or more arriving links (i.e. a child node) is more complicated because of the combinatorial explosion: values have to be specified for each state of the node, taking each state of the parent node(s) into account. On the one hand, in the CPT of 'need to work' in the example, the probability that there is a 'need to work' is 100% during regular 'work time', while there is no probability that there is 'no need to work' during regular 'work time'. On the other hand, under the circumstances of 'no work time', the decision maker indicates that there is still a probability of 20% that there will be a 'need to work', indicating high pressure of work and high chance of overtime hours.

The utility node and the decision node have values expressed as utilities. The utility node contains the utility function in a conditional utility table (CUT). According to Pearl (1988, p. 180): "*the leaves of the tree carry the numerical value of the utility associated with the scenario (path) leading to each leaf, or equivalently, the utility of the situation created by the sequence of events leading to the leaf*". Hence, utilities are values assigned by the decision maker to the states of the system, given activated needs in certain situations (Arentze et al., 2008). Utilities can be questioned and estimated directly. The use of utility functions in BIN is demonstrated as well, for instance by Winkler (1972). Finally, overall utilities of decision options are calculated when compiling the network, given a certain state of information at the time a certain choice is made.

In the example in Figure 19, the conditional utility function of professional 'fulfilment' is estimated for each decision option, i.e. 'work activity' or 'another activity', given each state of the node 'need to work'. Each value in this CUT can be interpreted as an answer to a question similar to the question for the value in the first cell of this table: "*Suppose that you need to work, and you choose to perform a work activity. How much professional fulfilment will you achieve?*" In case there is a 'need to work', the estimated value is positive (100) for the 'work activity', and negative (-150) for 'another activity'. The latter low estimation reflects professional failing. On the other hand, even when there is 'no need to work', some professional 'fulfilment' will be achieved when the decision maker decides upon a 'work activity' (50), although this is considered less rewarding, for instance because overtime is not paid. When there is 'no need to work' and 'another activity' is chosen, no professional 'fulfilment' is achieved.

Evidently, the estimation of utilities is far from easy. To break up the estimation of the relative size and impact of each partial utility in a BIN, Arentze et al. (2008) introduced intermediate chance nodes or 'benefit variables'. They replace the utility node and are complemented with a (partial) utility, which is linked to the benefit node at stake with a single arrow from the chance node to the utility node (see Hannes et al. (2009) for a detailed example). Moreover, in case of multiple partial utilities in a decision network, each utility node can have a different weight in the decision. Such weight values, including interaction effects, can be assessed by means of a stated preference experiment.

Finally, based on the input values in the network, calculated outcomes are represented as overall utility values for the decision options in the decision node. From a decision making perspective, the option with the highest overall utility will be chosen. BIN can handle uncertainties, as is shown in the example in

Figure 19 when there is 'no evidence' with regard to the 'work time'. Moreover, beliefs can be updated when evidence for certain chances becomes available and is entered in the network. For instance, in 'scenario 1' of the context node 'work time', the decision maker knows for sure that it is regular 'work time'. In that case, the outcome of the Bayesian propagation through the network shows that the 'work activity' has a higher overall utility compared to the 'no evidence' situation, and performing 'another activity' is much less useful (in terms of achieving professional fulfilment). While in 'scenario 2', evidence of 'no work time' is entered in the network, and the overall utility of the 'work activity' drops considerably. This calculation and inference of the Bayesian Network involves different steps, detailed here for the 'no evidence' option of the basic example shown in Figure 19.

Firstly, the joint probability of the 'need to work' (P_J^{Need}) is calculated: $P_j^{Need} =$

$$P(Need \mid WTime) \times P(WTime) + P(Need \mid NoWTime) \times P(NoWTime)$$

Hence, $P_j^{Need} = (1 \times 0.25) + (0.2 \times 0.75) = 0.4$

While the joint probability of 'no need to work' (P_J^{NoNeed}) is: $P_j^{NoNeed} =$

$$P(NoNeed \mid WTime) \times P(WTime) + P(NoNeed \mid NoWTime) \times P(NoWTime)$$

Hence, $P_j^{NoNeed} = (0 \times 0.25) + (0.8 \times 0.75) = 0.6$

Then, the expected overall utility for the 'work activity' (U_e^{Work}) is: $U_e^{Work} =$

$$(P_j^{Need} \times U(Work \mid Need)) + (P_j^{NoNeed} \times U(Work \mid NoNeed))$$

Hence, $U_e^{Work} = (0.4 \times 100) + (0.6 \times 50) = 70$

And the expected overall utility for 'another activity' ($U_e^{AnotherA}$) is: $U_e^{AnotherA} =$

$$(P_j^{Need} \times U(AnotherA \mid Need)) + (P_j^{NoNeed} \times U(AnotherA \mid NoNeed))$$

Hence, $U_e^{AnotherA} = (0.4 \times (-150)) + (0.6 \times 0) = -60$

Specialized software is available to calculate and infer BIN, such as HUGIN, NETICA and many more (Murphy, 2005). This software can deal with complex networks involving multiple interrelated decisions.

3.3.3.2 Applications of Bayesian (Inference) Networks

Arentze et al. (2008) initiated the use of BIN's as a computational elaboration of an individual's mental map of complex transportation related decision problems. They have developed an interview protocol (CNET) to elicit related mental representations, and this technique is applied in an experiment involving complex intertwined spatio-temporal travel decisions related to shopping-trip planning. Building on this pioneering work, Kusumastuti et al. (2010) have developed a computer-based survey to scrutinize less complex real-world decision making strategies related to fun shopping, in order to construct detailed individual BIN's. The degree of complexity in decision making is what distinguishes these two studies content-wise, as well as the application in this thesis. From this point of view, modelling the repertoire of individual travel routines constitutes a novel approach.

However, an interesting example of Bayesian networks to model individual travel routines worth mentioning, is the joint work of researchers affiliated to UC Irvine (Gogate et al., 2005, 2006) and UW Seattle (Liao et al., 2007). Based on raw data of observed travel behaviour of one of the authors, i.e. a six months log of GPS readings at 1-5 seconds intervals, a probabilistic Bayesian network of user's daily movement patterns is derived, using unsupervised learning. This model allows tracking and predicting a user's location, mode of transportation, trip destination and future movements, and detecting deviation from habitual behaviour. According to the authors this technique can be applied to help cognitively impaired people use public transport safely using GPS technology, by providing instant feedback in case of divergence from normal travel routines (Liao et al., 2007).

At first sight their Bayesian network implementation resembles the approach presented in this chapter, but there are three essential differences. Firstly, while the former application identifies and predicts travel routines based on observed, repeated behaviour, the BIN model defines routines as all fixed scripts present in human decision making processes. This contains often repeated or habitual behaviour as well as fixed, scripted behaviour in exceptional situations. The latter type of 'scripts' cannot be detected in datasets of observed behaviour. The second difference applies to the individual, subjective valuations of attributes related to decision outcomes. Such utilities are simply not taken into account in Bayesian networks consisting of probabilistic nodes only. Alternatively in BIN, joint probabilities are calculated in chance nodes and utilities are calculated in decision nodes and value nodes. Finally, since only externally observable variables are included in Liao et al.'s model, and subjective, personal valuations are not taken into account, their system is less suited to assess the likely behavioural adaptation of individuals to various travel demand management measures due to changing beliefs and evaluations in the activity-travel decision making process, while predicting such behavioural impact of transportation policies is the principal goal of travel demand models.

The next section of this chapter details the actual elaboration of the mental repertoire of work-related travel routines in a BIN.

3.4 Modelling Procedure

There are three distinguishable, yet interrelated decisions in the work-related travel repertoire shown in Figure , i.e. the activity decision, the work location choice and the related travel mode choice. The BIN is built for each of these decisions consecutively, following the three basic steps in the modelling process: firstly, the decision network needs to be drawn. In the second step, different parameters (probabilities and utilities) are estimated. In the third and final step, the sensitivity of the model is tested by entering evidence in the influence diagram. This way, different scenarios provided in the initial description can be checked and the model can be validated. The next sections explain these modelling steps in further detail for each decision. The process description of the activity decision is comprehensive, while the description of the work location decision and the travel mode choice is more concise because their modelling process resembles the activity decision to a large extent.

3.4.1 Activity Decision

3.4.1.1 Constructing the network

The first step in drawing a decision network consists of two parts: (1) identification of the different network nodes (i.e. relevant concepts and constructs) and (2) definition of the relationships between the nodes and configuration of the network structure.

To identify the nodes in the verbal account, shown in Figure , three essential components of a decision network need to be determined: decision nodes (D), relevant chance nodes (C) – be it situational variables or attributes – and benefit or value nodes (V). The states of the decision nodes represent individual, subjective choice sets. The states of the chance nodes represent meaningful categories to the decision maker. The pane on the right-hand side of Figure shows how these predefined code categories guide the qualitative analysis process to define various aspects related to all the decisions in this description.

In the second stage, the links and relationships between nodes are determined. The resulting network has to be a directed acyclic graph, because in a cyclic network, it is impossible to calculate joint distributions of parameters (Shachter, 1986). Links in BIN are represented by directed arrows according to their meaning in the decision network (see 3.3.2). Based on the code list and overarching code categories resulting from the qualitative analysis of the verbal account, an intermediate decision network can be drawn using the graphical tools of a CAQDAS package.

Figure 20 shows an example of the intermediate decision network of the activity decision. In this case, the 'script network view' tool of ATLAS.ti (version WIN 5.0) is used to examine and represent likely relationships. Code families (CF) and their 'neighbouring nodes' (see the dash lines in the graph) are imported in the network view window. Next, the nodes are linked according to their role in the network. This graph forms the basis for the eventual representation of the decision network in the BIN software.

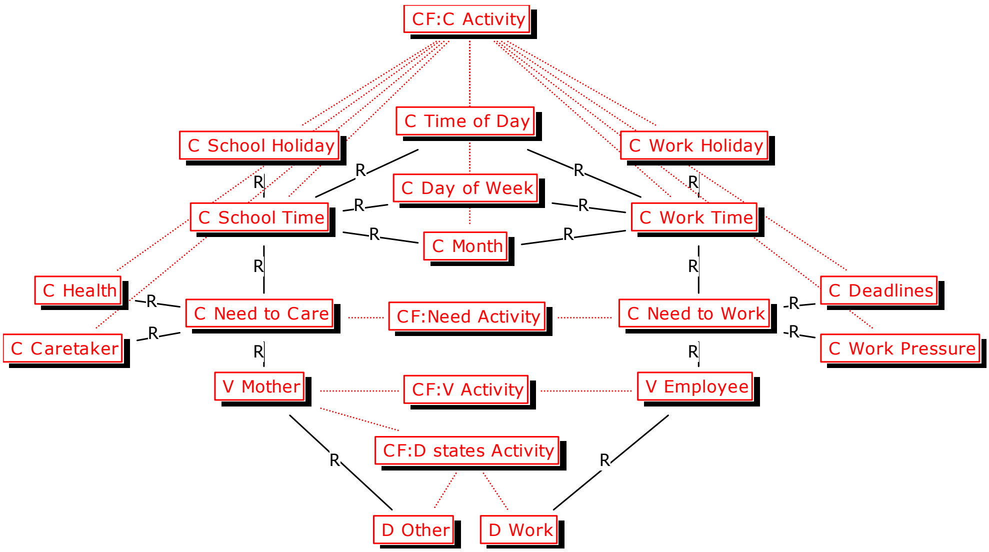


Figure 20 Intermediate Decision Network of the Activity Decision in ATLAS.ti

Elements of the most frequently used work routine are entered in the network to start with. Exceptional circumstances and explanatory factors for unusual choices are added later on. Nodes (put between single quotation marks further in this section) and alternative states of the nodes (indicated between brackets) of the usual work routine can be interpreted as follows: work is an 'activity' (work / other activity) largely determined by the normal 'work time' (work time / no work time). Its probability of occurrence depends on the 'month' (January / February / … / December), 'day of the week' (Monday / … / Sunday) and the 'time of day' (morning / afternoon / evening / night). Besides these variables, 'working holidays' (holiday / no holiday) have to be taken into account. Consequently, on normal work days, there is a 'need to work' (need to work / no need to work). In addition, this 'need to work' is related to varying levels of 'work pressure' (high / medium), for instance because of 'appointments' (yes / no) or 'deadlines' (yes / no). In terms of valuation, this 'need to work' is determined by the *social role* of full time 'employee' of this decision maker. Hence, the utility of the work activity is assessed in the light of the value or appropriateness of performing this activity in a given situation, related to the individual's beliefs of the social role of being a full time employee. How this valuation is achieved, is explained below (see 3.4.1.2).

Exceptions to this usual work routine can be caused by the fact that there is a 'need to take care' of the kids (need to care / no need to care). To a large extent, those times are determined by regular school holidays (school holiday / no school holiday) and regular 'school time' (school time / no school time), which is a function of 'month', 'day of the week' and 'time of day' similar to 'work time'. In addition, children's 'health' (healthy / sick) determines the 'need to take care' at some points in time. Of course, the availability of other 'caretakers' (available / not available) such as the partner or grandparents influences the 'need to take care' of this decision maker as well. The second state of the 'activity decision' (i.e. another activity), caused by the 'need to care' is related to the social role of 'mother' of three children. For instance, if a child is ill on a normal working day and there is no one else available to take care of the kid, the subjective image of motherhood will prompt the decision maker not to work but to stay with her ill child. In those cases, being a mother is valued higher than being a full time employee. Accordingly, the utility of performing another activity will be higher than the utility of the work activity (see 3.4.1.2). The resulting decision network of the activity decision generated with HUGIN Expert software (Version 5.7 Professional) is shown in Figure 21.

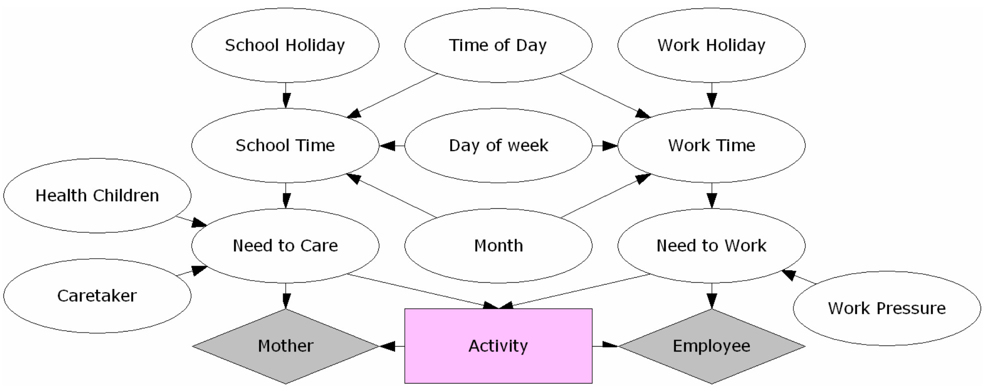


Figure 21 Decision Network of the Activity Decision in HUGIN

3.4.1.2 *Estimating the parameters*

After the network is drawn, the parameters have to be estimated. In the explanation below, references to variables and their states are indicated between single quotation marks and values are put between brackets. The probability estimations in the CPT's of various chance nodes can be detailed as follows: the CPT's of the parent nodes of 'work time' and 'school time' are mere objective frequencies, e.g. each 'day of the week' is assigned a probability of 1/7; the values of each 'month' depend on the amount of days in a year; the 'time of day' is set at 5/24 for a 'morning' (i.e. 7 am – 12 am), an 'afternoon' (12 am – 5 pm) and an 'evening' (5 pm – 10 pm) and 9/24 for the remaining 'night' according to this decision maker's usual day rhythm. The CPT's of 'work time' and 'school time' need to be estimated by the decision maker for all feasible combinations of states of the parent nodes. Obviously, the size of the table grows exponentially with the number of feasible attribute values. In this case, the result is an extensive table, but thanks to fairly fixed characteristics of the activity pattern, this is rather simple to estimate.

The CPT's of 'work pressure', 'health' children and 'caretaker' are mere subjective estimations of the decision maker, based on earlier experience. For instance, 'high work pressure' is deemed to appear in a quarter of cases while 'medium work pressure' holds for 75 percent of the time. The CPT's of 'need to work' and 'need to care' are subjective estimates as well, related to the states of the parent nodes. However, most of the matrix is simple to complete using 0 and 1 values. Only a combination of 'high work pressure' and 'no work time' is truly subjective. The decision maker's estimate here is that chances are 50 percent that this will lead to a need to work, as is shown in the screenshot of the CPT as inputted in HUGIN in Figure 22.

Work Pressure	High		Medium	
Work Time	Work time	No work time	Work time	No work time
Need to work	1	0.5	1	0
No need to work	0	0.5	0	1

Figure 22 Conditional Probability Table of the 'Need to Work' Node in HUGIN

Next, the CUT's of the value nodes are estimated. For the full time 'employee' CUT, the reasoning is similar to the basic example detailed in section 3.3.3.1: the activity 'work' while there is a 'need to work', has the highest utility (100). 'Work' while there is 'no need to work' is valued less (50), because there is no payment. 'Not working' while there is a 'need to work', is causing a disutility for the full time 'employee' (-150). This is inappropriate behaviour that might cause feelings of guilt, fear of getting caught or simply getting behind with present workload. 'Not working' while there is 'no need to work' is neutral (0) for the utility of the full time worker. Valuing utilities against the social role of 'mother' follows a similar line of thought: to 'work' while her children 'need care' causes disutility for the mother in terms of feelings of guilt and worries (-100). Taking care of the children ('other activity') while they need to be looked after ('need to take care') is valued most by this mother of three children (150). Finally, there is no appeal to her motherhood when there is 'no need to care' (0), whether she is working or not.

Note that in this conceptualization of routines, no detailed partial utilities are used to calculate overall utilities but decisions are assessed against holistic images of corresponding alternatives. In this case, these are individual subjective images of social roles and the appropriate behaviour related to possible activities given certain well-defined contexts. This corresponds to compound pattern matching models of routine decision making (see 3.3.1). In this case, the construct of 'social role' is crucial to understand the decisions modelled by this BIN. Following social role theory, such self-concepts guide the behaviour of individuals through a number of cognitive and motivational procedures. Eagle et al. (2005, p. 279) explain that: "*In one such process, gender role norms are internalized and adopted as personal standards against which people judge their own behaviour*". At the same time, such social roles and identities are shown to influence people's proclivity to local, context-dependent decision making (Shafir, 2007).

The idea to put the concept of the 'social role' in operation in the BIN originates from interview experiences in the qualitative exploration phase. In these interviews, references to typical role behaviour appeared as a justification for the engagement in certain activities. Besides daily commitments stemming from 'being a parent' or 'being an employee', even less routine behaviour was assessed this way. For instance, being asked the question: "*How often do you visit your parents?*", a respondent claimed: "*Um, as a good son, I should say once a week now, I guess, but in fact, it is much less…*"

3.4.1.3 Inferring the Network

Once a BIN is composed and its parameters are estimated, the third and final step includes testing its performance. A sensitivity analysis enables to analyze how susceptible the decisions are to minor changes. Changes may consist of variations of the parameters of the model or may be changes of the evidence (Jensen, 2001). In the current application, HUGIN is used to draw and compile the network. This BIN software supports the use of application programming interface (API) procedures to run combinations of states automatically. However, in this case study evidence to calculate various scenarios is entered in the system manually. This process is detailed in the next few paragraphs.

Figure 23 shows the outcome on the level of the activity utility of the inference of two usual scenarios in HUGIN. In the first scenario, an ordinary Monday morning in June is assumed. Therefore, the evidence entered in this node is '1' for 'Monday'. Furthermore, there is no work holiday, no school holiday and the children are healthy, as is shown in the evidence entered in the nodes of scenario 1. Besides this, work pressure is moderate. Propagation of this evidence through the network results in a clear decision in favour of the work activity (i.e. 100) and a disutility (i.e. -150) of any other activity (see bottom scores in Figure 23).

In the second scenario, evidence of a usual summer holiday is entered in the contextual nodes of the BIN: it's a Monday morning in July, school is out for summer, the children are healthy, the decision maker took holiday from work and work pressure is medium. In this case, the activity with the highest utility is not 'working' (25), but 'another activity' (37.5), and it is assumed that the latter option will be chosen. Note that in this application, only the ranking of the decision option utilities is interpreted, not their actual size.

Besides these usual situations, scenarios with exceptional circumstances can be calculated as well. Figure 24 shows the outcome of such an exercise. Scenario 3 in this figure builds on the usual work situation as sketched in scenario 1 in Figure 23: on a regular Monday morning in June, one of the children becomes ill. No other caretaker appears to be available. In this case, calculations show a clear impasse: the utility of the work activity is reduced to zero, and the valuation of other activities is increased to zero.

Therefore, the mother has to decide to take a day off from work (accordingly, work holiday evidence is entered), as is shown in scenario 4. This reduces the need to work and hence, the utility of this activity (-50). Hence, a decision in favour of another activity (150) is made.

So far, the BIN of the work-related travel repertoire contains only one decision, i.e. the activity to perform. However, the descriptive mental script model emphasized the interrelationship between activity, location and transport mode decisions and their simultaneous appearance in certain typical situations. Therefore, the network needs to be extended. The next sections describe the addition of the work location decision and the travel mode decision subsequently, similar to the three basic steps of a BIN modelling process. The composition of the network and the estimation of the parameters are detailed for each decision separately, while the inference of the network is demonstrated, after the BIN is compiled completely for all decisions.

