

Pamela, a parking analysis model for predicting effects in local areas

Citation for published version (APA):

Waerden, van der, P. J. H. J. (2012). *Pamela, a parking analysis model for predicting effects in local areas*. [Phd Thesis 1 (Research TU/e / Graduation TU/e), Built Environment]. Technische Universiteit Eindhoven.
<https://doi.org/10.6100/IR739991>

DOI:

[10.6100/IR739991](https://doi.org/10.6100/IR739991)

Document status and date:

Published: 01/01/2012

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

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Pamela, a Parking Analysis Model for predicting Effects in Local Areas

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus, prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties in het openbaar te verdedigen
op dinsdag 9 oktober 2012 om 16.00 uur

door

Petrus Johannes Henricus Joseph van der Waerden

geboren te Veldhoven

Dit proefschrift is goedgekeurd door de promotor:

prof.dr. H.J.P. Timmermans

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Technische Universiteit Eindhoven
Faculteit Bouwkunde, Urban Planning Group

Cover illustration: Demi Soetens
Cover design: Jac de Kok, Tekenstudio Faculteit Bouwkunde
Printed by the Eindhoven University of Technology Press Facilities

BOUWSTENEN NR 169

ISBN 978-90-6814-651-6
NUR- code 955: Bouwkunde

Preface

Many years ago, just before I started to work at the Urban Planning Group, I did an internship at the same group as part of my studies at the NHTV. For three months, I worked on the development of a choice model for pedestrian movements in the city center of Maastricht. When I joined the group for work one year later, I was involved in a similar study in the city of Sittard. In both studies, the movements of pedestrians in the center were modeled using different characteristics of the urban street network. The developed models were used to predict the pedestrians' movements after the introduction of certain planning measures, such as the opening of a shop and renewal of street furniture. These planning measures could affect both the layout and the composition of the city center and its street network. A major assumption in these studies was that the points where pedestrians enter the shopping center were fixed in the before and after situation. This assumption limited the working of the model, because it is reasonable to assume that visitors of the city centers might change their entry point due to changes in the layout and composition of these centers. Visitors could change the choice of the parking facility to park their car, the bicycle stall to store their bicycle, or the bus stop to get off the bus. In addition, these changes influence the points where visitors enter the center. This fact sparked my interest in parking choice behavior of visitors of shopping centers.

I started with a focus on parking choice behavior. Visitors who traveled to the shopping center by car have to park the car. I assumed the choice of parking was influenced by characteristics of the available parking facilities. My first parking choice model was developed for the city center of Veldhoven. During many years, I extended my knowledge concerning parking choice behavior with the inclusion of other travel choices such as destination and mode choice. Together with my colleagues (especially Aloys Borgers and Harry Timmermans) and students, I carried out several studies in Veldhoven, Eindhoven, and Boxtel. In 1997, I decided to set up a data collection that incorporated various aspects of parking choice behavior. The

data collected covered the composition of consideration sets, the choice of mode, destination, and parking facility/bicycle stall, and the adaptive parking choice when a car driver faces a fully occupied parking facility. The data included both revealed and stated data. In the years after 1997, I wrote a variety of papers covering different parts of the data collection and modeling attempts. In 2002, a compilation of different parts of the parking studies was published in Transportation Research Record. In fact this was the beginning of the writing of my thesis.

A standard work concerning parking behavior is missing in the growing interest in parking in general, and parking in specific areas such as shopping and residential areas in particular. I faced this need when I was invited in 2009 and 2010 to present my work to the employees of Empaction BV, to members of the Dutch organization of Real Estate Researchers (VOGON), and participants of the 2nd National Parking Discussion Day. In all events, the audience asked me questions indicating a lack of knowledge concerning car drivers' behavior in relation to parking. On top of that, new developments such as dynamic parking information and parking information in navigation systems require accurate insights into car drivers' parking choice behavior.

The collection of the data, the estimation and evaluation of the various models, and the writing of the thesis required a lot of time. Several times the project was interrupted because of other (also interesting) studies that demanded effort and time. During this process several people supported me and had faith in me. First of all, I want to thank my supervisor Harry Timmermans, who always gave me the opportunity to extend my knowledge concerning parking behavior of car drivers and the influence of parking on different travel choices. A special gratitude goes to Aloys Borgers, who I involved in my enthusiasm for parking. I think I asked him almost everything about data collection, data analyses, and choice modeling. We talked a lot about parking during the years we carpooled between our homes and the university. I don't hope these talks were the reason he moved to the 'deep' south. I want to thank Marloes de Bruin-Verhoeven who stimulated me to finish my thesis and, as she said not loudly, become a 'real researcher'. My thanks also goes to all my colleagues of the Urban Planning group, Astrid, Han, Leo, Mandy, and Theo, and to all the PhD students who passed our group during the years I worked on this research.