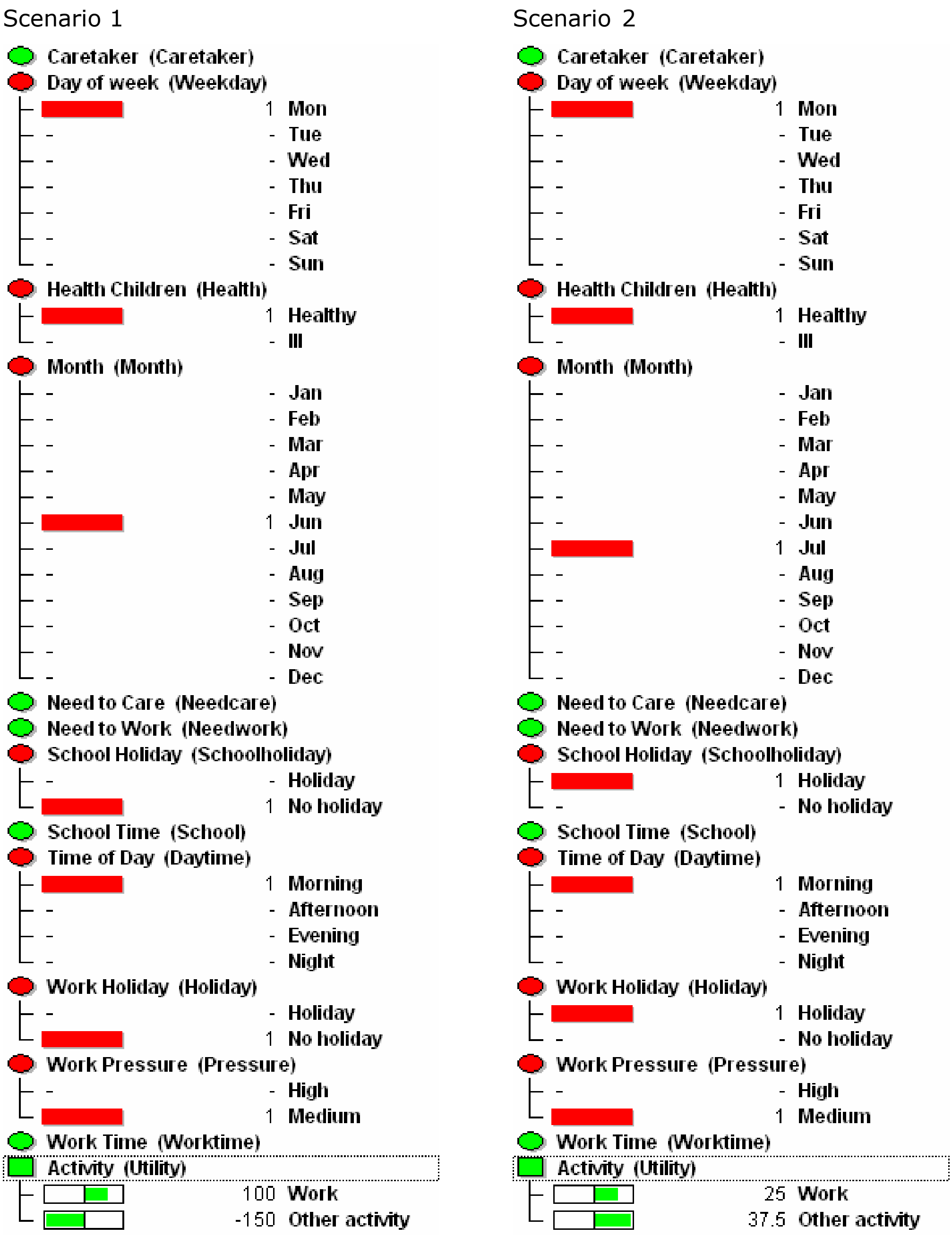


Figure 23 Activity Utility of Two Usual Scenarios in HUGIN

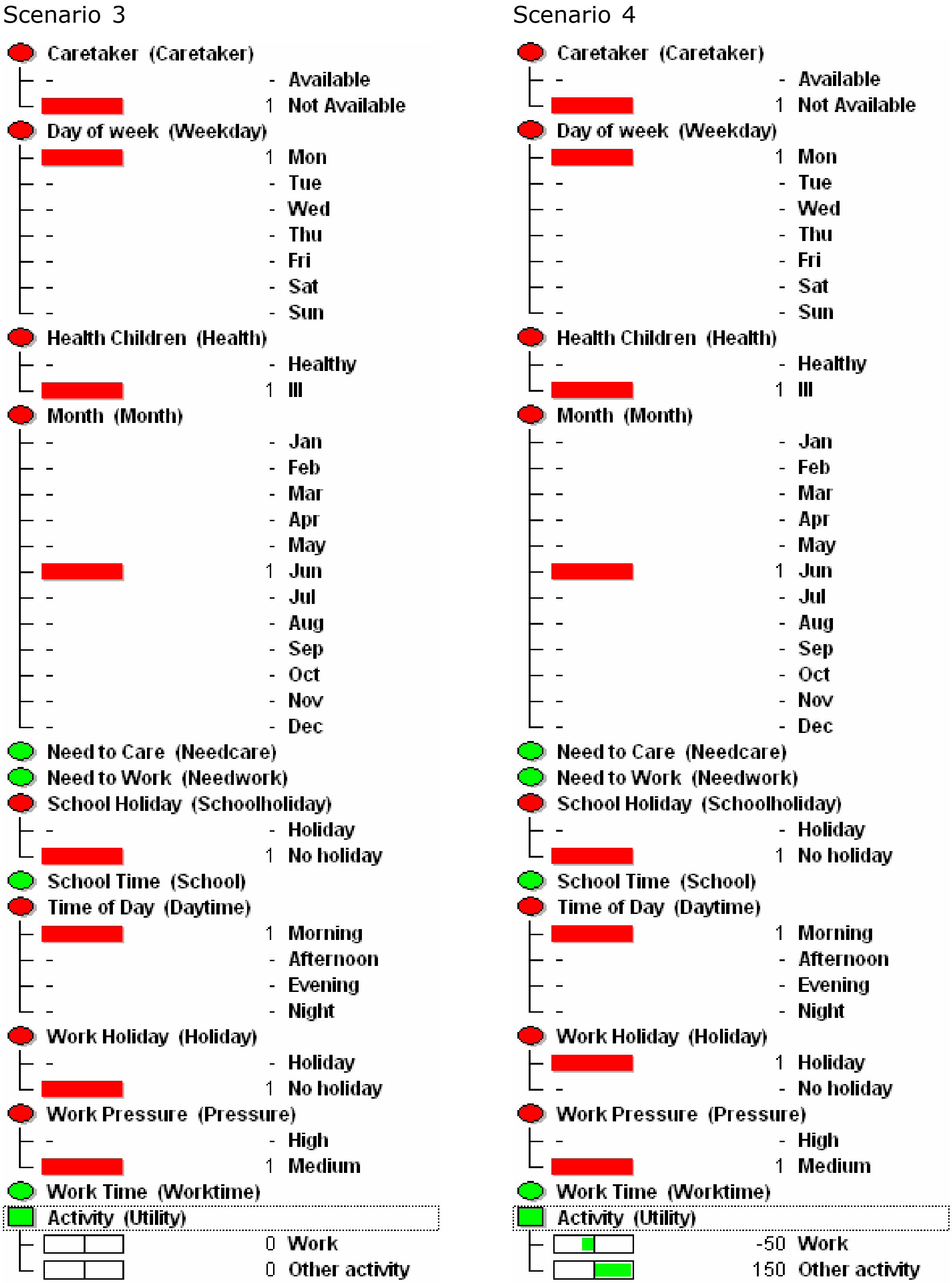


Figure 24 Activity Utility of Two Exceptional Scenarios in HUGIN

3.4.2 Work Location Decision

The second decision to be modelled from the descriptive mental repertoire (see Figure) is the work 'location' decision (Hasselt University (UH) / work at home / other city). Therefore, the network structure is drawn, starting with the addition of the usual work location choice to the preliminary activity decision network. The usual work location is the UH, because the agent 'needs to be at UH' (need to be at UH / no need to be at UH) on regular 'UHasselt times' (UHasselt time / no UHasselt time), determined by certain 'days of the week' and certain 'times of day'. The latter two nodes were entered in the network earlier on (see 3.4.1.1). Besides this, the need to be at UH is also influenced by fixed 'appointments at UH' (appointments UH / no appointments UH) such as teaching duties, meetings, etc. The valuation of the appropriateness of the décor of UH for the work activity is related to the image of being a 'UH colleague': it is part of the job to work together and social contacts matter.

Exceptions to this normal routine occur when it is decided to 'work at home' or to 'work in another city'. 'Work at home' depends on the previously mentioned 'day of the week'. This occurs on Wednesdays because the 'need to care' and the 'need to work' (again, previously mentioned variables) have to be combined in the afternoon when school is out, resulting in a 'need to multitask' (need to multitask / no need to multitask). Sometimes this need is activated by 'deadlines' as well (deadlines / no deadlines) since working at home saves (travel) time and is quieter. Therefore, the valuation of the home as a décor for work is related to the social role of being a 'working mum', thrifty with time. The second exception involves 'working in another city'. This choice largely depends on 'appointments in cities' (appointments city / no appointments city) like conferences, workshops, etc. Taking part in such events is part of the job of being a 'PhD student': 'need to learn' and need to build a social network (need to learn / no need to learn).

Figure 25 shows how the nodes related to the location decision are entered in the network and linked to the present activity decision network.

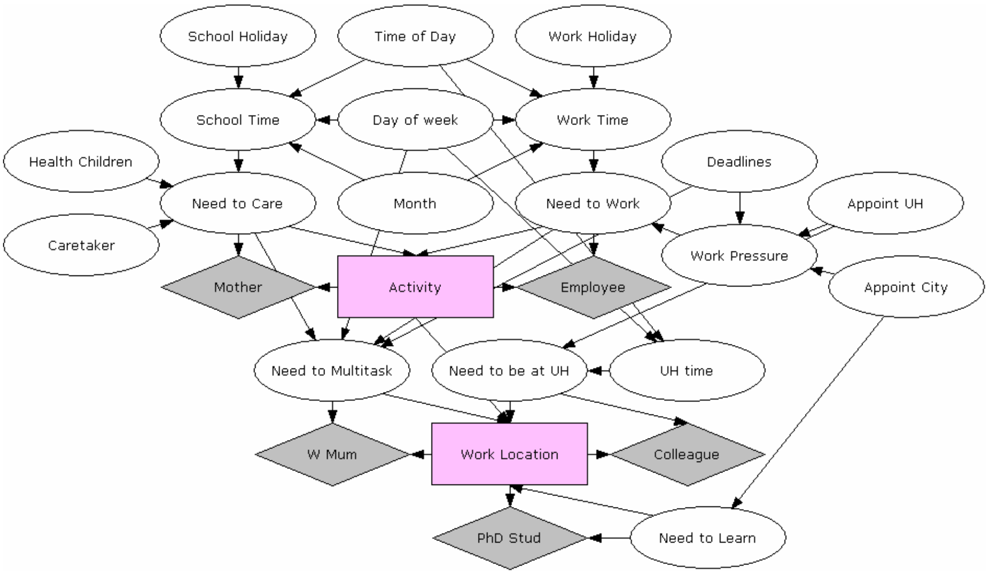


Figure 25 Decision Network of the Activity and Location Decision in HUGIN

The probability estimates for 'deadlines' (once a month on average), various 'appointments' (half of all working days at UH and about 10 days per year in other cities) and 'UHasselt time' (regular work times) are subjective estimates, based on past experiences. Next, the probabilities of the 'need to be at UH' are estimated by the decision maker, given 'UHasselt time' and 'appointments at UH'. In case of 'appointments', the 'need to be at UH' is valued '1'. In case of 'UHasselt time' and 'no appointments', the 'need to be at UH' is estimated '0.7'. The 'need to learn' is present (value '1') only in case of 'appointments in cities'. Furthermore, the 'need to multitask' varies with varying states of the 'need to work', the 'need to care', the 'day of the week' and the presence of 'deadlines'.

Estimated utilities can be explained as follows: as a 'colleague', 'working at UH' when there is a 'need to work at UH', is valued highest (100), while 'working at home' or 'working in another city' when there is a 'need to be at UH' causes a disutility (-80) in terms of the image of being a good 'colleague'. When there is 'no need to be at UH', clearly, 'colleague' related utilities are irrelevant; these utilities are set to 0. From a networking and learning point of view, working as a

'PhD student' pays of most in 'another city' (150). Being at 'UH' offers a small disutility in that respect, as well as the 'home' décor (-50). The role of 'working mum' can only be played to the full when multitasking at 'home' (750). When there is a 'need to multitask', other work places but home offer a disutility (-50), while none of the work locations is relevant for the 'working mum' when there is 'no need to multitask'. Whether these defined utilities lead to the expected decisions in different scenarios, is tested when the complete model is drawn, including the travel mode decision network.

3.4.3 Travel Mode to Work Decision

Figure 26 shows the resulting BIN of the complete work-related travel repertoire. Travel mode decisions are added to the network and modelled in the same vein as the other decisions.

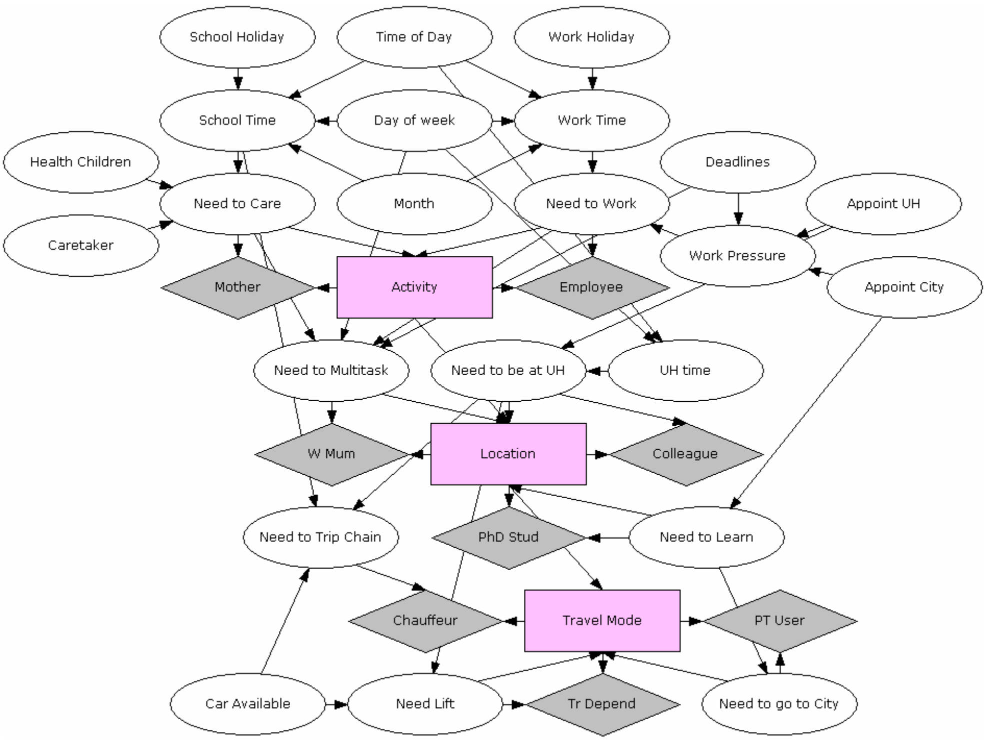


Figure 26 Bayesian Inference Network of a Work-related Travel Repertoire in HUGIN

In short, the procedure is as follows: on normal 'work days' when there is a 'need to be at the UH' workplace, and the kids have 'school time', the decision maker needs to make a 'trip chain' (need to trip chain / no need to trip chain) in the morning. Therefore, the car needs to be 'available' (car available / no car available). The holistic evaluation of the utility or appropriateness of this travel mode in different situations is valued in terms of being a 'chauffeur'. If the car is 'not available' and there is a 'need to go to the UH', the 'need for a lift' (need lift / don't need lift) arises, and its utility is measured by the decision maker as 'travel dependent'. Another exception occurs when the decision maker needs to 'go to another city' (need to go to city / no need to go to city). The holistic appraisal of the 'accessibility' of other cities by various transportation modes leads to assigning the highest utility to PT by the decision maker, who takes the perspective of a 'PT user' in such situations.

Finally, different scenarios are calculated by entering evidence into the network and assessing the outcomes to postulated decisions in the initial description of work routines.

Figure 27 shows the outcome of two usual scenarios. Firstly, a normal work situation is chosen, comparable to the first scenario calculated in the single activity network (see Figure 23): it's a Monday morning in June, there is no work holiday, no school holiday and the children are healthy. Entering these contexts in the network and performing the Bayesian propagation determines the rank of the choice options of the interrelated decisions as follows: the work activity, at the UH location and the car as travel mode have the highest scores respectively. This is consistent with the usual work script of this decision maker.

In a second exercise, the day is set to Wednesday, and the time of the day is set to the afternoon. As detailed in the descriptive account, in this situation the decision maker will work (activity) at home (location). In both decisions, these choice options have the highest utility in the calculated outcomes of the BIN indeed. Moreover, the car (travel mode) remains the most relevant option because of the mother's responsibility to chauffeur the children to school.

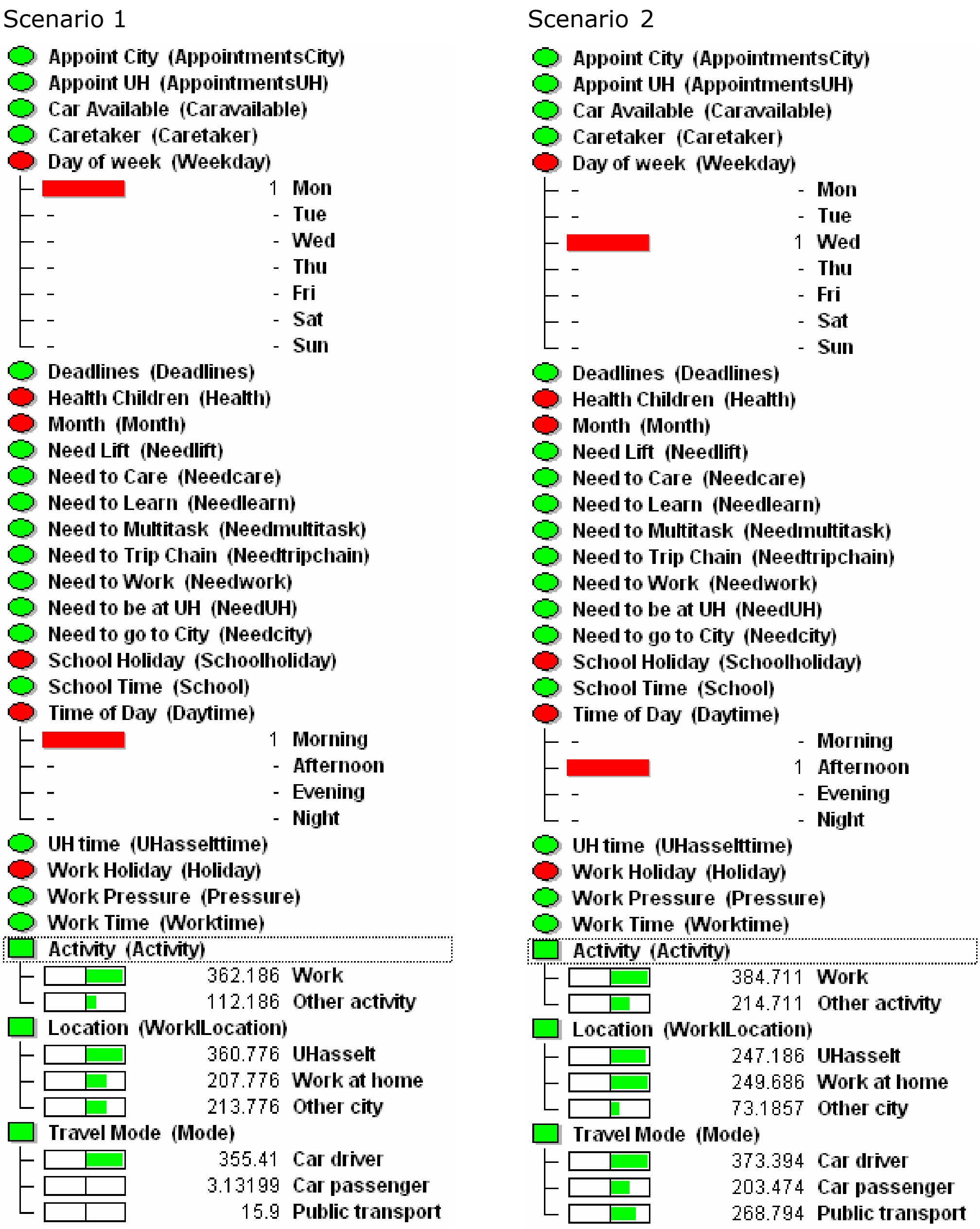


Figure 27 Decision Utilities of Two Usual Scenarios in HUGIN

Scenario 3 Scenario 4

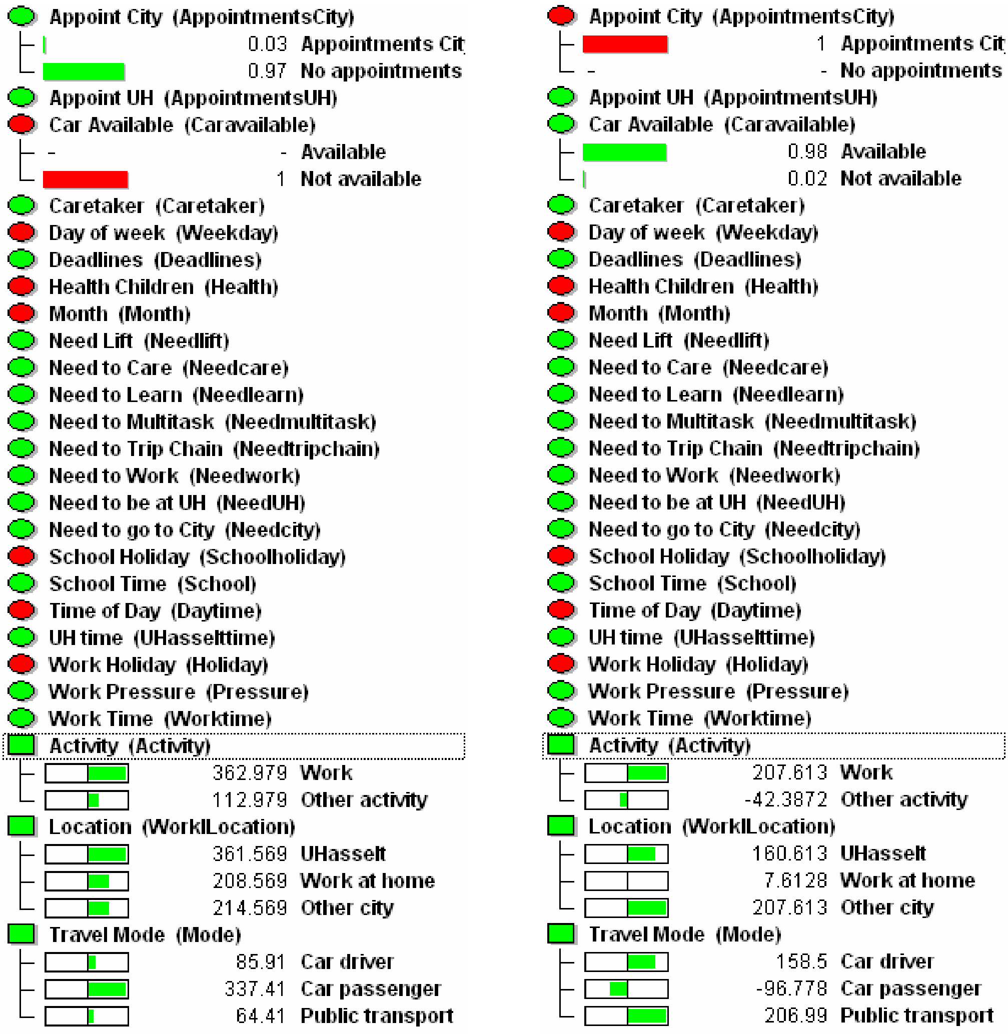


Figure 28 Decision Utilities of Two Exceptional Scenarios in HUGIN

In the exceptional scenarios in Figure 28, scenario 3 represents a normal work day (similar to scenario 1 in the previous figure), apart from the fact that the car is not available (for instance because it needs to be serviced). Entering this evidence changes the ranking of the utilities of the travel mode options in favour of the car passenger, consistent with the verbal description of the work-related travel routines. In the last example, the decision maker needs to be in another city on a normal working day, for instance because of a conference. This evidence is entered in the corresponding node and immediately after performing the automated Bayesian propagation, the utilities of the location and travel mode options change. In this scenario, working in another city (location) and travelling by public transport (travel mode) have the highest ranked utility in these decisions. Again, this reflects the actual choices as indicated in the basic qualitative description.

3.5 Conclusion and Discussion

In this chapter, a first step is taken to bridge the gap between findings of mere qualitative research into individuals' daily activity and travel decisions based on content analysis of in-depth interviews, and the primarily quantitative field of travel demand modelling. Therefore, a conceptual computational model of an individual's mental map of daily travel routines is formulated and an illustrative example is elaborated based on a verbal account of an individual's repertoire of work-related travel scripts of a full-time working mother of three children.

Supported by routine decision modelling theory, this mental repertoire is mapped as a BIN, a compact graphical and mathematical representation of decision situations, evaluations and outcomes. The building blocks of the model represent different relevant decision contexts that trigger different needs, which in turn are assessed against holistic images of social roles, related to the decision alternatives at stake. Thus, interrelated activity, location and travel mode decisions are prompted as soon as situational evidence enters the network. A numerical example shows that this inference can generate actual stated decision outcomes.

A clear advantage of modelling daily activity-travel routines as a BIN is its compact network representation with intuitive semantic features. Whereas traditional decision trees typically show an exponential growth in the number of branches with each variable modelled (the so-called 'bushy mess' phenomenon (Bielza & Shenoy, 1999), BIN's offer a concise way to model mental representations of decision problems in a natural way, increasing its computational efficiency. This is a recurrent finding in comparative research, e.g. Bielza and Shenoy (1999), Howard and Matheson (2005) and Owens et al. (1997). Especially the ability of BIN's to include interrelated decisions in one compact graph is appealing, since this reflects the actual behavioural mechanisms underlying activity-travel planning and execution found in the first phase of this PhD research. Such an immediate interrelatedness is much harder to achieve in a decision tree representation (Howard & Matheson, 2005).

Besides these differences inherent to the modelling technique, this BIN application differs from the current decision tree structures in AB models of travel demand from a content point of view as well. Three differences can be indicated: (1) the wide range of contextual factors, (2) the explicit integration of exceptional scenarios and (3) the behavioural valuation perspective.

Although represented compactly, the BIN is rich in its representation of contexts and conditions that trigger both typical and exceptional behaviour to start with. By including contextual variables such as 'day of week' and 'month of year', travel patterns on different days (e.g. Mondays and Wednesdays) and yearly recurrent events (e.g. school holidays) are explicitly taken into account in the BIN model. Such seasonal variability is not present in current AB models, and the distinction between days is usually limited to differences between weekends and weekdays, although both travel and traffic analyses have shown variability of travel patterns between workdays (Cools, 2009; Weijermars, 2007).

Secondly, meaningful unexpected or special events (e.g. the illness of a child) and influencing factors in the likely behavioural response (e.g. the presence of another caretaker) are present in this BIN, indicating further causes of variability in an individual's activity-travel pattern, as opposed to current decision trees that focus on mainstream behaviour. Although the relevance of integrating such detailed idiosyncratic aspects in a generic AB model of travel demand is debatable, mapping out behavioural responses to incidents can increase the understanding of present behavioural change, hence improve the prediction of future behavioural responses to new conditions. In this respect, weather conditions are indicated in the first exploratory phase to cause changes in travel mode choice. Besides this, other research has shown the impact of weather conditions on travel as well (Cools et al., 2010). Although not present in the mental map model presented in this chapter, such contextual aspects can be introduced in a BIN model easily.

A third difference of this BIN compared to the decision tree structure in an AB model of travel demand is its explicit definition of the valuation perspective in the utility nodes and utility functions. This conceptualization helps to understand intuitively *why* certain decision outcomes occur. In current decision trees, behavioural outcomes are based on mere associations with available population characteristics, emphasising decision outcomes, not decision mechanisms.

However, potential pitfalls of a BIN must be recognized as well. Although the example presented in this chapter clearly shows how parameters can be estimated to represent actual decisions, it can be a demanding task to complete CPT's and to force valuations of decision alternatives into practicable utility functions. The probability estimations in BIN are discrete values. In our application, the decision maker has to estimate these probabilities one by one. The correctness of such subjective probability estimates is debatable (Fox & Clemen, 2005), especially for hazy, value laden concepts. In this respect, admittedly, the current conceptualization of the utility node for the travel mode decision as holistically valued from the perspective of a traffic participant is rather forced and needs further attention. Besides this issue, somewhat contradictory to behavioural decision making, the computation of BIN's is restricted to Bayes theorem and maximum expected utility theory. At the same time, a model of 'local rationality' seems feasible thanks to the emphasis on contexts and situations.

One of the distinct challenges for future research is to develop this work model to accommodate a number of other routine daily activity-travel decisions such as weekly grocery shopping, education, sport routines, etc. In addition to this, a procedure needs to be developed for large-scale, systematic collection of scripted repertoire data, i.e. both network related features and relevant parameters. To scale-up the methodology, one line of thought is to develop a semi-structured interview protocol comparable to the CNET-elicitation technique for complex decisions developed by Arentze et al. (2008), or the computer-based CNET-survey for assessing semi-complex travel decisions developed by Kusumastuti et al. (2010). Alternatively, observed data such as used in related research with regard to activity-travel routines, e.g. Gogate et al. (2005), could serve as a basis for assessing existing routines in a subsequent survey and to gather additional information with regard to complementary, exceptionally used, fixed scripts and subjective valuations of choice options.

Clearly, the computational approach presented in this chapter demonstrates how primarily qualitative findings can be adopted in quantitative modelling methods to achieve a natural representation of reality. However, more research effort is needed to accomplish the actual implementation of this conceptual model of one individual in an operational AB model of travel demand of a complete population, or the development of a similar practical application beyond the mere research realm.

In this respect, a few drawbacks for the use of BIN are apparent. Since AB models of travel demand ultimately serve to assess the behavioural impact of a variety of travel demand management measures, models based on real life representations of decision strategies should ideally lead to more accurate, policy responsive forecasts. Whereas this BIN model of scripted routines is able to represent simple mental shortcuts in routine decision making, it does not (yet) account for the full cycle of development of behavioural scripts, their preservation or their likely change. Formation and adoption of simple behavioural heuristics could be a matter of original conscious reasoning with repetitive execution leading to mental shortcuts in decision making, as if the decision network is pruned. To understand their preservation or their potential to sustainable change, their strength needs to be measured.

From such a dynamic simulation perspective, the BIN modelling technique might even proof to be inadequate. First of all, a BIN has to be a directed acyclic graph in order to be able to calculate the system. Although forward propagation (calculating utilities from defined probabilities) and backward propagation (calculating probabilities from defined goals) through the network is possible, it is primarily a static system. This is likely to limit its application for the representation of decision making processes in the light of learning (such as spatial learning) and habit formation as the outcome of repeated considered choices (Danner et al., 2007). In addition, calculating BIN is restricted to linear propagation and the types of relationships between variables are limited, while in actual decision making, different types of relationships and various complex correlations might be needed to represent true decision making mechanisms.

A final comment is related to the future integration of individual representations in an agent-based travel demand model. With BIN, it is possible to create one or a few generic structures, capable of representing the network or structure of all decision makers' individual mental maps. However, it is not possible to estimate the parameters of all individuals separately in such a single generic structure. Thus, this impracticability to merge BIN is likely to cause computational problems in applications that predict the travel behaviour of thousands. To meet some of these problems, the FCM technique is proposed as an alternative approach to model individuals' mental representations of decision problems (Hannes et al., 2009). Only recently, this method is tested to the mental representation of semi-complex fun shopping decisions in a related PhD research project. Nevertheless, the routine activity-travel decision making process could be modelled similarly.

Obviously, the actual integration of such comprehensive individual mental models in the current scheduler of an AB model of travel demand constitutes a research program on its own in terms of developing new data gathering procedures, data collection, actual modelling and model validation. Therefore, the next chapter of this PhD thesis proposes a different approach to integrate mental map characteristics in an AB scheduler, based on the qualitative findings of the first research phase and the case study detailed in the second research phase. In the next research phase, the emphasis shifts to the usual and default daily activity routines, being a skeleton for the individual schedule. At the same time a population perspective is adopted. This enables framing the case study focussed on in this chapter, and positioning it in the occurrence of various types of skeletons across population groups.

4 MENTAL MAP ASPECTS IN AN AB MODEL OF TRAVEL DEMAND

– THRUSHES –

Tracking Household Routines Using Scheduling Hypothesis Embedded in Skeletons

4.1 Introduction

The key objective of the research presented in this chapter is to conceptualize a true representation of routine decision making in an AB model of travel demand, notably FEATHERS. Based on qualitative findings presented in Chapter 2 and the individual model of the mental repertoire of fixed scripts presented in Chapter 3, it is argued that the blank canvas presumed in the current scheduler of daily activities (see 1.3.3) is a misconception.

Indeed, in the current lay-out of this AB model, an individuals' activity calendar is built from scratch by scheduling all daily activities in a priority-based manner, starting with mandatory activities such as 'work' and 'bring or get' people, and completed with non-obligatory activities according to a predefined priority-order (Arentze & Timmermans, 2004). Moreover, on the household level, the scheduler models individual activity calendars of maximally two household heads successively. In this process, choices of the first adult can constrain choice options in subsequent schedules, assuming hierarchic household interactions.

Evidence has shown that people do not generally plan their activities consciously on a day-to-day basis (Hannes et al., 2009a, 2008). Instead, they rely on fixed routines or scripts, executed during the day without much consideration. This framework containing space and time-related anchor points predefines individual activity-travel behaviour to a large extent, and restricts further scheduling flexibility. Moreover, on the household level, a consensus routine is reached regarding certain joint travel and activity episodes such as work, care and household commitments that do not require daily negotiation. In modelling terms, such fixed patterns could be represented as a so-called ‘skeleton’ (Joh et al., 2007), replacing the initial blank calendar in current scheduling procedures.

The individual mental map model detailed in Chapter 3 represented normal and exceptional work routines of a mother of three young children. Herein, responsibilities arising from motherhood and employment triggered the need to engage in activities given a number of well defined contexts, leading to repetitive, settled components of activity-travel patterns. To further generalize this model, this chapter focuses on the normal workday organization of households with young children (age 6-12).

Young children and their parents constitute a distinct group that needs further study regarding their activity-travel scheduling behaviour in general. After all, to date, travel behaviour analysis has paid limited attention to specific activity and travel needs of children (Copperman & Bhat, 2007), and leading operational activity based (AB) models of travel demand to support transport policy making do not model children’s schedules explicitly. At the same time, the urging importance of considering intra-household interactions and group decision making in travel behaviour analysis and modelling is widely acknowledged, as witnessed by Bhat and Pendyala (2005) and Timmermans and Zhang (2009), amongst others.

The inability to use certain means of transportation independently reduces children’s free mobility and restrains others’ schedules: children depend on others – usually their parents – to fulfil their activity-travel needs. In turn, parental care commitments and related gender role norms constrain the action spaces of the responsible adult(s) to a large extent. Moreover, this mutual dependence is likely to render activity-travel decisions in daily schedules of parents less flexible or dynamic compared to their unbound peers.

Therefore, this chapter explores the incidence of 10 hypothetical family skeletons for working households with young children in Flanders and develops a concise model of fixed routines in daily activity-travel patterns based on a representation of activity-travel episodes in sequences. By explicitly considering young children's travel needs and the organization of care responsibilities amongst adult household members, this research constitutes a novel approach to activity-travel analysis. Furthermore, the objectification of family skeletons in family sequence patterns representing different household members, offers a new and promising modelling concept. From a methodological point of view, the formulation of sequence patterns based on a priori-defined classes is a novelty.

The train of thought underlying the model's development structures the remainder of this chapter: the following keynote section addresses the basic assumptions of the family skeleton concept, i.e. the existence of daily activity-travel routines, the Flemish school system and the hypothetical classification of families with young children. Subsequently, the actual segmentation of Flemish households is described, including a presentation of data, procedures and results. In the next section, sequences are introduced, individual child and adult sequence patterns are drawn and finally, the actual family skeletons are proposed. Then, these models are used to benchmark the output of FEATHERS. To finish this chapter, the major conclusions are summarized and future research is discussed.

4.2 The Family Skeleton Concept

Individual activity and travel behaviour is restricted by a number of fixed scripts, due to (long-term) commitments and various constraints. Many of these individual constraints to activity-travel planning and execution are defined on the household level in shared responsibilities and resources, as Kaufman-Scarborough (2006, p. 69) observes: "*households negotiate a collective schedule and pace of time based on consensus of its members and their external demands*". This way routine, settled components in activity-travel patterns arise.

This is especially true for households with young children. After all, children constrain parents' time use and travel behaviour to a large extent (Glorieux & Minnen, 2004; Zwerts et al., 2006), in particular at this stage of the family life cycle (Heggie, 1978; Jones et al., 1983). Children have to be housed, fed, educated, entertained, etc. Hence, school and school hours, work and work regimes, participation in clubs and social commitments, drop off and pick up duties, etc. constitute typical critical anchor points in the spatio-temporal organization of weekday routines of young households. In turn, these routines define fixed, skeletal frameworks in the daily activity-travel scheduling process.

For instance in Flanders, compulsory school attendance starts at the age of six, and six to 12-year olds have to attend classes for at least 28 school hours of 50 minutes per week (Ministerie van de Vlaamse Gemeenschap, 2005). According to regulations, school starts after 8 am and ends between 3 pm and 5 pm on weekdays, except for Wednesdays when school ends around noon. Within these boundaries, each school defines its fixed timetable for all children. School choice is free, but a common practice is to choose a school close to home. About 90% of all school children attends classes less than 5 kilometres from home (Van Ourti & Mortelmans, 2004), but they are generally considered too young to travel independently or to be left on their own at home. For instance, the major shift in dependent to independent school travel is established only at the turn from primary to secondary school, i.e. at the age of 12-13 (Peetermans & Zwerts, 2006). Thus, resulting chauffeuring and care responsibilities shared by parents have to be accommodated to work regimes (or vice versa) and assigned to individual activity-travel schedules.

Based on this knowledge ten hypothetical family organization structures can be formulated for a typical school and workday (excluding Wednesday) depending on the number of adults, their employment status and the division of care responsibilities. Three main categories are considered: single-parent, dual-earner and single-earner households. In each category, several combinations of drop off and pick up responsibilities can be distinguished on a given day. On the one hand, in single parent households, the adult either accompanies the child on both morning and evening school trips, or only on one of the two, or none of the trips are joined. Two adults on the other hand have the additional possibility to split morning and afternoon duties. Table 5 on page 131 (which will be explained further in this chapter) shows an example of a schematic time path for each of these family types along the results of the segmentation of the Flemish population discussed in the next section.

4.3 Population Segmentation

4.3.1 Data Set and Data Cleaning

To calculate the frequency in each of the predefined classes, enriched census data of Flemish households containing at least one child between six and 12 are selected from the most recent Belgian General Socio-Economic Survey (FPS Economy - Directorate-general Statistics en Economic Information, 2001). Since one of the topics in this questionnaire is related to individual travel characteristics on a typical work or school day (including trip chaining for working adults) and records for all household members can be linked, the population can be segmented according to their correspondence with one of the 10 predefined family types and the relative share of each cluster in the Flemish household population can be calculated.

Appendix B shows a detailed description of all procedures. In short, the data cleaning and reduction procedures in SAS involved selecting people living in Flanders (N = 5,968,074) out of the entire Belgian population (N = 10,296,350). Households containing at least one child aged 6-12 (N = 426,210) were selected out of all the selected Flemish households (2,428,578). Subsequently, all households with more than two adults (N = 14,833) or missing values (N = 215,641) on the critical commuting questions were deleted.

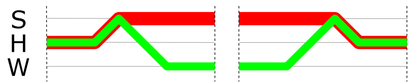
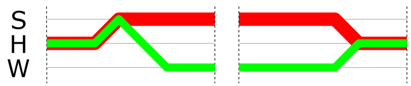
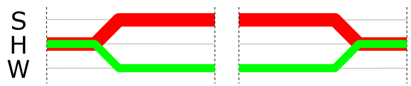
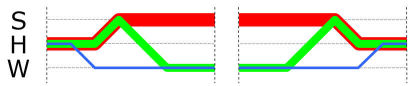
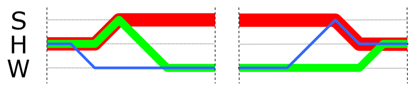
After excluding these records, some socio-economic characteristics of the obtained sample of households (N = 195,686) are compared to the population of Flemish households containing at least one six to 12 year old (N = 426,210) in order to check whether this sample still adequately represents the entire population. For this purpose, a chi-square test is performed to compare the observed sample values to complete population data. Pearson's test values are computed based on relative frequencies, using actual population proportions as expected values. P-values for the work regime of the household derived from parents' employment status (χ^2= 1.2863 and 5 degrees of freedom), age of the oldest adult in the household (χ^2 = 4.7721 and 3 degrees of freedom) and possession of cars (χ^2 = 0.2348 and 2 degrees of freedom) are 0.9363, 0.1876 and 0.8892 respectively, indicating that the observed distribution in the sample does not differ significantly from the population distribution.

4.3.2 Results

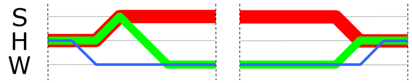
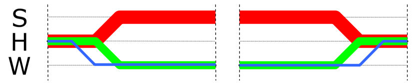
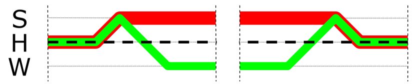
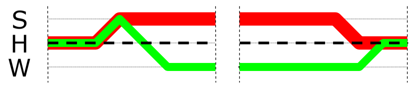
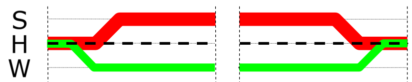
Table 5 shows the results of further household segmentation procedures for the selected households. Households without employed adults (N=10,377) were not analyzed because workday data are lacking. With a share of 70.31%, dual-earner households constitute the main category in this population. However, in the majority of these cases, only one of the two employed adults drops off and/or picks up the child(ren) as part of the normal workday routine on a typical workday, indicating an unequal distribution of care responsibilities in most households (family type 6 + 91,81% of family type 4). At the same time, a fair share of children in all main categories is not brought to school by either of the employed adults in the household, but travels either independently, or supervised by someone outside the household, or is chauffeured by the unemployed parent in single-earner households.

Additional analysis on socio-economic characteristics shows that women have to juggle work commitments and care responsibilities far more often than men. Table 6 demonstrates that this difference is related to the employment status. While in dual-earner households about half of the women work part-time (25.70% of female parents), only 1.08% of male parents are not full-time employed in this main category. This division is further reflected in all subcategories of the dual-earner households, apart from family type 7 in which adults neither drop off, nor pick up the children. Relaxed care responsibilities seem to offer the opportunity to a larger share of women to engage in full-time employment (29.36%) or, put the other way round, full-time employed women have to delegate care responsibilities more often. This traditional image of men as main breadwinner and women as main caregiver is even more apparent in single-earner households, where the majority of unemployed adults are female (45.57%) and the school run is not assigned to the employed partner, as can be seen from the size of family type 10.

Table 5 Segmentation of Working Households with Preschool and School Children (185,309) According to the Division of the Responsibility to Chauffeur the Children to School, Their Size and Their Relative Share

Family Type	Number	Share	Schematic Time Path Example
Single-parent households	***17,283***	***9.33%***	Morning / Afternoon
1. Adult drops off and picks up > Female: 88.86%	8,466	4.57%	
2. Adult drops off or picks up > Female: 84.66%	2,641	1.43%	
3. Adult neither drops off, nor picks up > Female: 72.86%	6,176	3.33%	
Dual-earner households	***130,295***	***70.31%***	Morning / Afternoon
4. One adult drops off and picks up > One adult all weekdays: 91.81% > Female: 74.63% ; Male: 17.18%	62,693	33.83%	
5. One drops off, the other picks up	10,839	5.85%	

Continued on Next Page…

Family Type	Number	Share	Schematic Time Path Example
6. One adult drops off or picks up > Female: 65.64%	21,219	11.45%	
7. Adults neither drop off, nor pick up	35,544	19.18%	
Single-earner households	***37,731***	***20.36%***	Morning Afternoon
8. Employed drops off and picks up > Female employed: 29.28%	3,354	1.81%	
9. Employed drops off or picks up > Female employed: 13.84%	4,430	2.39%	
10. Employed doesn't drop off / pick up > Female employed: 6.66%	29,947	16.16%	

Note: S (School); H (Home); W (Work); (Child's time path); (Employed 1); (Employed 2); (Unemployed)

Table 6 Adults' Type of Employment per Family Type and Sex

	Female			Male		
Family Type	Not %	PT %	FT %	Not %	PT %	FT %
Single-parent household adult (N = 17,283)	***-***	***33.21***	***49.18***	***-***	***1.02***	***16.60***
1. Adult drops off and picks up (N = 8,466)	-	36.67	52.00	-	0.83	10.50
2. Adult drops off or picks up (N = 2,641)	-	36.44	48.22	-	0.68	14.66
3. Adult neither drops off, nor picks up (N = 6,176)	-	26.81	45.57	-	1.44	26.18
Dual-earner household adults (N = 260,590)	***0.00***	***24.34***	***25.57***	***0.00***	***1.08***	***49.01***
4. One adult drops off and picks up (N = 125,386)	-	25.70	24.39	-	1.13	48.79
5. One drops off, the other picks up (N = 21,678)	-	25.95	24.09	-	1.19	48.77
7. Adults neither drop off, nor pick up (N=71,088)	-	20.11	29.36	-	0.97	49.55
Single-earner household adults (N= 75,462)	***45.57***	***1.74***	***3.00***	***4.82***	***0.91***	***43.96***
8. Employed drops off and picks up (N = 6,706)	36.56	5.86	8.73	13.46	3.06	32.32
9. Employed drops off or picks up (N = 8,859)	43.44	2.44	4.48	6.56	0.93	42.16
10. Employed doesn't drop off / pick up (N = 59,897)	46.91	1.17	2.13	3.58	0.67	45.55
All adults (N = 353,335)	***9.73***	***19.94***	***21.90***	***1.03***	***1.04***	***46.36***

Note: Not (unemployed); PT (Part-time employed); FT (Full-time employed)

Table 7 Households' Car Ownership and Children's Transport Mode Choice per Family Type

Family Type	0 Cars %	1 Car %	> 1 Car %	Slow %	CP %	BTM %
Single-parent households	***15.80***	***77.09***	***7.11***	***31.74***	***55.47***	***12.78***
1. Adult drops off and picks up	12.53	81.20	6.27	20.32	71.55	8.13
2. Adult drops off or picks up	14.33	77.18	8.49	30.72	55.99	13.29
3. Adult neither drops off, nor picks up	20.96	71.36	7.68	48.43	32.38	19.19
Dual-earner households	***1.63***	***47.45***	***50.91***	***30.63***	***60.77***	***8.60***
4. One adult drops off and picks up	1.34	44.20	54.46	21.19	72.98	5.83
5. One drops off, the other picks up	1.02	26.28	72.70	18.28	76.48	5.24
6. One adult drops off or picks up	1.57	47.33	51.10	32.85	57.58	9.57
7. Adults neither drop off, nor pick up	2.36	59.78	37.86	50.41	35.44	14.15
Single-earner households	***4.52***	***60.14***	***35.34***	***38.77***	***48.02***	***13.20***
8. Employed drops off and picks up	5.54	55.27	39.19	25.14	64.32	10.55
9. Employed drops off or picks up	2.97	44.07	52.95	26.18	63.88	9.94
10. Employed doesn't drop off / pick up	4.64	63.06	32.31	42.22	43.78	14.00
All households	***3.51***	***52.73***	***43.76***	***32.38***	***57.69***	***9.92***

Note: Slow (slow modes, i.e. walk or bicycle); CP (Car Passenger); BTM (Bus, Train or Metro)

Furthermore, the car ownership of households and children's travel mode choice (see Table 7) proves to be interdependent with the family types. Transport modes allowing children to travel unsupervised such as collective transport or (only moderately) slow modes, are consistently higher when adults neither drop off, nor pick up their child(ren), while car ownership is lower in these categories. Chauffeuring children to school by car is most popular in dual-earner households. It is hardly surprising that in these categories, the largest shares of car ownership can be seen. It can be noticed that 72.70% of households in which one adult drops the child off while the other picks the child up, owns more than one car. Clearly, such an equal distribution of care responsibilities amongst employed partners comes at the cost of a second car.

4.4 Family Sequence Patterns

4.4.1 Method

So far, the share of each family type across all Flemish households is calculated and examined. The next step consists of defining the components of the family skeleton in a comprehensive yet concise model that captures the essence of the order of events and interrelationships of the daily activity-travel routines of multiple individuals. Here, sequence alignment stemming from bioinformatics comes into play. Based on the idea that sequences of events such as activities and travel can be coded and represented as strings of characters similar to DNA or protein sequences, Wilson (1998) was the first to introduce this method to travel behaviour analysis. Joh et al. (2002; 2006) advanced this method even further by introducing a technique to explore multiple dimensions of individual activity-travel behaviour simultaneously (e.g. activity, location and transport mode).

In most of these cases, if not all, sequences are drawn from individual travel diary data and similarity measures between these sequences are calculated using sequence alignment and pattern matching methods (Navarro & Raffinot, 2002). Consequently, clusters of similar sequences (hence recurrent activity-travel patterns) or natural classes are derived from the data, and groups of people sharing similar activity-travel behaviour are identified. Subsequent linking of socio-economic characteristics to these clusters, results in a rich description of patterns of travel behaviour across population groups, e.g. Wilson (1998).

In this research, a reverse approach to sequence pattern formulation is applied based on an a priori classification of households in subpopulations according to a few significant variables, as opposed to standard automatic classification approaches. Figure 29 shows the consecutive steps in the derivation of the patterns. Next to the definition of family types (see step 1, detailed in section 4.3 of this chapter) individual sequence patterns are drawn for children and adults in step 2a and b. Steps 1 and 2 are parallel processes. In the third step, the individual patterns from step 2 are combined in family sequence patterns according to the family type classification defined in step 1. The last two steps are explained below.

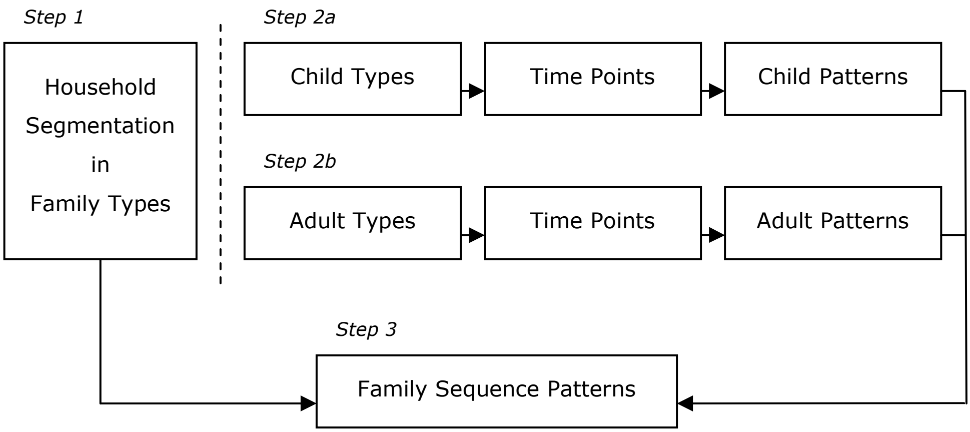


Figure 29 Family Sequence Pattern Framework

Sequence patterns represent a set of consensus characters occurring with a similar probability (Liu, 2007). Components of the pattern can be well-defined or ambiguous, and wildcard regions of fixed or variable length can be included in order to allow a more flexible representation of the consensus characters. Thus, patterns strive to extract the important functional sites (here: fixed household routines) in multiple sequences, while allowing activity patterns to be seen in their entirety.

Consider this example of an individual sequence pattern typical for a particular category of children (C_1) that is further developed and explained throughout the remainder of this paper, to grasp the various notions involved to start with:

$$C_1 = x(85,101).H^{(86,102)}.D(1,8).S^{(92,106)}.x(76,115).S^{(183,208)}.D(1,9).H^{(186,213)}.x(74,101).x^{288}$$

Each capital letter (H, D, S, C, T) refers to a particular activity (Home, Drop off/pick up trip, School, Child care, Travel), while the minor-case letter x represents any possible activity (wildcard). The order of letters corresponds to the order of activities during a day. Each day is subdivided into 288 positions in the pattern and each position corresponds to an activity episode of 5 minutes, yielding a so-called long-form sequence (Wilson, 1998). The numbers between brackets following a letter indicate the minimum and maximum number of positions (hence, the likely duration) of a certain activity. For instance, the length of the trip to school (e.g. D(1,8)) varies from 5 to 40 minutes across all observed children in this category. The index in superscript defines the exact position (one number) or the region of positions (lower boundary, upper boundary) where at least one position of a certain activity should be retrieved. For instance in the morning, the child arrives at school (e.g. $S^{(92,106)}$) between 7:40 and 8:50 am. Dots mark the transition to a new or differently defined stage in the sequence. For a likely combination of activities in a certain episode, relevant letters can be included in between square brackets. All these features can be used to compose sequence patterns.

4.4.2 Individual Sequence Patterns

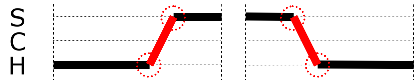
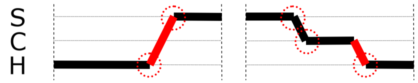
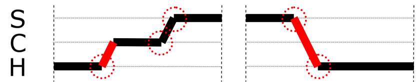
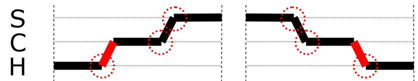
4.4.2.1 Children

Because of their education needs and general dependence, small children can constrain their parents' activity schedule to a large extent. The family skeletons aim to define the constraints in the parents' schedules based on the presence of children in the age category 6-12. Therefore, for each household in the dataset containing multiple children, the 'representative' child is set to be the child weighing the most on the adult(s) in terms of the school trip. This selection procedure prioritizes the travel mode implying dependent travel (car), followed by school travel that may imply dependent travel (walking, biking). If more than one child meets this requirement, the variables "lunch at home" and "child care outside school" are compared. Next, travel times coinciding with the parents' travel times are sought. If all these variables are the same for multiple children within the household, one representative child is chosen randomly. This concept of a 'representative' child is demonstrated before in a RUM-based joint time allocation model of a nuclear family developed by Kato and Matsumoto (2009).

Furthermore, four types of children are defined based on their participation in extramural childcare. Since school hours can differ considerably from work rhythms, some children need child care outside school in order to tune conflicting commitments. Table 8 shows the resulting segmentation of the children and the order of activities that characterizes the sequence pattern of their school day routine.

In the schematic time path examples in Table 8 the time points available for each child in the dataset are indicated. These include: time to leave for school and time of arrival at school in the morning and time to leave school and arrive from school in the afternoon. When applicable, the time to leave to childcare and the arrival time home from childcare is available as well. These time points are used to further specify the individual sequence patterns. Figure 30 shows a graph with the time span retrieved for each of these time points per child type in the training set containing 75% of the data. This figure indicates the 5th percentile and the 95th percentile of each variable in the data, and the observed mean.

Table 8 Segmentation of Representative Children (185,309) According to their School Day Organization and Basic Sequence Pattern

Child Type and Basic Sequence	Number	Share	Schematic Time Path Example (Morning / Afternoon)
1. No child care outside of school	107,187	57.84%	
C_1 = **x.H.D.S.x.S.D.H.x**			
2. Afternoon child care outside of school	70,888	38.25%	
C_2 = **x.H.D.S.x.S.T.C.D.H.x**			
3. Morning child care outside of school	3,077	1.66%	
C_3 = **x.H.D.C.T.S.x.S.D.H.x**			
4. Morning and afternoon child care	3,541	1.91%	
C_4 = **x.H.D.C.T.S.x.S.T.C.D.H.x**			
5. Boarding School	616	0.33%	

Note: H (Home); S (School); C (Child Care); D (likely Drop off/pick up trip); T (Travel); x (Wildcard); ◌ (Data point)

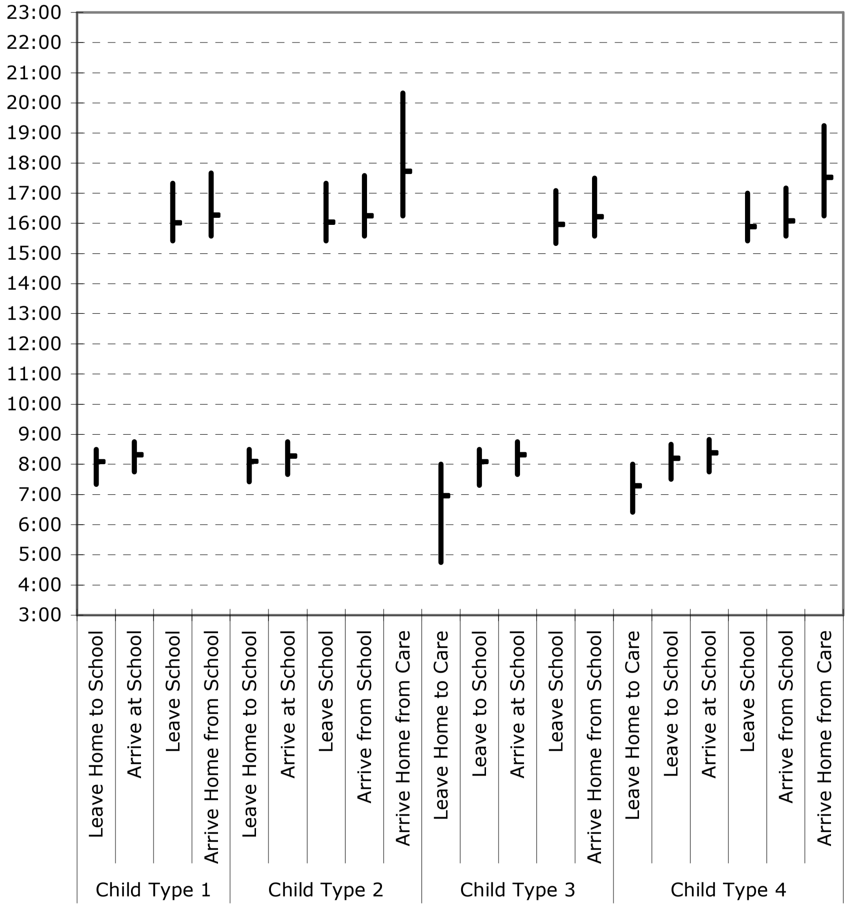


Figure 30 Children's Time Points, 5th Percentile, 95th Percentile and Mean (-)

When completing the sequence patterns, the variance in these anchor points is added first by indicating boundaries of positions in superscript to the corresponding letters in the basic sequence (i.e. H, S and C). Since the trip length to and from school can be derived from the data, the flexibility of this region is added next to the corresponding letter (i.e. D or T). Based on this knowledge, the other flexibilities in the pattern are derived. For instance, the minimum amount of positions of the region of wildcards (x) between the positions S (indicating the arrival time at school and the time to leave school), is defined by the latest arrive time possible and the earliest departure time possible in the sequence, while the maximum covers the time span between the earliest arrival time and the latest departure time. Figure 31 shows the result of this process for all child types.

In addition to this, one generalized child sequence pattern is drawn that combines the largest observed flexibility in any of the four patterns. For instance, the last episode of 5 minutes at home (H) in the morning can be found at position 55 the earliest (C_3), and 102 the latest (C_1 and C_2). Hence, the position of this last episode at home (H) in the morning varies between position 55 and 102 in the generalized child (C_g) sequence pattern.

$C_1 = x(85,101).H^{(86,102)}.D(1,8).S^{(92,106)}.x(76,115).S^{(183,208)}.D(1,9).H^{(186,213)}.x(74,101).x^{288}$

$C_2 = x(86,101).H^{(87,102)}.D(1,6).S^{(91,106)}.x(76,116).S^{(183,208)}.T(1,7).C^{(186,212)}.C(0,54).D(1,55).H^{(194,245)}.x(42,93).x^{288}$

$C_3 = x(54,95).H^{(55,96)}.D(1,44).C(0,43).C^{(86,102)}.T(1,9).S^{(91,106)}.x(75,113).S^{(182,205)}.D(1,7).H^{(186,211)}.x(76,101).x^{288}$

$C_4 = x(75,96).H^{(76,97)}.D(1,26).C(0,25).C^{(89,105)}.T(1,6).S^{(92,107)}.x(76,112).S^{(184,205)}.T(1,7).C^{(186,207)}.C(0,41).D(1,42).H^{(194,232)}.x(55,93).x^{288}$

Generalized Child Sequence Pattern (C_g)

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

Figure 31 Sequence Patterns per Child Type and Generalized Child Sequence Pattern

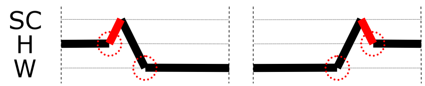
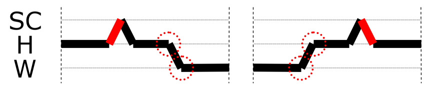
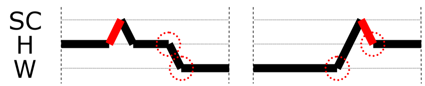
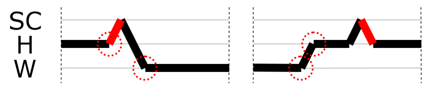
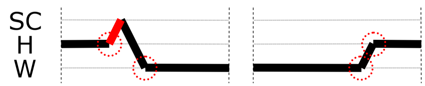
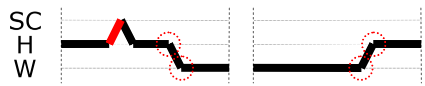
4.4.2.2 Adults

To build the adults' sequence patterns, a procedure similar to the one for the children's sequences is applied. Table 9 shows the segmentation of the adults' daily care and work routine according to the variability that can be observed theoretically: employed adults who have a certain drop off or pick up responsibility either chauffeur the children in a distinct home-based trip, or they make a trip chain on their way to or from work. The corresponding shares show that the latter combination of trips is applicable in the majority of cases. Again, the order of activities is indicated in the strings of letters of the basic sequence pattern for each adult type.

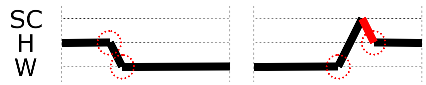
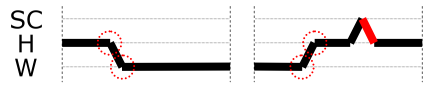
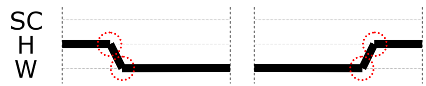
Figure 32 shows the time points on which the elaboration of the adults' sequence patterns is based. Comparing school trip time bands in Figure 30 to the variance in work trip time points in Figure 32 reveals that work rhythms are much more variable. Accordingly, sequence time bands in adults' patterns show a higher degree of flexibility. Nevertheless, the classification of adults according to their school trip duties and trip chaining behaviour is reflected convincingly in the time bands. For instance, work trip times of an adult type 1 who drops off and picks up the child on the way to and from work clearly fluctuate around school hours, while the average working hours of adult type 2 are much shorter, since he goes home before going to work and arrives home before picking up the children from school.

The individual adult sequence patterns are illustrated in Figure 33. Additional general sequence patterns are drawn for each main category of adults, reflecting the initial family classification.

Table 9 Segmentation of Employed Adults (315,604) According to their Workday Organization and Basic Sequence Pattern

Adult Type and Basic Sequence	Number	Share	Schematic Time Path Example (Morning / Afternoon)
Adult drops off and picks up			
1. Trip chain to and from work	60,308	19.11%	
A_1 = **x.H.D.T.W.x.W.T.D.H.x**			
2. No trip chain to or from work	2,242	0.71%	
A_2 = **x.H.D.T.H.T.W.x.W.T.H.T.D.H.x**			
3. Trip chain from work, not to work	7,563	2.40%	
A_3 = **x.H.D.T.H.T.W.x.W.T.D.H.x**			
4. Trip chain to work, not from work	10,190	3.23%	
A_4 = **x.H.D.T.W.x.W.T.H.T.D.H.x**			
Adult only drops off in the morning			
5. Trip chain to work	23,846	7.56%	
A_5 = **x.H.D.T.W.x.W.T.H.x**			
6. No trip chain to work	5,298	1.68%	
A_6 = **x. H.D.T.H.T.W.x.W.T.H.x**			

Continued on Next Page

Adult Type and Basic Sequence	Number	Share	Schematic Time Path Example
Adult only picks up in the afternoon			
7. Trip chain from work	16,484	5.22%	
A_7 = **x.H.T.W.x.W.T.D.H.x**			
8. No trip chain from work	4,917	1.56%	
A_8 = **x.H.T.W.x.W.T.H.T.D.H.x**			
Adult neither drops off nor picks up			
9. No joint trip	184,755	58.54%	
A_n = **x.H.T.W.x.W.T.H.x**			

Note: H (Home); W (Work); D (Drop off / Pick up trip); T (Travel); x (Wildcard); ◌ (Data point); SC (School or Care)

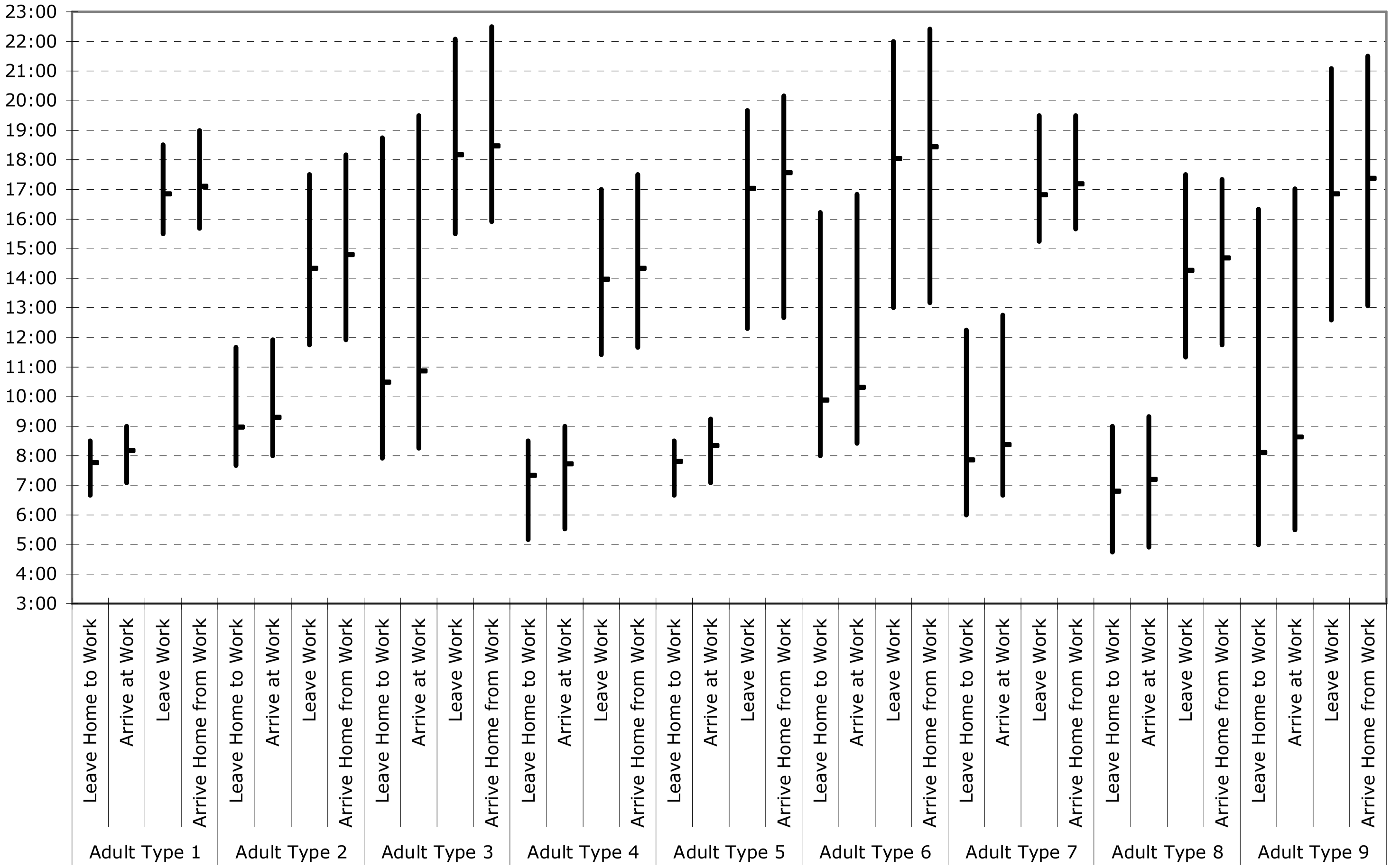


Figure 32 Adults' Time Points, 5th Percentile, 95th Percentile and Mean (-)

Adult drops off and picks up

$A_1 = x(77,101).H^{(78,102)}.D(1,14).T(1,14).W^{(84,109)}.x(74,137).W^{(184,222)}.T(1,14).D(1,14).H^{(187,229)}.x(58,98).x^{288}$

$A_2 = x(0,137).H^{(0,138)}.D(1,44).T(1,44).H^{(90,140)}.T(1,9).W^{(95,144)}.x(0,114).W^{(139,210)}.T(1,9).H^{(142,219)}.T(1,55).D(1,55).H^{(145,287)}.x(0,140).x^{288}$

$A_3 = x(2,222).H^{(3,223)}.D(1,44).T(1,44).H^{(93,225)}.T(1,12).W^{(98,235)}.x(0,166).W^{(184,265)}.T(1,11).D(1,11).H^{(190,271)}.x(16,97).x^{288}$

$A_4 = x(59,101).H^{(60,102)}.D(1,11).T(1,11).W^{(65,109)}.x(25,138).W^{(135,204)}.T(1,10).H^{(139,211)}.T(1,55).D(1,55).H^{(142,287)}.x(0,143).x^{288}$

Generalized adult sequence pattern, full drop off / pick up responsibility (A_f)

$A_f = x(0,222).H^{(0,223)}.D(1,44).T(1,44).x(0,231).W^{(65,235)}.x(0,166).W^{(135,265)}.x(0,150).T(1,55).D(1,55).H^{(142,287)}.x(0,143).x^{288}$

Adult only drops off in the morning

$A_5 = x(77,102).H^{(78,103)}.D(1,15).T(1,15).W^{(84,112)}.x(33,151).W^{(146,236)}.T(1,14).H^{(151,243)}.x(44,136).x^{288}$

$A_6 = x(4,191).H^{(5,192)}.D(1,44).T(1,44).H^{(94,195)}.T(1,12).W^{(100,203)}.x(0,163).W^{(154,264)}.T(1,12).H^{(157,270)}.x(17,130).x^{288}$

Generalized adult sequence pattern, morning drop off responsibility (A_m)

$A_m = x(4,191).H^{(5,192)}.D(1,44).T(1,44).x(0,195).W^{(84,203)}.x(0,163).W^{(146,264)}.T(1,14).H^{(152,269)}.x(18,135).x^{288}$

Adult only picks up in the afternoon

$A_7 = x(69,146).H^{(70,147)}.T(1,12).W^{(100,203)}.x(0,133).W^{(181,234)}.T(1,15).D(1,15).H^{(187,235)}.x(52,100).x^{288}$

$A_8 = x(52,107).H^{(53,108)}.T(1,11).W^{(58,113)}.x(0,131).W^{(88,190)}.T(1,12).H^{(140,209)}.T(1,55).D(1,55).H^{(143,287)}.x(0,144).x^{288}$

Generalized adult sequence pattern, afternoon pick up responsibility (A_a)

$A_a = x(52,146).H^{(53,147)}.T(1,12).W^{(58,203)}.x(0,133).W^{(88,234)}.x(0,196).T(1,55).D(1,55).H^{(143,287)}.x(0,142).x^{288}$

Adult neither drops off, nor picks up

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

Figure 33 Individual Sequence Patterns per Adult Type and Generalized Adult Sequence Patterns

4.4.2.3 Stability Test

To estimate the sequence pattern model, a training set containing 75% of all individuals was randomly sampled in each category. The remaining subset of 25% is used to test the parameter stability of the model. To this end, the flexibilities of the time points in the individual patterns are derived from the 5th percentile and 95th percentile of each time point separately (see Figure 30 and Figure 32). Next, the resulting sequences (consisting of a combination of different time points and their flexibilities) are then compared to the original records per case in both training and test set. All observed time points in each individual's activity-travel pattern have to lie in the time ranges defined in the corresponding sequence pattern in order to give a true positive hit in the test. For the adults' patterns, the results show that on average (weighted) 80.73% of the training data (ranging from 79.08% for adult type 8 to 85.66% for adult type 9), and 79.67% of the test data (ranging from 72.79% for adult type 3 to 83.71% for adult type 9) match the sequence models. Additionally, comparing training set and test set results indicate a random, unbiased division of the data set. For the children's patterns on average (weighted) 79,67% are true positive hits in the training set (ranging from 73.08% for child type 2 to 78.16% for child type 3) and 66.29% in the test set (ranging from 63.41% for child type 2 to 68.24% for child type 1). These slightly lower scores reflect a reduced stability of the model parameters due to the combination of 6 time points in the children's sequence patterns, as opposed to 4 in the adults' models.

4.4.3 Family Sequence Patterns

4.4.3.1 Patterns

Eventually, the generalized individual patterns are combined into family sequence patterns according to the family classification (see Figure 34, Figure 35 and Figure 36 for single-parent households, dual-earner households and single-earner households respectively). Each sequence in these patterns represents a member of the household, i.e. one or two adults and one representative child. Each pattern unambiguously defines the default workday routine of a particular family type, due to the specific position and connection of the drop off/pick up trips (D) across the different sequences of the pattern.

Therefore, one additional modification to the original generalized sequences is executed. In the adults' sequences, all characters and their specifications before the drop off trip or after the pick up activity, and the actual joint travel episode itself (D) are attuned to the specifications of the generalized child's pattern of the representative child, if applicable. Specifically, in the pattern of the adult responsible for a drop off/pick up trip (D), all characters before the work trip (T) in the morning and/or the characters after the work trip (T) in the evening (if applicable) are replaced by the string sections present in the generalized child pattern (C_g), and the flexibilities of the remaining characters and positions in the adult's pattern are adjusted accordingly.

F1. Adult drops off and picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_f = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,231).W^{(65,235)}.x(0,166).W^{(135,243)}.x(0,150).T(1,55).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

F2. Adult drops off or picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_m = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,195).W^{(84,203)}.x(0,163).W^{(146,264)}.T(1,14).H^{(152,269)}.x(18,135).x^{288}$

or

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_a = x(52,146).H^{(53,147)}.T(1,12).W^{(58,203)}.x(0,133).W^{(88,234)}.x(0,196).T(1,55).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

F3. Adult neither drops off, nor picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

Figure 34 Family Sequence Patterns for Single-parent Households

F4. One adult drops off and picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_f = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,231).W^{(65,235)}.x(0,166).W^{(135,243)}.x(0,150).T(1,55).D(1,55).\ H^{(186,245)}.x(42,101).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

F5. One adult drops off, the other picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_m = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,195).W^{(84,203)}.x(0,163).W^{(146,264)}.T(1,14).H^{(152,269)}.x(18,135).x^{288}$

$A_a = x(52,146).H^{(53,147)}.T(1,12).W^{(58,203)}.x(0,133).W^{(88,234)}.x(0,196).T(1,55).D(1,55).\ H^{(186,245)}.x(42,101).x^{288}$

F6. One adult drops off or picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_m = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,195).W^{(84,203)}.x(0,163).W^{(146,264)}.T(1,14).H^{(152,269)}.x(18,135).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

or

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_a = x(52,146).H^{(53,147)}.T(1,12).W^{(58,203)}.x(0,133).W^{(88,234)}.x(0,196).T(1,55).D(1,55).\ H^{(186,245)}.x(42,101).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

F7. Adults neither drop off, nor pick up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

Figure 35 Family Sequence Patterns for Dual-earner Households

F8. Employed adult drops off and picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_f = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,231).W^{(65,235)}.x(0,166).W^{(135,243)}.x(0,150).T(1,55).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_u = x(0,288)$ and (x = all but W)

F9. Employed adult drops off or picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_m = x(54,101).H^{(55,102)}.D(1,44).T(1,44).x(0,195).W^{(84,203)}.x(0,163).W^{(146,264)}.T(1,14).H^{(152,269)}.x(18,135).x^{288}$

$A_u = x(0,288)$ and (x = all but W)

or

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_a = x(52,146).H^{(53,147)}.T(1,12).W^{(58,203)}.x(0,133).W^{(88,234)}.x(0,196).T(1,55).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_u = x(0,288)$ and (x = all but W)

F10. Employed adult neither drops off, nor picks up

$C_g = x(54,101).H^{(55,102)}.D(1,44).[CT](0,48).S^{(91,107)}.x(74,116).S^{(182,208)}.[CT](0,59).D(1,55).H^{(186,245)}.x(42,101).x^{288}$

$A_n = x(57,195).H^{(58,196)}.T(1,16).W^{(65,205)}.x(0,187).W^{(149,253)}.T(1,16).H^{(156,259)}.x(28,131).x^{288}$

$A_u = x(0,288)$ and (x = all but W)

Figure 36 Family Sequence Patterns for Single-earner Households

4.4.3.2 Stability Test

Similar to the individual sequence patterns, data from the training set and the test set are used to test how well observed instances match the family sequence patterns. For each family type all registered time points of household members are compared to the predefined time ranges in the family skeletons. A true positive hit in the test signifies that all the observed time points of a particular household lie within the flexibilities of the family sequence pattern into consideration. Note that in this test, due to the combination of generalized individual sequence patterns, the time ranges in the family models are less strict compared to the initial individual sequence patterns, while the number of time points to match is increased considerably.

On average (weighted), this test shows 63.87% true positive hits in the training set, and 57.45% in the test set. In both sets, the pattern of family type 6 performs worst (57.25% hits in the training set, 50.08% in the test set). Best matching patterns are family type 10 in the training set (77.40%) and family type 3 in the test set (62.92%). Not surprisingly, patterns without intra-household constraints perform better compared to family patterns in which generalized adults' schedules are restricted further to accommodate the child's travel needs.

Additional sensitivity analysis shows that a decrease of the flexible anchor points of 2 positions (lower boundary +5 minutes and upper boundary -5 minutes) causes a decrease in performance up to on average 52.27% in the training set and 43.73% in the test set. A similar increase of 2 positions on the other hand, improves the models' performance up to 66.92% in the training set and 62.16% in the test set. One additional step of 10 minutes causes an increase up to 70.96% true positives in the training set and 67.65% in the test set. However, tightening or relaxing these flexibilities does not impact the vital and clear-cut link between household members due to the constraints in the family sequence patterns because joint trip positions (D) have to correspond.

4.5 Benchmarking FEATHERS

The use of population data in the family sequence pattern models holds a clear opportunity. Particularly, together with the results of the SEE data segmentation of Flemish households according to predefined family classes, these patterns and their distribution can be used to benchmark the outcome of the newly developed AB model of travel demand (FEATHERS). By quantifying the goodness-of-fit, it can be assessed how well observed individual and household routines in activity-travel patterns and their distribution across the population are predicted by the travel demand model.

First of all, the family segmentation can be tested. Therefore, the predicted activity and travel schedules of adult household members are used to assign each household to a family type based on the presence of bring/get activities in the parents' schedules. Next, the share of each family type in the output is calculated, and the distribution of family types across the output sample is compared to the distribution in the segmentation of the population data. A chi-square test reveals whether the distributions in the FEATHERS sample still adequately represent the entire population. Subsequently, the family sequence pattern models can be tested. Therefore, the FEATHERS output is analyzed further to check whether the predictions in each family type match the according sequence pattern models based on the SEE data. In this test, the predicted time points for bring/get travel in the adults' schedules are compared to the time-ranges in the sequence models. The results of these two tests (i.e. the family segmentation test and the family sequence pattern test) are presented consecutively in this sub chapter. The report of each test is followed by a discussion of the outcomes.

The FEATHERS output data are based on a FRAC 20 run (a fraction representing 5% of the population) of ALBATROSS in the FEATHERS platform on March 23rd 2010. In this version, the decision trees of the scheduler are trained on OVG 3 data, i.e. the third wave of Flemish travel surveys in 2007-2008 (Janssens et al., 2009), and the input data come from the population synthesizer (Nakamya et al., 2010). (For a general introduction to this model, see Section 1.3.3). Further processing of this dataset creates the subset of young households by restricting the age category of the youngest child in the household to 6-12 year olds ("child = 2"). This output is converted into a database to calculate the distribution of the family types in SAS and to test the time points of the family sequence patterns. Table 10 shows an initial comparison of some general population data and output sample characteristics.

Table 10 Comparison of SEE 2001 Data and Population Output Characteristics in FEATHERS

SEE 2001 DATA		population OUTPUT FEATHERS	
Population		**Population**	
No. of persons in Flanders	5,968,074	No. of persons in Flanders	298,368
No. of households in Flanders	2,428,578	No. of households in Flanders	121,330
Avg. household size	2.46	Avg. household size	2.46
		No. of adults' schedules	197,577
Subset of young households		**Subset of young households**	
Households, 1 child (6-12)	426,210	Households, youngest (6-12)	13,432
Young households in Flanders	17.55%	Young households in Flanders	11.07%
Persons in young households	1,737,169		
% living in young households	29.11%		
Avg. young household size	4.08		
		Predicted adults in young hh	25,565
		Schedules / young household	1.92
Young hh, adults unemployed	22,589	Young hh, adults unemployed	751
% of unemployed young hh	5.30%	% of unemployed young hh	5.86%
Young hh, min. 1 employed	403,621	Young hh, min. 1 employed	12,073
% of working young hh	94.70%	% of working young hh	94.14%
Hh with missing travel data	218,321	Hh with missing work status	608

The definition of 'young household' in the SEE 2001 dataset differs from the definition in the FEATHERS output due to data limitations in both datasets. While in the SEE data all households containing at least one 6-12 year old are selected, the FEATHERS output contains only households with the youngest child in this age category, since this is the most accurate information present in the input data. Neither household size data, nor household members' ages are available. This distinct definition of young households explains the smaller share of this group in the FEATHERS output (11.07%) compared to the SEE 2001 share (17.55%) in Table 10. With respect to the comparison of employment status, the shares of unemployed and employed young households in the FEATHERS output subset match the observations in the SEE 2001 data subset.

4.5.1 Family Segmentation Test

Since the original SEE 2001 data only contain work and school travel data for working adults, unemployed families are discarded from the FEATHERS dataset for further analysis. The resulting segmentation of remaining working households is shown in Table 11.

Table 11 Segmentation of Working Young Households in SEE 2001 and FEATHERS Output

	SEE 2001		FEATHERS	
Family Type	**Number**	**Share**	**Number**	**Share**
I. Single-parent households	***17,283***	***9.33%***	***615***	***5.09%***
1. Adult drops off and picks up	8,466	4.57%	9	0.07%
2. Adult drops off or picks up	2,641	1.43%	49	0.41%
3. Neither drops off, nor picks up	6,176	3.33%	557	4.61%
II. Dual-earner households	***130,295***	***70.31%***	***9,493***	***78.63%***
4. One adult drops off and picks up	62,693	33.83%	678	5.62%
5. One drops off, the other picks up	10,839	5.85%	75	0.62%
6. One adult drops off or picks up	21,219	11.45%	2,074	17.18%
7. Neither drop off, nor pick up	35,544	19.18%	6,666	55.21%
III. Single-earner households	***37,731***	***20.36%***	***1,965***	***16.28%***
8. Employed drops off and picks up	3,354	1.81%	58	0.48%
9. Employed drops off or picks up	4,430	2.39%	215	1.78%
10. E. neither drops off, nor picks up	29,947	16.16%	1,692	14.01%
TOTAL	**185,309**		**12,073**	

In order to check whether the distributions in the FEATHERS sample still adequately represent the entire population, a chi-square test is performed to compare the observed sample values to the SEE population data. Pearson's test values are computed based on relative frequencies, using actual population proportions as expected values.

As far as the distribution of the general family categories is concerned (single-parent households, dual-earner households, and single-earner households) the P-value derived from these general categories (χ^2= 3.7290 and 2 degrees of freedom) is 0.1550 (> 0.05), indicating that the observed distribution in the sample does not differ significantly from the SEE distribution (see Table 12) with respect to these general socio-demographic characteristics. This observation also implies that the input from the population synthesizer is valid.

Table 12 Comparison of the Distribution of General Family Types

	Observed % in FEATHERS	**Expected % based on SEE 2001**	**Computed differences for Pearson**	
I. Single-parent households	5.09	9.33	1.9269	
II. Dual-earner households	78.63	70.31	0.9845	
III. Single-earner households	16.28	20.36	0.8176	
			3.7290	χ^2
			0.1550	p

To check the distributions of the categorization of the families based on their internal distribution of drop off and pick up responsibilities, a similar test is performed for each general family category separately. To apply the Pearson test statistic based on percentages in a correct way, the percentage of categories containing observations smaller than 5, may not exceed 20%. Therefore, this test cannot be applied to the 10 family types in total.

Table 13 shows the comparison of the distribution of single-parent families based on the arrangement of drop off and pick up activities. The P-value derived from these categories (χ^2= 134.2220 and 2 degrees of freedom) is very small (< 0.05), indicating that the observed distribution in the sample does differ significantly from the SEE distribution. The number of single parents that drop off and pick up their children is underestimated, while the number of single parents that neither bring nor get their children is overrepresented in the FEATHERS output.

Table 13 Comparison of the Distribution of Single-parent Family Types

	Observed % in FEATHERS	Expected % based on SEE 2001	Computed differences for Pearson	
1. Adult drops off and picks up	1.46	48.98	46.0964	
2. Adult drops off or picks up	7.97	15.33	3.5277	
3. Neither drops off, nor picks up	90.64	35.69	84.5979	
			134.2220	χ^2
			7.1459E-30	p

Table 14 shows the comparison of the distribution dual-earner families based on the arrangement of drop off and pick up activities. The P-value derived from these categories (χ^2= 111.2014 and 3 degrees of freedom) is very small again (< 0.05), indicating that the observed distribution in the sample does differ significantly from the SEE distribution. The number of families in which 1 parent drops off and picks up the children from school is underestimated, as well as the number of families in which one adult drops the children off at school while the other parent picks the children up from school. In turn, the two other categories show an overestimation, especially category 7. Again, FEATHERS predicts too little bring/get trips for adults in young families.

Table 14 Comparison of the Distribution of Dual-earner Family Types

	Observed % in FEATHERS	Expected % based on SEE 2001	Computed differences for Pearson	
4. 1 adult drops off and picks up	7.14	48.12	34.8914	
5. 1 drops off, the other picks up	0.79	8.32	6.8152	
6. One adult drops off or picks up	21.85	16.29	1.9001	
7. 2 neither drop off, nor pick up	70.22	27.28	67.5946	
			111.2014	χ^2
			6.0503E-24	p

Finally, Table 15 shows the comparison of the distribution of family types for single-earner families. The P-value derived from these general categories (χ^2= 4.5902 and 2 degrees of freedom) is 0.1008 (> 0.05), indicating that the observed distribution in the sample does not differ significantly from the SEE distribution. However, in this case, the SEE data do not contain any information on drop off/pick up activities for the unemployed parent. Therefore we can only conclude that the FEATHERS prediction of bring/get activities in single earner families is good as far as the employed parent is concerned.

Table 15 Comparison of the Distribution of Single-earner Family Types

	Observed % in FEATHERS	Expected % based on SEE 2001	Computed differences for Pearson	
8. Employed drops off and picks up	2.95	8.89	3.9677	
9. Employed drops off or picks up	10.94	11.74	0.0545	
10. Neither drops off, nor picks up	86.09	79.37	0.5680	
			4.5902	χ^2
			0.1008	p

4.5.2 Discussion of the Family Segmentation Test Results

Several sources for the observed differences in the comparison of the family segmentation based on SEE 2001 data and FEATHERS output can be indicated. The first set of explanations relates to data limitations, while the second series of likely causes concerns the inner workings of the travel demand model. These issues are discussed in the next few paragraphs.

4.5.2.1 Data Limitations

The different nature of the SEE 2001 dataset and the FEATHERS output is likely to cause some bias in the segmentation of working young families according to the division of drop off and pick up responsibilities amongst present adults.

There are 3 important limitations:

(1) Differences in the definition of a 'young household': as mentioned before, 'young households' in the SEE 2001 data are defined as 'households containing at least one child aged 6-12', while in the output of FEATHERS, 'young households' are defined as 'households with the youngest child aged 6-12'. Therefore, families with a 6-12 year old including additional younger children are not present in the FEATHERS output. Since older children travel independently somewhat more often, this difference may result in some fewer bring/get activities in the FEATHERS output compared to the drop off/pick up duties in the SEE 2001 data.

(2) Differences in the definition of 'bring/get' and 'drop off/pick up' activities: in the SEE 2001 data, drop off/pick up activities are limited to school travel, since only the usual work and school travel routines are interrogated. In the FEATHERS output, bring/get activities represent a wider category, including delivering goods, or chauffeuring people to and from all sorts of activities, similar to the interpretation of bring/get activities in OVG 3, i.e. travel motive nr. 8 in the travel diary (Ministerie van de Vlaamse Gemeenschap, 2009). Since drop off/pick up travel represents a share of all bring/get activities, the FEATHERS output should contain more bring/get activities compared tot the SEE 2001 data.

Unfortunately, OVG 3 data do not determine the destination nor the travel party in bring/get activities in sufficient detail to check the relative size of the share of pick up/drop off travel in this travel category; destinations are mere addresses, prone to errors of respondents, while the travel party is just the number of people travelling along, irrespective of their relationship to the respondent. Moreover, Flemish time use data can't shed a light on this issue either since the definition of the relevant travel motive in this research differs completely (i.e. '1030: travel for the children'), the travel party is not specified, and the trip destination is not known for travel to other places but home or work (Glorieux et al., 2000; Koelet & Glorieux, 2007). Therefore, additional research is needed to determine the share of school chauffeuring travel in bring/get activities in Flanders.

(3) Different observations represented by the data: while the SEE data show an individual's 'normal workday routine' as indicated by respondents, the FEATHERS output represents the actual behaviour on one (typical) Monday. Descriptions of the normal workday routine might be based on travel patterns occurring on the majority of working days, yet not on any given day. Therefore the SEE 2001 might represent an overestimation of the actual behaviour on one particular day. Indeed, intra- and interday variability of travel patterns in Flanders has been shown in previous research, e.g. Cools (2009).

Nevertheless, the large shares of each 'neither drop off, nor pick up' category in each general family class of working young households (see family type 3, 7 and 10 in Table 11) in the FEATHERS output compared to the SEE 2001 data raise some concern with respect to the number of bring/get activities that is generated in FEATHERS for this specific category of working young households to date. Although the current version of FEATHERS adequately predicts the general number of bring/get activities for the whole Flemish population (see Figure 37), de distribution of this specific activity category across population groups needs further attention.

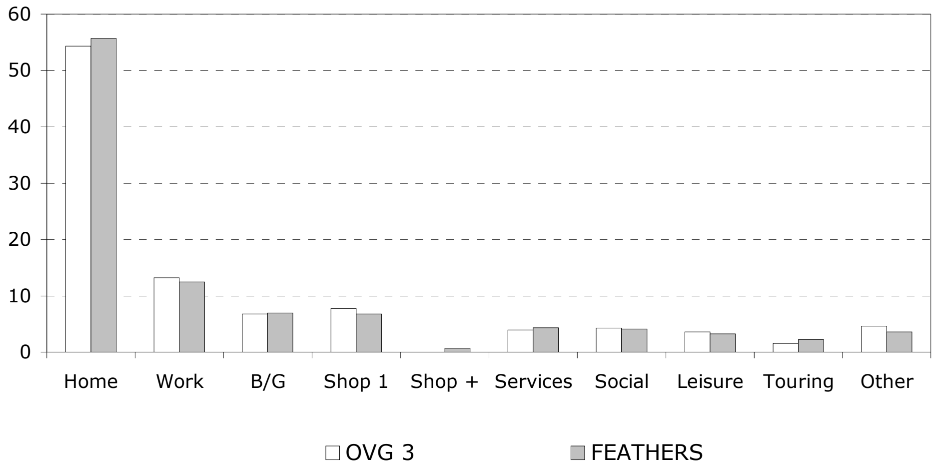


Figure 37 Comparison of Observed Activity Percentages in OVG 3 and Predicted Activity Percentages by FEATHERS (Based on ALBATROSS)

Indeed, not only the SEE 2001 data reveal that the presence of young children in a household and their school travel determine the amount of bring/get activities to a large extent; other surveys observing travel patterns of children in Flanders have shown their travel dependency as well. For instance, in 2008 Creemers (2008) observed that on average 71,97% of primary school children in Flanders does not travel to school independently, while Peetermans and Zwerts (2006) observed that even in the oldest category of primary school children (aged 10-12), 39,66% of children is accompanied to school by one of their parents. This share drops to 15% at the turn of primary school to secondary school (Peetermans & Zwerts, 2006).

In addition to this, observed travel mode choices for children's school travel lead to similar conclusions: 50,00% (Creemers, 2008) to 53,99% (Van Ourti & Mortelmans, 2004) of primary school children travel to school by car, chauffeured by an adult, while an additional 33,30% (Van Ourti & Mortelmans, 2004) to 43,00% (Creemers, 2008) of primary school children walks or bikes to school. In the latter category, some primary school children might do this independently, but the majority will be accompanied. Clearly, the age category of children and their school travel is a discriminating factor, determining the presence of drop off/pick up activities in a household.

4.5.2.2 FEATHERS Limitations

The current insensitivity of the model with respect to the presence of children in households and the underestimation of bring/get activities can be explained by two factors: limitations of the OVG 3 data that are used to train the ALBATROSS trees of the scheduling engine of the AB model of travel demand, and subsequent limitations of the scheduler.

First of all, travel diary data in OVG 3 are based on observations of a sample of the population. This sample contains 8,800 persons older than 6 in Flanders and hence 8,800 households, since only 1 person per household is asked to keep a travel diary in OVG 3 (Janssens et al., 2009). The current working young household segmentation and subsequent sequence pattern models apply to only 11% of this sample, yielding 968 relevant observations in OVG 3 at most. Since

OVG 3 is a 1 day diary survey, only 4/7 of these observations will apply to 'a normal work or school day', leaving only about 553 day schedules to learn the travel patterns for the 10 family types. Bearing the rough guideline in mind that each category should contain at least 30 observations to allow statistical inference, the smallest share in the segments cannot be smaller than 5.42%. Based on the SEE shares shown in Table 11, it can be seen that there is insufficient information in OVG 3 to determine at least half of the family types.

Moreover, in OVG 3, knowledge about the household composition is limited to the number of persons living at the same address as the respondent and the age of the respondent. Besides this, only 1 respondent is questioned per household, making household interactions impossible to determine in these data. Since the decision trees of the scheduler in FEATHERS (based on ALBATROSS) are trained on OVG 3 data, items that are not shown in the basic data can never determine relevant classes in the decision trees. Hence, the decision to include a bring/get activity in the prediction by the scheduling model will not depend on the presence of young children in the household nor on the work status of the partner, although these may be determining factors in reality. It's simply impossible to establish this based on OVG 3 data.

In FEATHERS (based on ALBATROSS), 5 decision trees (DT) are used to schedule bring/get activities. The scheduling process of bring/get activities is illustrated in the flow chart in Figure 38. Only one external constraint is present in this part of the scheduling procedure: the number of bring/get activities per person per day is limited to 4. This limitation is based on domain knowledge of the expert developer.

Whether or not to include a bring/get activity in the preliminary schedule, is determined based on the first decision tree (DT 1: 'Include B/G?'). Table 16 shows all possible condition variables in the ALBATROSS system for the inclusion of bring/get activities, and the table indicates the condition variables in the dataset that have lead to a meaningful split in the observations when training the decision trees, in the Netherlands (based on Dutch travel survey data) and in Flanders (based on OVG 3 data).

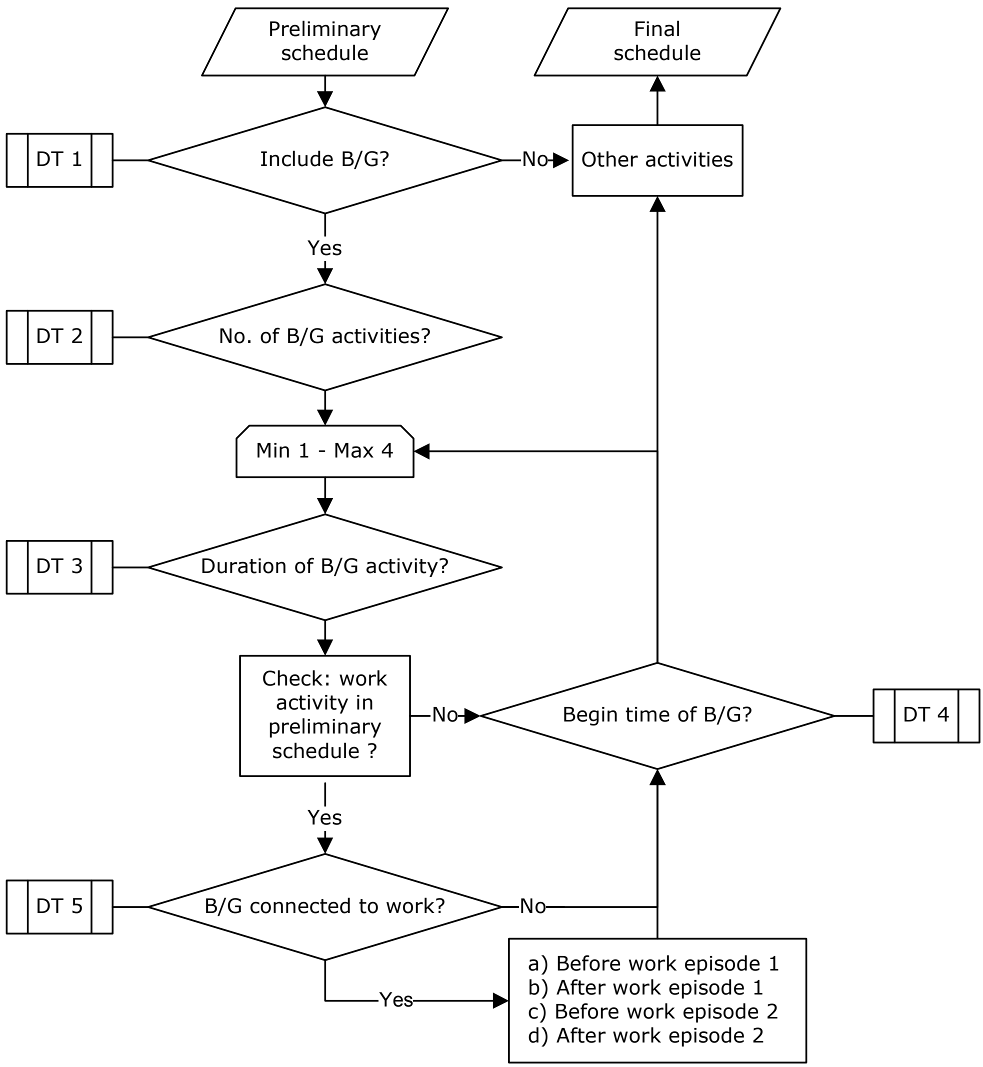


Figure 38 Flow Chart of Bring/Get Scheduling Procedures in FEATHERS (ALBATROSS)

Based on Table 16 it is clear that the original ALBATROSS decision tree structure is meant to include (amongst others) child ages in the variable 'Child' (in 4 categories to be specific, namely: no children (0); < 6 years old (1); 6-12 years old (2); > 12 years old (3)), household composition characteristics in the variable 'Comp' (in 5 categories, namely: single without children (0); single with children (1); single with parents (2); partner without children (3); partner with children (4)), and the work status of the partner 'Pwstat' (in 2 categories: no work (0); work (2)). Moreover, the Dutch decision tree actually splits on these variables. In the Flemish version of ALBATROSS (based on OVG 3) the variables 'Child', 'Comp' and 'Pwstat' are unavailable. Therefore, a constant value is used for these condition variables when training this tree. Hence, when using this tree for predictions, decision outcomes are insensitive to these characteristics.

Table 16 Comparison of Condition Variables for the Inclusion of Bring/Get Activities in the Dutch (NL) and Flemish (FL) Version of ALBATROSS

VARIABLE	MEANING	NL	FL
Urb	Urban density	X	-
Comp	Household composition	X	0
Child	Children category	X	0
Day	Day of the week	X	X
pAge	Age category	X	X
SEC	Household income	X	X
Ncar	No cars in the household	X	X
Gend	Gender	X	X
Driver	Driving licence	X	X
wstat	Work status	X	X
Pwstat	Work status of partner	X	0
Xdag	No employees daily good sector within 3.1 km from home	-	-
Xn-dag	No employees non-daily good sector within 4.4 km from home	-	X
Xarb	No employees total within 4.4 km from home	-	-
Xpop	No households within 3.1 km from home	X	X
Ddag	Distance to nearest 160 employees daily good sector	X	-
Dn-dag	Distance to nearest 260 employees non-daily good sector	X	-
Darb	Distance to nearest 4500 employees total	-	-
Dpop	Distance to nearest 5200 households	-	-
Act	Activity type under consideration	X	X
Brget	Activity type under consideration is bring/get activity	X	-
yWo	Schedule includes work activity	-	-
Dur	Total duration (min.) work activity	X	X
yNep	More than one work episode	-	X
Ratio	Duration ratio (%) between first and second work episode	-	-
Inter	Duration (min.) between first and second work episode	-	-
BT	Start time work activity	-	-
T1, T2, … T8	Time available in the 1st, 2nd,… 8th episode of the day	X	X

Note: Variables are meaningful (X), unimportant (-) or unavailable (0)

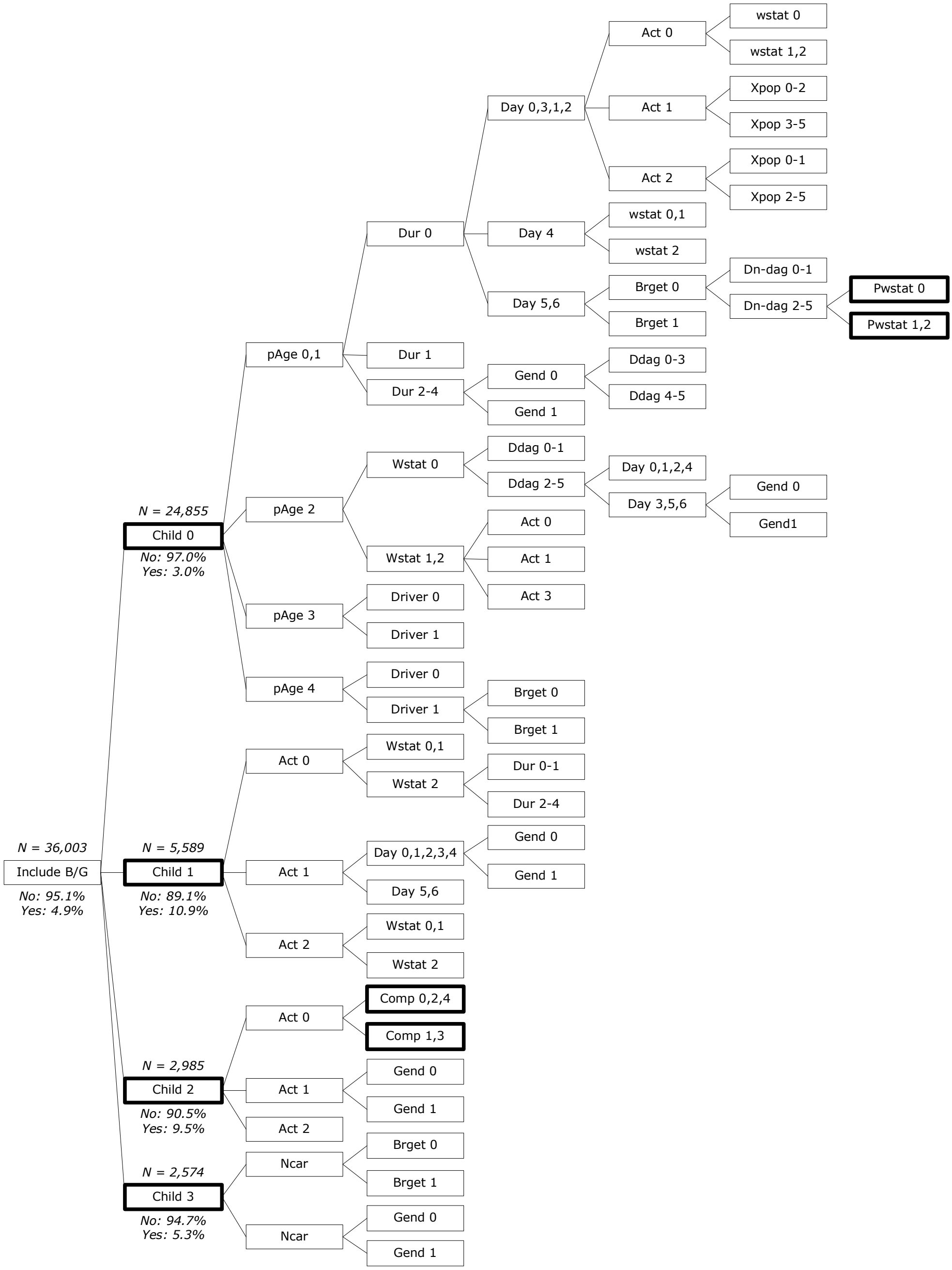


Figure 39 Decision Tree of the 'Include B/G' Decision in ALBATROSS (Dutch Version)

Further analysis of the Dutch decision tree shows that the very first split in the original ALBATROSS system is based on the 'Child' condition variable (see Figure 39). This early split indicates the explanatory power of the 'Child' attribute in the observations of bring/get activities in the Dutch travel survey data. The number of bring/get activities is higher in 'Child 1' and 'Child 2' compared to the overall distribution of bring/get activities in the population (shown in the fist node in Figure 39). The variable 'Comp' can be found at the third level in the tree, and the variable 'Pwstat' is nested deepest in the decision tree.

For statistical models that are used to predict future outcomes based on other related information, the coefficient of determination (R^2) is generally used to express the proportion of variability in a dataset that is accounted for by the statistical model. Table 17 shows that the R^2 is 0.0194, indicating that 1,94% of the variance in the model is explained by the split of the tree on 'Child' compared to a no model situation. Against the overall share of 4,9% bring/get activities to include, this is a considerable result.

Table 17 R^2 and Percentage Explained by Split on 'Child' Compared to No Model

%No	in Node	No	Yes		Prob.	Formula
ROOT						
0.951	36,003	34,231	1,772	S_tot	1684.785	=Yes*(1-%No)²+No(0-%No)²
NODE 1						
0.970	24,855	24,109	746		723.610	=Yes*(1-%No)²+No(0-%No)²
0.891	5,589	4,980	609		542.641	=Yes*(1-%No)²+No(0-%No)²
0.905	2,985	2,701	284		256.980	=Yes*(1-%No)²+No(0-%No)²
0.947	2,574	2,438	136		128.814	=Yes*(1-%No)²+No(0-%No)²
ALL				S_err	1652.044	=SUM(Prob. NODE 1)
				R²	0.019433	=1-S_tot/S_err

The variable 'Child' is not only important in the decision whether or not to include a bring/get activity, but this condition variable also determines the number of bring/get episodes in the schedule to a large extent. Figure 40 shows that the decision tree 'Number B/G Activities' determines the number of episodes for the bring/get activity ('Act 1') firstly based on the presence of children younger than 12 in the household. Moreover, it shows that the number of bring/get episodes in schedules of adults without children or with children older than 12 ('Child 0,1') is lower, and there are less double trips compared to the shares of the number of bring/get episodes shown in the node 'Child 1,2'.

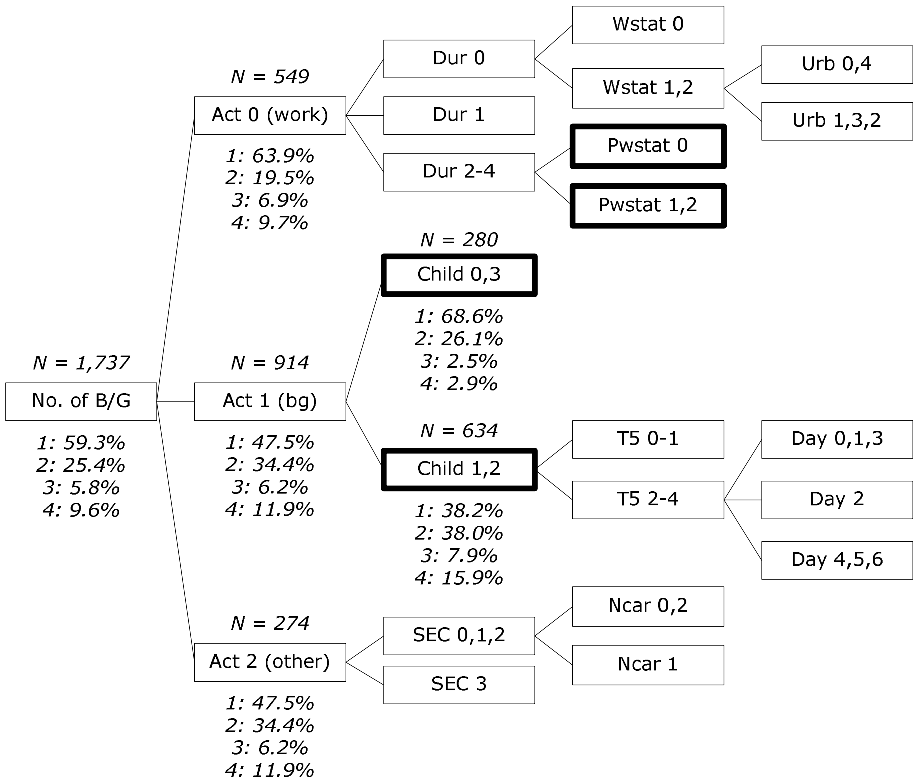


Figure 40 Decision Tree of the 'Number B/G Activities' Decision in ALBATROSS (Dutch version)

Based on this evidence, it can be concluded that the household composition, the presence of children and the work status of the household members are important in the prediction of bring/get activities. Therefore, a model to account for the impact of these variables should be estimated based on available data or additional research. These results should be integrated in the FEATHERS system to improve its forecasting accuracy.

Indeed, this limitation of the current version of FEATHERS has some consequences for the use of this model to assess the impact of policy measures. Whereas the model might be useful to assess general policies such as the extension of shop hours or reduced work hours that are likely to affect the major share of the population, prudence is called for the assessment of policy measures affecting specific target groups, such as the relaxation of school hours up to regular working hours proposed by the Flemish political party GROEN (Woussen, 2008) or policy measures that will interfere with household interactions, such as increased taxes on second family cars. Moreover, although primary effects of general policies such as compressed work hours are clear on an individual level (Sundo & Fujii, 2005), likely secondary effects at the household level cannot be assessed yet.

4.5.3 Family Sequence Patterns Test

Subsequently, the FEATHERS output can be analyzed further to check whether the observations in each family type match the sequence pattern models developed based on the SEE data. There are activity and travel schedules of 25,565 adults living in working young households in the predicted FEATHERS dataset. Among these, only 2,271 adults (this is 8.88%) conduct both work and bring/get activities on the predicted Monday.

According to the sequence models, these adults carry the responsibility to drop the children off at school or to pick them up. Therefore, these parents' schedules should be geared to the children's activity and travel needs. This assumption is tested in the FEATHERS output by comparing the time points in the travel pattern of the responsible adult to the time ranges indicated for this responsible adult in the SEE-based family sequence patterns. For each adult, the time points in the according family type model are selected in the test.

Four time points available in the FEATHERS dataset are tested. They are indicated in Table 18 below. Firstly, each of these time points separately is compared to the time ranges defined in the according family sequence pattern.

Table 18 Comparison of Separate Time Points in the FEATHERS Output with SEE 2001 Based Sequence Model Time Ranges

	YES, a match		NO, no match	
Time Point	**Number**	**Percent**	**Number**	**Percent**
1) Adult leaves home in the morning	2,108	92.82%	163	7.18%
2) Adult arrives at work	2,233	98.33%	38	1.67%
3) Adult leaves work	2,064	90.89%	207	9.11%
4) Adult arrives home in the evening	1,447	63.72%	824	36.28%

For three out of four time points more than 90% of the predicted time points lie within the time ranges defined in the sequence patterns based on the SEE 2001 population data. Only the fourth predicted time point performs somewhat worse: up to 63.72% of the predictions conform to the time ranges in the models. The most likely account for these small and larger differences may be the wider definition of bring/get activities in FEATHERS. Especially in the evening when there is more time left after school and work duties, other bring/get activities might occur besides picking the children up from school. Therefore, the sequence patterns will not match the restricted definition of drop off/pick up school activities in the SEE 2001 data.

Finally, the series of 4 time points of each predicted adult are compared to the time ranges of the responsible adult in the according family sequence pattern. Table 19 shows that 55.79% of all predicted schedules match the SEE 2001 sequence patterns on all 4 time points, even with different definitions of chauffeuring activities.

Table 19 Comparison of Time Point Series in the FEATHERS Output with SEE 2001 Based Sequence Model Time Ranges

	YES, a match		NO, no match	
Time Point	**Number**	**Percent**	**Number**	**Percent**
Series of 4 time points	1,267	55.79%	1,004	44.21%

4.5.4 Conclusion Benchmarking FEATHERS

In conclusion, the current analysis shows that there is room for improvement of the FEATHERS model both with respect to the travel patterns of young households (e.g. the number of bring/get activities in this particular population segment) and with respect to the household interactions (e.g. the division of bring/get responsibilities amongst adult household members). Although the current sequence patterns are limited to school related drop off/pick up activities, a major part of the sequence models coincides with current predictions. Therefore, a similar implementation of these patterns as skeletons or default settings for further scheduling in the scheduler of the FEATHERS model might yield a valuable specification of the model, improving its behavioural realism.

4.6 Discussion

In this chapter, family skeletons representing the collective schedule of young households and their standard organization of daily work, care and school commitments and related travel demand are developed. Different viable family sequence pattern models are derived for different family types. Consequently, the skeletons represent a typical weekday activity-travel pattern of a representative child, together with the constrained parents' patterns due to the presence of at least one 6-12 year old in the family.

Some issues in these models should be examined further, such as multiple children, other activities, variability in travel patterns and heterogeneity in routine decision making.

First of all, the patterns could be extended to accommodate all children in households with *multiple children*, by adding more child sequence(s) to the pattern and constraining the responsible parent's sequence accordingly. Siblings in the same age group are assumed to have similar activity-travel patterns to the representative child. In any case, they will not introduce additional restrictions to the parents' activity-travel patterns because the representative child was chosen as the most dependent child. The additional effect of older siblings on the adults' patterns due to school travel is likely to be moderate, since teenagers are allowed to travel alone more often, while children younger than 6 probably add some more constraints. Unfortunately, to date, no data are available to test the latter assumption.

A second point of attention is the introduction of *additional variables and activity categories* to the skeletons. Indeed, the flexible regions in the current patterns likely contain additional daily routines such as family meals and bedtime habits, yielding an extra frame of reference in daily activity-travel scheduling of all household members. Other data sources, such as detailed activity diary data from time use research, are required to reveal these patterns, since such variables are not available in current population data.

Thirdly, these sequence models represent the (most) regular workday routine. However, since household organization is a dynamic process per se and travel patterns in general vary systematically across weekdays (Cools, 2009), some sort of intra-day and inter-day *variability* is likely to occur in weekly travel patterns of households. Again, it is impossible to shed a light on such issues based on the travel data available in the current population dataset. Ideally, activity and travel diary data of at least one week should be recorded to reveal such distinct weekly rhythms within one household.

In addition to this, such data of week patterns could be useful determine the impact of a related issue, notably the likely occurrence of *heterogeneity* in routine decision making. Indeed, differences may exist between families in the same family type category with respect to the stability and vigour of the default, routine pattern. Some families might keep their routine very strict, while other families might show regular deviations from the basic pattern in order to resolve scheduling conflicts with other activities and commitments. Although the present flexibilities in the family sequence model are able to account for some variation as far as the timing of activities is concerned, the occurrence of more fundamental deviations from the skeleton needs further attention, as well as its accurate representation in an AB model of travel demand.

Because the family sequence patterns are based on Flemish population data, they can be used to benchmark the outcome of the newly developed AB model of travel demand (FEATHERS). To this end, the shares of predefined family classes are compared in both datasets. In this exercise, the underestimation of bring/get activities for young families is revealed, and limitations of the current FEATHERS scheduling engine are shown. However, the predictions of critical bring/get time points in the adults' schedules containing such an activity, match with the according parameters in the family sequence patterns to a large extent. Further research is needed to determine the share of repetitive, school related drop off/pick up activities in the wider activity category of bring/get activities.

Furthermore, the family classification and the exploration of their socio-economic characteristics indicates likely correlations of family types and variables such as sex, employment status, car ownership and travel mode choice to school. Further statistical examination may substantiate a model that is able to predict the family type of young working households (and hence the routine daily activity-travel organization of all household members) based on given socio-economic information. Such a model could constitute a *household organizer* module in a modular AB modelling platform such as FEATHERS to improve the representation of household interactions.

Although the incorporation of a *household organizer* module representing the mental repertoire of intertwined activity travel routines of households will add to the complexitiy of the AB model and requires more detailed information, it is believed that the assessment of the effects of travel demand policies and socio-demographic evolutions will benefit from this extension. On a general level, modelling outcomes could gain credibility, since the inner workings of the model reflect actual, empirically grounded behavioural mechanisms. For the FEATHERS model in specific, including family patterns will enchance the ability of the model to assess policy measures targeting young families, such as extended school hours. Moreover, such a model extension could enable the detection of secondary effects of general policy measures that affect individual patterns due to their repercussions on the household level, for instance the secondary effects of compressed work hours.

Additionally, in future developments of AB models of travel demand, sequence patterns can be used as skeletons within the scheduling engine, representing the implicit frame of reference of decision makers in the scheduling process. For this purpose, an extension of the sequence patterns to sequence profiles is recommended. Despite the accurate representation of a sequence pattern, still part of the information is lost, i.e. the probability that a certain activity-travel episode can occur at a certain position. In bioinformatics, profiles are position-specific scoring methods to improve the modelling of large regions corresponding to conserved as well as divergent sites (Liu, 2007). This technique can be applied to the family sequence models. In such an application, a Position Specific Scoring Matrix (PSSM) describes the probability that each activity-travel episode occurs at each position in the sequence based on observed data, and thus quantitatively characterizes a pattern. Since the flexibilities in the current sequence patterns are rather large, adding such information in profiles can definitely improve the performance of the travel demand model.

Traditional activity-travel analysis is generally restricted to adults' activity participation. By taking young children's activity and travel needs into account, as well as their closely knitted parents' work-care balance, all in all, this research adopts a novel, more universal approach. In addition to this, it is explained that travel demand modelling efforts too could benefit from such an approach and that the application of the developed concept of family skeletons as family sequence patterns and profiles shows great promise.

5 FINAL CONCLUSIONS

In this chapter, some major conclusions are summarized in the first section and the room for improvement in consecutive steps in this PhD research process is addressed next. Furthermore, an outlook on further research needs is provided, and a final discussion section sheds a critical eye on travel demand modelling in general.

5.1 Conclusions

This manuscript reports on PhD research to establish a better representation of behavioural mechanisms underlying activity-travel behaviour in an AB model of travel demand in order to improve its forecasting ability. The focus of this investigation is the 'mental map' as a representation of both an individual's decision making base and spatial understanding of daily travel. To this end, three distinct research steps are outlined: (1) the mental map concept is explored in a qualitative study to start with to identify behavioural principles in daily travel, yielding a descriptive model of activity-activity travel scheduling and execution, (2) in order to achieve formal quantification, an exemplary mental map based on findings of this in-depth exploration is objectified and transferred to a computational BIN model, representing a first model concept for the individual work-related mental map of a mother of three young children, and (3) further generalization of this microscopic model is achieved in the definition of a second model concept for routine weekday activity-travel patterns of households with young children in sequences. These final sequence patterns not only define a framework for the integration of the mental map as a skeleton in an AB model of travel demand, but they are used to benchmark the outcome of an AB model as well, notably FEATHERS, a CPM recently developed for the region of Flanders. This way, the room for improvement in the representation of behavioural principles in current modelling efforts is checked.

From a methodological perspective, the most important merit in this overall process is the integration of primarily qualitative findings in a quantitative modelling framework. Content-wise, the next few paragraphs highlight the main conclusions that result from these three distinct research steps in a bird's-eye view.

5.1.1 In-Depth Exploration

Without any doubt, the most striking observation in the in-depth interviews is the fact that, unlike the assumptions in current AB models of travel demand, a number of daily activities and trips are not planned or scheduled consciously or carefully on a day-to-day basis. Instead, interwoven choice facets of individual travel behaviour are set in routines and scripts that can be triggered automatically given certain contexts and conditions. Hence in daily life, considered choice options, if any, are few, and decision making processes are ultra-short.

Furthermore, these findings imply the existence of decision making mechanisms at another level, different from daily scheduling. Indeed, daily emerging choice outcomes are anchored in and restricted by long-term commitments such as the job, the house, the family, the car, the social club, etc., and established, successful routines are not questioned in everyday conduct. These findings call for a different conceptualization of daily routines, mandatory activities and various engagements in an AB scheduler.

As for spatial cognitive factors, the activity space is a mere functional décor in this settled daily life, a well-known yet hardly noticed background of opportunities. Accordingly, the spatial mental map and the decision making mental map of daily routines can be defined as one skeleton, i.e. a mental repertoire of fixed activity and travel scripts in which spatio-temporal anchor points chalk out the blueprint of individual activity and travel schedules, thus determining the boundaries for the planning and execution of other, discretionary activities on a day-to-day basis.

5.1.2 Transition: Modelling a Single Case

Scrutinizing an exemplary work-related mental repertoire of a working mother of three children in a verbal description, the importance of situational social role norms stemming from long-term commitments in activity and travel choices is shown. Hence, instant, subjective interpretations of appropriate role behaviour given well-defined contexts can constitute the valuation mechanism in a computational decision model that represents scripts of interrelated activity, location and travel mode choices in typical situations, be it normal or exceptional routines. An individual Bayesian decision network example shows that predictions of actual behaviour can be established by mapping the mental repertoire accordingly. This way, the BIN is able to bridge the gap between qualitative description and quantitative computation.

Moreover, BIN offer a better representation of actual decision making mechanisms compared to the current decision tree structures used in a CPM model of travel demand, since BIN enable to model interrelated decisions simultaneously. Besides other technical advantages of BIN, such as its compactness, intelligibleness, computational efficiency and ability to account for uncertainty, three important merits of the application of BIN structures are shown from a content point of view: (1) the decision context is taken into account explicitly, detailing a wide range of behavioural scenarios, (2) besides normal routines, exceptional behaviour in exceptional situations is mapped, yielding a clear representation of current behavioural change, and (3) the pronounced valuation perspective indicates why choices are made, hence the behavioural mechanism underlying choice outcomes.

However, a major drawback for the actual implementation of this BIN concept in an AB model of travel demand is the fact that such individual, idiosyncratic mental maps cannot be merged into a single network structure to represent the mental map of an entire population in one generalized concept model.

5.1.3 Generalization and Modelling Framework

A second model concept is developed in the third research step. While the individual model of the mental repertoire unifies routine as well as exceptional scripts in the workday organization of a mother of 3 young children, a more aggregate modelling approach of regular behaviour generally acknowledged in AB models of travel demand is sought by focussing on normal routines in households with young children. Therefore, the Flemish population of households containing at least one child aged 6-12 is segmented according to their interrelated school and work travel routine pattern using enriched census data. This procedure reveals an unequal, gender-specific distribution of care responsibilities amongst adult household members in the majority of Flemish households.

Typical school travel routines of the representative school child are conceived concisely in a sequence pattern model. In the same vein, adults are categorized according to their work travel and chauffeuring duties, and a sequence pattern representing adults' workday routines is derived from the population data. Finally, when merging these individual sequence patterns of household members based on the segmentation of Flemish households, 10 family sequence patterns are defined, detailing family skeletons to replace the blank canvas presumed in current scheduling procedures of the AB model of travel demand. At the same time, these family skeletons reveal the outcome of decision strategies at the household level, preceding the day-to-day completion of individuals' schedules. Hence, the addition of a household organizer module in an AB model of travel demand is suggested to generate the family skeletons.

Finally, using the sequence family patterns to benchmark the outcomes of the current version of FEATHERS reveals some important limitations in terms of the sensitivity of the model for Flanders to household composition and its representation of household interactions. The major cause for this defect is the lack of relevant data to train the model in this respect, yielding an underestimation of bring/get activities in individual schedules of young parents. However, to better the representation of behavioural decision mechanisms on the household level, data addition alone will not suffice. Such an improvement calls for the integration of a household organizer module.

5.2 Room for Improvement

Admittedly, each step in this PhD research process is open to improvement. In the first, qualitative research phase, the research findings might be more formally supported by procedures such as member validation (Bygstad & Munkvold, 2007), multiple coding and intercoder reliability checks (Lombard et al., 2002). The former method suggests that confirmation of results with participants can reduce likely bias caused by the subjective interpretation of the researcher, although opponents argue that individuals will not and do not necessarily recognize themselves in synthesized results, abstracted from individual respondents (Morse et al., 2002). Moreover, practical issues such as language barriers (be it actual different languages or differences between everyday speech and jargon) may hinder the implementation of member validation. For instance in this PhD research, the interviews are conducted in Dutch, but the analysis and output are English. In addition to this, there is a considerable time lag between the data gathering and the presentation of the findings. Because the interview topic of daily travel is rather trivial and context-dependent, respondents might not be able to recall the mindset of the initial interviews. Likewise, practical drawbacks such as limited resources and manpower may jeopardize the measurement of interrater agreement, since it requires that at least two independent coders interpret important pieces of the raw data to start with.

In the second research phase, the case study following the qualitative exploration can be extended by gathering more data and modelling different examples to counter suspicions of data and model retrofit that might arise based on this single case. However, solid evidence of a similar modelling approach will be demonstrated in the near future, since the computer-based CNET protocol was applied successfully only recently, and well-performing individual BIN's could be derived from a structured questionnaire (Kusumastuti et al., 2010b). In addition, the initial choice of the BIN modelling technique seems rather arbitrary and other modelling techniques could be considered, such as FCM. This is a point of attention in current research efforts (Hannes et al., 2010).

Finally, in the last research phase, it can be concluded that the developed model is determined by the available SEE data to some extent. Nevertheless, the initial hypothetical family skeletons have evolved from the individual case model and wider Flemish time use and travel behaviour findings before selecting this dataset to test the theoretical assumptions. The initial patterns even include sleep and meal episodes. Indeed, the SEE data limit the sequence patterns to morning and afternoon anchor points in school and work travel of families with children aged 6-12 on a typical workday. These available data undeniably cover important aspects of daily travel, but the existence of additional anchor points in the spatio-temporal organization of households is conceivable, as is the likely occurrence of inter and intra-day variability in activity and travel routines and the incidence of week and season patterns.

Ideally, a tailor-made survey, geared to the research questions and hypothesis at stake, could be administered to obtain all necessary activity and travel data. Current Flemish time use and travel survey diary data come close, but their sample size does not suffice to substantiate such a niche model of households with young children, covering (only) 17.55% of all households in Flanders and 29.11% of all Flemish inhabitants. However, thanks to the availability of enriched census data, a high level of detail is obtained in the developed family sequence patterns.

5.3 Future Research

In line with Jenkins' statement (2004, p. 12) that: "*science is an ongoing process in which the most important sign of progress is often that results of an experiment or observational study lead to a new set of questions*", research needs arising from the efforts and findings reported in this PhD thesis are addressed below along two major outlines: AB modelling and travel decision making.

5.3.1 AB Modelling

AB models of travel demand are deemed a promising tool to rationalize transportation policy making because of their power to estimate impacts of various TDM measures. Whether this assertion is true and applicable to Flemish transportation policy, is yet to be shown, since to date, only few operational AB models of travel demand are used worldwide (Shiftan & Ben-Akiva, 2008). Additionally, for the sake of the current research, the model for Flanders is still premature.

Accordingly, the proposed behavioural advancement based on routine skeletons or a household organizer module still needs to be implemented, tested and validated, and model results have to be compared to earlier approaches to show likely improvements. Moreover, the current family skeletons apply to only a part of the population, and analogue skeletons for other population groups are yet to be developed.

As far as the representation of decision making in AB models of travel demand is concerned, the current mainstream RUM approach is found to lack sense of reality on the one hand while the empirical foundations of CPMs can be questioned on the other hand. Nevertheless, a CPM is favourable to represent behavioural decision making mechanisms since it is inherently process oriented and allows for a flexible integration of various decision making paradigms, especially when it is integrated in an object-oriented platform such as FEATHERS. In this respect, new, advanced modelling techniques such as reinforcement learning might offer opportunities to incorporate different decision making perspectives in AB models, e.g. Vanhulsel (2010).

5.3.2 Travel Decisions

Still, modelling techniques per se cannot reveal nor explain the underlying behavioural mechanisms involved in human conduct. On the contrary, actual computational approaches should accommodate a 'general theory of action' that is yet to be developed in social sciences (Kroneberg, 2006) and to be tested for its applicability in different fields. Established theories of decision making strategies such as rational choice and rule-based choice could be incorporated as special cases in this general framework. Likewise, the occurrence of different decision making styles and mechanisms in travel decisions should be a topic for further research, since different decision making approaches might be discernible, depending on individual characteristics and situations.

Given our observation of context dependent behaviour, the recent general decision 'model of frame selection' based on the definition of the situation and variable rationality such as proposed by Kroneberg (2006), advancing ideas of Esser (1993), is appealing. 'Scripts' of action are a central concept in their frame-selection model, as well as in the findings and modelling approaches presented in this dissertation.

Regarding these behavioural scripts in activity and travel decisions, measures of strength and stability should be developed and impacting factors should be determined to enable estimations of likely behavioural changes due to travel demand management measures. In this respect, in-depth methods such as the CNET approach (Kusumastuti et al., 2010b) definitely have a role to play. Additionally, uncovering the origin and establishment of present scripted behaviour is required to understand the full cyclic process of script formation, application and adaptation.

Finally, decision making processes in long-term choices, such as housing, employment, family size, etc., and mid-term decisions, such as joining a club, taking a season ticket, and their interrelationships with daily travel should be analysed further, since long run commitments clearly determine short-term processes such as daily travel. As Verhoeven (2010) argues, activity-travel patterns should be analyzed along various time horizons to enable dynamic modelling of behavioural change, for instance by taking a life course perspective. To observe such long-term processes, panel data are required, e.g. Prillwitz et al. (2007). Yet mobility panel data are scarce, and even nonexistent in Flanders. Therefore, qualitative methods such as biographic interviews might offer a valuable alternative to explore long-term dynamics in depth and breath.

5.4 Musings on Models

Developing an ultra complex, detailed simulation and prediction model of human behaviour such as a disaggregated AB model of travel demand obviously implies making assumptions, categorisations, and generalisations. As an example, the coarse representation of human decision making in current AB models is denounced in this PhD thesis. However, it is unfair to stress the shortcomings of travel demand models without acknowledging their merits. Besides their weaknesses and strengths, opportunities arising from modelling practice and threats ensuing from their application in policy making can be identified.

5.4.1.1 Weaknesses

Putting an AB model of travel demand into operation is a complex task for an expert developer. Although crucial, the adequate representation of behavioural mechanisms is but one challenge to accomplish in this respect. Moreover, the issue of behavioural realism of travel demand models touches an ongoing debate about complexity versus parsimony in modelling approaches (Walker, 2006); the more complex the model, the more resources required to build it. Hence, the additional costs need to weight up against the added value of complexity or behavioural realism. As long as actual behavioural model applications still need to be implemented in modelling and policy making practice, such issues will remain unresolved. Moreover, there is an undeniable theoretical and technical advancement in travel demand analysis (Shiftan & Ben-Akiva, 2008) and current applied modelling practice can't seem to keep pace with this rapid scientific progress.

5.4.1.2 Strengths

Although yet to be demonstrated in Flanders, it is believed that well-crafted AB forecasting models can help policy makers to envision future scenarios, scrutinize a variety of evolutions and identify opportunities to steer the course of events. Models of travel demand help to further inform their choices, and enable rational, efficient and scientifically grounded policy making, in line with sustainability goals.

5.4.1.3 Opportunities

The very act of modelling complex human activity and travel behaviour at the level of individual agents holds clear opportunities from a scientific point of view, since these computational implementations require far-reaching formalizations and mathematical transformations of hard-to-measure psychological phenomena such as human decision making. This process alone can reveal weaknesses in former, fuzzy ideas and theories about certain phenomena, and areas of incomplete knowledge and room for improvement can be uncovered. This way, formal, computational modelling enhances the discrimination of limitations and boundaries of existing knowledge.

5.4.1.4 Threats

Since AB modelling of travel demand clearly is an experts' domain, policy makers might struggle to grasp the complex details of modelling procedures. Hence, they rely on modellers and experts to provide correct information about the model and the interpretation of the outcomes. In this respect, complete information about assumptions and simplifications is necessary to understand what can and can't be learned from current AB models and hence, to improve political decision making.

Moreover, a travel demand model is but one instrument in good transportation policy making. An instrument that requires a careful, informed and critical operator. Surely, modelling outcomes may provide valuable information, but modelling results alone can never replace a clear vision or ethical outlook, nor set the goals to guard our children's future.

Fine feathers make fine birds, they say… However, it takes more than FEATHERS to fly high in managing travel demand.

Appendix A

Guideline Interview 1

Introduction

Thank you for your cooperation!

- Presentation of the interviewer/researcher from Hasselt University:
  - Teacher in BA/MA transportation sciences
  - Researcher in IMOB, i.e. travel behaviour
- Research goal and plan:
  - How do people experience space, distances, the environment… and how does that influence their travel behaviour?
  - 1st phase = in-depth research of 20 people with a different travel pattern.
- Explain the current interview:
  1. General activity space questions
  2. Activity and travel plans for the coming week
  3. Explain the hand-held device and logging system, the activity-travel diary to complete and the written questionnaire
- Ask permission to record the conversation.
- Privacy is guaranteed: no names in future reports.
- Ask if there are any questions so far?

General activity space questions

The home location

- Where do you live? Could you describe this location? (e.g. situation, neighbourhood…)
- Since when do you live here?
- Why did you choose this location?
- If you would have to choose a place to live now, what would you look for?

Perception of distances: is your house far or close to…?

Work	☐ km, time
School	☐ km, time
Family / friends	☐ km, time
Shops (grocery shopping / other)	☐ km, time
Services (doctor, post office…)	☐ km, time
Leisure facilities / hobbies	☐ km, time

'Reach' from home considering various travel modes:

- What do you do regularly from home *by foot*? Now and then? Where? How far? (km, time).
- What do you do regularly from home *by bike*? Now and then? Where? How far? (km, time).
- What do you do regularly from home *by bus*? Now and then? Where? How far? (km, time). Where are bus stops located? How do you go to the bus stop? What is the bus frequency at that bus stop? Where can these busses take you?
- What do you do regularly from home *by train*? Now and then? Where? How far? (km, time). Where is the train station? How do you go to the train station? What is the train frequency at that train station? Where can these trains take you?
- What do you do regularly from home *by moped or motorbike*? Now and then? Where? How far? (km, time).
- What do you do regularly from home *by car*? Now and then? Where? What kind of distances do you drive? (km, time). What do you consider to be 'far'? (km, time).

Activity and travel plans for the coming week

You will be asked to specify your plans of the coming week day by day, what you will do and where you will go (as far as this is known today). About your planned travel in this agenda, a few additional questions will be asked. We'll start with day 1, tomorrow.

Day schedule

- What does your day look like? Please specify subsequent activities from the time you get up.

Travel within this activity calendar

- Where will you perform this activity? Address? Neighbourhood?
- Distance? Is that close? Far?
- Why there?
- Have you been there before?
    - If no: how did you get to know this place?
    - If yes: how often do you go there?
- Is this activity always performed at this place?
    - If no: on which occasions there and when elsewhere?
    - If yes: could you do this elsewhere?
- How do you travel to that place? Travel mode?
- How much time does it take?
- What is the cost?
- Why do you choose this travel mode to go there?
- Do you always choose this travel mode to go there?
    - If no: when this travel mode and when another?
    - If yes: could you do this another way?
- How accessible is this place by foot / bike / PT / car?
- Which route do you take? Could you explain the route?
- Why do you take that route?
- Do you always take that route?
    - If no: when do you take this route, and when do take another?
    - If yes: could you go another way?
- Ask for a sketch map of one of these trips: a commuting route to work or school. If no such trips are made, a grocery shopping route should be drawn.

'Day schedule' questions and 'travel within this activity calendar' questions are repeated for all days in the coming week.

General week schedule questions

- Is this a usual week, or is this week rather special?
- Is there any activity that you plan to do next week, that is not exactly planned yet and not discussed in the schedule before?
    - If no: stop
    - If yes: What? When most likely? Where most likely? How most likely?...
- Are there specific circumstances that might occur in the coming week and that might influence your travel behaviour, not yet discussed in the schedule before?
    - If no: stop
    - If yes: What? When most likely? Where most likely? How most likely?...

End of the interview part. Do you have any further questions or remarks?
Thank you for your cooperation!

Further explanation

- How to use the hand held device and GPS logging system
- How to complete the activity-travel diary
- How to complete the written questionnaire

Guideline Interview 2

Registration week in general

- How did it go?
- How was the GPS logging? Did you forget about this? Other problems?
- How was the completion of the activity-travel diary? Have you been accurate? Have you done things differently because of the diary you had to complete?
- How was the questionnaire? Did it take you long to complete it? Was it difficult to complete?

Comparison

The activity schedules from interview 1 are compared to the diary data, day by day, starting with the first day of the registration.

Day by day, in general

- The executed calendar looks / doesn't look like the planning?
- Is this 'change of plans' often the case?

Each activity out-home that was already discussed in interview 1

- When did you take the decision to execute it?
- Is it habitual, planned or impulse behaviour?
- Did you consider other places?
  - If yes: which ones?
  - If no: why not?
- Did you consider other travel modes?
  - If yes: which ones?
  - If no: why not?
- Did you consider other routes?
  - If yes: which ones?
  - If no: why not?

Each activity out-home that was not yet discussed in interview 1

- When did you take the decision to execute it?
- Is it habitual, planned or impulse behaviour?
- Where will you perform this activity? Address? Neighbourhood?
- Distance? Is that close? Far?
- Why there?
- Have you been there before?
  - If no: how did you get to know this place?
  - If yes: how often do you go there?
- Is this activity always performed at this place?
  - If no: on which occasions there and when elsewhere?
  - If yes: could you do this elsewhere?
- How do you travel to that place? Travel mode?
- How much time does it take?
- What is the cost?
- Why do you choose this travel mode to go there?
- Do you always choose this travel mode to go there?
  - If no: when this travel mode and when another?
  - If yes: could you do this another way?
- How accessible is this place by foot / bike / PT / car?
- Which route do you take? Could you explain the route?
- Why do you take that route?
- Do you always take that route?
  - If no: when do you take this route, and when do take another?
  - If yes: could you go another way?
- Ask for a sketch map of one of these trips: a commuting route to work or school. If no such trips are made, a grocery shopping route should be drawn.

‘Day by day’ questions, including questions about previously discussed and untouched activities are repeated for all days in the coming week.

In general

- Was this a ‘special’ week, or an average week? Was it busy or calm?

Spatial cognition

Some questions in the questionnaire consider your ability to orientate yourself in an environment. A few additional questions:

- If you have to go somewhere where you have never been before, how do you plan this?
- Do you know how to read a map?
- Do you get lost in an unknown environment? Rather easy or not at all? How do you solve this?
- When you have to go somewhere, do you usually arrive early, just in time or late?
- Questions about some specific locations < a list of 9 locations is generated for every respondent, in 3 categories depending on the distance to the respondent's house >
    - Have you been there?
        - If yes: how often?
        - If no: have you heard of this place?
    - Where is it? (In which direction, close to…?)
    - How far is this place from your home?

End of the interview part. Do you have any further questions or remarks?
Thank you for your cooperation!

- HAND OVER THE UNANNOUNCED GIFT VOUCHER OF 20 EURO -

Appendix B

SAS Procedures to Extract Family Skeletons

The procedures to extract family skeletons in the region of Flanders are implemented in SAS, and they involve the following steps:

1. Extract data for the region of Flanders from the entire Belgian population dataset. The entire population dataset 'clean014', in which each record represents a person, is searched for the sub-population from the region of Flanders. The variable 'GEWEST' is used for this search. In total, 5,968,074 records (persons) are obtained, and they are from 2,428,578 households. These data are processed further.

2. Extract records for children going to pre-school or primary school, including: (1) Children who are between 3 and 12 years old (indicated with the variable 'Leeftijd') and have pre-school, school or a missing value as education status (indicated with the variable 'mc_Q14'); (2) Children who are 13 years old and have pre-school or school as education status. In total, 658,533 children meeting such requirements are obtained. They are the target group of children in this study and they are termed 'school-children (school-child)'.

3. Search the population of Flanders for persons who are from households with at least one school-child. In total, 426,210 households are obtained, each having at least one school-child, and these households include 1,737,169 persons in total.

4. Remove households with more than 2 adults or no adults. In general, adults in a household are the parents, but they can have other relationships with school-children as well, such as grand-parents. In this study, all the adults are termed 'parents'. In total, 14,883 households have more than 2 parents and 3,115 households have no parents. The remaining 408,212 (426,210 - 14,883 -

3,115) households each have two or one parent; they are used for further analysis.

5. Extract persons who are school-children or parents, remove all other children in each household.

6. Remove households where school-children have missing or inconsistent values on the commutating time data between school and home (or care centre). (1) Remove school-children who have missing time values. In total, 267,574 school-children are removed. The total number of school-children before the removal is 545,317, and thus the removing rate is 49%. (2) Remove school-children who have time values outside a certain time range. The normal time range for school-children is defined as follows: (a) The earliest leaving home (or care centre) time is 5:55 am and 2,492 school-children leave before this time. (b) The earliest school starting time is 6:30 am (including school care) and 2,237 school-children arrive at school before this time. (c) The latest school starting time is 10:00 am and 2,423 school-children arrive at school after this time. By comparison, 5,206 arrive after 9:00 am, thus we use 10 am as the threshold value. (d) The earliest school ending time is 3:00 pm and 9,201 leave school before 3:00 pm. By comparison, 20,260 leave before 3:20 pm, thus we use 3:00 pm as the threshold value. (e) The latest school ending time is 18:30 pm (including school care) and 945 leave school after this time. (f) The latest arriving home (or care centre) time is 19:35 pm and 392 arrive home (or care centre) after this time. In total, 27,449 school-children are removed. The total of school-children is 277,743 before the removal, and thus the removing rate is 9.9%. After the cleaning, 195,686 households are retained and they include 631,278 persons in total.

7. Analyze the distribution on certain socio-economic variables between the original dataset of 408,212 households and the cleaned one consisting of 195,686 households. The results show that there is no significant difference between these two datasets. Thus, the cleaned household dataset is used to represent the entire Flemish population, and it is analyzed further.

8. Define two variables ‘bring’ and ‘get’ to indicate whether a parent brings a school-child to school or get him/her back from school. If the parent brings the school-child to school, ‘bring’=1; otherwise, ‘bring’=0. If the parent gets the school-child from school, ‘get’=1; otherwise, ‘get’=0. If all the parents in a household have missing values for ‘bring’ or ‘get’, and if the school-child in the family travels dependently, two assumptions are made. (a) If one of the parents has no job, it is assumed that the jobless parent takes the responsibility. This is because the data item, from which the values of the variables ‘bring’ or ‘get’ are derived, are not applicant for jobless people in the population survey. (b) If all the parents in the household have jobs, it is assumed that the responsibility is taken by people outside the household.

9. Select a representative school-child if there is more than one school-child in a household. The school-child, who is most dependent on the parents in terms of school-home (or care centre) commuting travel, is preferably chosen. The decision rules are as follows: (1) Select the school-child with dependent travel ('HVM_SW’<8). If there is more than one child meeting this requirement, then the next rule is applied. (2) Select the child with lunch at home (‘nr_drt’=2). If there is more than one such child, then, (3) select the one who leaves from care centre to school (‘Q25’=N). If there is more than one, then, (4) select the one who leaves home at the same time as the parent who has a 'bring' responsibility. If there is more than one such child, then, (5) select the one who arrives home at the same time as the parent who has a 'get' responsibility. If there is more than one such child, then one school-child is randomly chosen.

10. Decide whether a school-child leaves from home or from a care centre to school and whether he/she comes back from school to home or to a care centre. (1) A school-child goes to school from home if ‘Q25’=Y (or Z) and from a care centre if Q25=N. (2) A new variable ‘Q25_back’ is defined to indicate if a school-child leave schools to a care centre (Q25_back=1) or to home (Q25_back=0). The variable value is determined as follows: if the time for the child to leave school is earlier than the time for the parent with the ‘get’ responsibility to leave work, or if the time for the child to arrive home (or care centre) is earlier than

the time for the parent with the 'get' responsibility to arrive home, Q25_back=1. In other cases, Q25_back=0.

11. Remove the household where all parents are unemployed. In total, 10,377 households are removed. 185,309 are retained for further analysis.

12. Family classification. Four new variables are defined as follows:
(1) numOfparents.
numOfparents=1: only one parent in a household.
numOfparents=2: two parents in a household.
(2) numOfWork.
numOfWork=1: at least one parent works.
numOfWork=2: both parents work in a two-parent household.
(3) commit1, used for the first parent.
commit1=1: the parent has both responsibilities ('bring'=1, 'get'=1).
commit1=2: the parent has a 'bring' responsibility ('bring'=1, 'get'=0/999999).
commit1=3: the parent has a 'get' responsibility ('bring'=0/999999, 'get'=1).
commit1=4: the parent has no 'bring' or 'get' responsibility ('bring'=0/999999, 'get'=0/999999).
(4) commit2, used for the second parent if there are two parents in a household.
commit2=1: the parent has both responsibilities ('bring'=1, 'get'=1).
commit2=2: the parent has a 'bring' responsibility ('bring'=1, 'get'=0/999999).
commit2=3: the parent has a 'get' responsibility ('bring'= 0/999999, 'get'=1).
commit2=4: the parent has no 'bring' or 'get' responsibility ('bring'=0/999999, 'get'=0/999999).
Based on these four variables, all households are classified into 10 groups.

13. School-children's classification and pattern identification. All school-children are classified into 5 groups, based on the variables of 'nr_wwst' (the number of school-home (or care centre) commuting per week), 'Q25' and 'Q25_back'. In each group, the mean, 5^{th} percentile and 95^{th} percentile are calculated for each of the following variables relevant to the school-home (or care centre) trip:
(1) Time for leaving from home or care centre to school.
(2) Time for arriving at school.

(3) Time for leaving school.
(4) Time for arriving home or care centre after school.
(5) Time for travelling to school.
(6) Time for travelling to home or care centre after school.
(7) Time for leaving home to care centre, and it is only applicable if the school-child leaves from a care centre to school.
(8) Time for arriving home from a care centre, and it is only applicable if the school-child arrives at a care centre from school.
The obtained time points constitute the sequence pattern for the corresponding group of school-children.

14. Parents' classification and pattern identification. All parents are clustered into 9 groups based on the variables of 'bring', 'get' and 'workStatus' (indicate whether the parent is employed or not, 1=yes and 0=not). In each group, the mean, 5^{th} percentile and 95^{th} percentile are calculated for each of the following variables which are related to the work-home commuting time and the time to bring or get school-children if they have such responsibilities:
(1) Time to leave home for work or for bringing the children to school.
(2) Time to arrive at work.
(3) Time to leave work.
(4) Time to arrive home.
(5) Time to arrive at school if the parent has a 'bring' responsibility.
(6) Time to arrive at school to get the children if the parent has a 'get' responsibility.
(7) Time to go to school to bring the children before leaving for work, if the parent has a 'bring' responsibility.
(8) Time to arrive home from school, after coming back home from work, if the parent has a 'get' responsibility.
(9) Time to travel from home to work.
(10) Time to travel from work back to home.
The obtained time points constitute the sequence pattern for the corresponding group of parents.

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PUBLICATIONS 2004 - 2010

International publications with peer review

Hannes, E., Janssens, D., & Wets, G. (2009). Does Space Matter?: Travel Mode Scripts in Daily Activity Travel. Environment and Behavior, 41(1), 75-100. doi: 10.1177/0013916507311033.

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PARTICIPATION AT CONFERENCES

Q & Coffee Meeting, 2010, March 12, Rotterdam, The Netherlands

Platform: Q-Statements

2nd International Workshop on Computer Aided Qualitative Research, 2009, June 4-5, Utrecht, the Netherlands

Platform: Integrating qualitative findings in quantitative applications: modelling decision networks using CAQDAS and Bayesian network software.

88th Annual Meeting of the Transportation Research Board, 2009, January 12-15, Washington DC, USA

Platform: Mental Map of Daily Activity Travel Routines.

Aspecten van integratie van ruimtelijke ordening en mobiliteit, 2008, November 6, Mobiliteitsacademie, Brussels, Belgium

3[e] ITS Belgium Verkeerstechnologie Congres, 2008, October 23, Brussels, Belgium

4[th] International Conference on Traffic & Transport Psychology, 2008, August 31 - September 4, Washington DC, USA

Platform: Activity Travel Repertoires Objectified as Bayesian Inference Networks (AT-ROBIN).

1[st] International Workshop on Computer Aided Qualitative Research 2008, 2008, June 10-11, Amsterdam, the Netherlands

Dag van het Onderwijs, Associatie Universiteit – Hogescholen Limburg, 2007, December 11, Hasselt, Belgium

10th International Conference on Computers in Urban Planning and Urban Management (CUPUM), 2007, July 11-13, Iguassu Falls, Brazil

Platform: Heuristic Use of Mental Map INformation Gained from Behavioural Inspection of Routines in Daily activitieS (HUMMINGBIRDS).

BIVEC-GIBET Transport Research Day, 2007, April 3, Rotterdam, the Netherlands

Platform: The Use of Choice Heuristics in Daily Activity Travel Behaviour: an Expert System.

Symposium Kwalitatief Sterk 2006. Analyse in kwalitatief onderzoek: theorie en praktijk, 2006, November 27, Antwerp, Belgium

Tweede Belgische Geografendag – Deuxième Journée Géographique Belge, 2005, November 9, Ghent, Belgium

Platform: Proximity is a State of Mind. The Role of 'Spatial Cognition' in Travel Choice Behaviour: an Explorative Qualitative Survey.

9th International Conference on Computers in Urban Planning and Urban Management (CUPUM), 2005, June 29 - July 1, London, United Kingdom

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count your feathers, spread your wings,

trust the wind and… fly!