I also want to thank all the students of the NHTV in Tilburg and later in Breda who participated in the various parking studies I initiated. They worked on the various specifications of the parking choice models, the composition of parking choice sets, and several data collection issues. A special word of thanks goes to Koen van Waes who set up the validation study in Veghel. All students stimulated me to continue with the research on parking behavior.

My family sometimes lost me. How can someone pay so much interest and time to a subject as parking? Where are your thoughts? At other moments I overloaded them with my stories about parking. Our sons, Paul and Jaap, and daughter, Roos, were several times involved in the data collection and contributed to the contents of this thesis. I asked them always 'kindly' to deliver questionnaires or to observe parking behavior. I also received many help from two of my closest friends, Ed Geelen and Antonio Nelson Rodrigues da Silva, thanks guys. My father, sisters, brothers, and several friends stimulated me to continue my work by asking me every time when I saw them: 'How is the parking project going?'

Finally, I want to thank my beloved wife Tienieke. Once she married a man who was working at a financial department of the Dutch Railways. It was an easy job from nine to five, no extra time and no confusing thoughts. Then he became a student with a great enthusiasm for everything that rides, with a need for extra time and many confusing thoughts. After that he became a researcher at the Urban Planning Group of the Eindhoven University of Technology with a special interest for teaching and conducting research, spending a lot of time on these activities. Whatever he did, she always had faith in him and was proud when he finished a report, a paper, or a presentation. It cost her some effort to let him finishing his thesis but: ‘Tienieke I did it also for you...’.

Peter van der Waerden
Eindhoven, July 2012

For Tienieke and my mother and father who always took care of me when I needed them.

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CHAPTER 1

Introduction

1.1 Introduction

This thesis documents the development of a parking analysis model that describes and visualizes the role of parking facilities in travelers' decision making processes when a traveler is going out for *weekly or non-weekly shopping*. In this first chapter, parking is introduced as part of the governments' mobility management concept (section 1.2). With a variety of parking measures, transportation planners and decision makers try to regulate not only the use of parking facilities but also the choice of routes, travel modes, and shopping destinations. In the next section (section 1.3), parking is considered in the context of shopping where the car is an important travel mode. In section 1.4, several trends regarding parking are presented. The trends show an increase of demand for parking facilities both in number and quality, which stimulates the development of comprehensive parking analysis tools. The adopted research aim is presented in section 1.5. The chapter ends with the outline of the remainder of this thesis (section 1.6).

1.2 Mobility management

The increase of car traffic and the decrease of available land for parking spaces needed to park cars forces municipalities to regulate both car traffic and parking in urban areas. In recent years, parking has become an important part of governments' mobility management programs (CROW, 2002). Mobility is defined as the possibilities an individual has to move and to use these possibilities. Possibilities

consist of all kinds of roads including bus lanes, bicycle paths and footways, and all kinds of parking facilities including bicycle stalls. Mobility management includes a set of activities aiming to improve choice alternatives of travelers; remove obstacles to use favorable choice alternatives; informing individuals about available choice alternatives; spread out the demand of mobility in time and space and reduce the necessity of moving. The government tries to achieve these goals by facilitating and stimulating, and not by compelling (CROW, 2002).

Parking facilities are the possibilities for car drivers to park their car after moving from one place to another. The car drivers' parking behavior expresses the use of the available parking facilities. In the context of mobility management, the role of the government is to define a favorable policy towards parking and to direct initiatives regarding the optimization of parking. Parking policy can be described as 'an instrument to organize parking in a specific area in the stalls of transportation, environmental, and spatial planning' (CROW, 2004). The instrument can be used by both transportation planners and decision makers. In general, *parking policy* covers the following issues.

- a. A general vision on the required parking situation in the area;
- b. Definition of specific goals with respect to mobility in general and parking in particular;
- c. A description of preconditions that have to be taken into account when measures are suggested or implemented;
- d. A list of parking measures to achieve the goals as detailed below.

With parking policy, transportation planners aim to achieve the following general *goals* (e.g., O'Flaherty, 1986; Maetani *et al.*, 1996; Marsden, 2006):

- Regulate car use in congested areas to control accessibility and living conditions of these areas;
- Regulate the distribution of scarce space and stimulate economic development in Central Business Districts;
- Regulate traffic flows;
- Regulate parking of employees and visitors of a variety of facilities (shops, schools, child care, etc.);
- Regulate users' and developers' costs;
- Regulate parking in relation to landscaping.

To achieve the policy goals transportation planners have a variety of parking measures at their disposal. In general, the measures to organize parking can be divided into four different groups (e.g., CROW, 1994; 2003a; 2003b; Litman, 2006):

- Measures related to **parking volumes**: number of spaces and location of parking lots and parking garages;
- Measures related to **parking charges**: level of parking tariffs, period(s) of payment, and 'money back'-regulation;
- Measures related to **parking duration**: maximum parking duration and opening hours of parking facilities.
- Measures related to **parking communication**: parking balance and parking information.

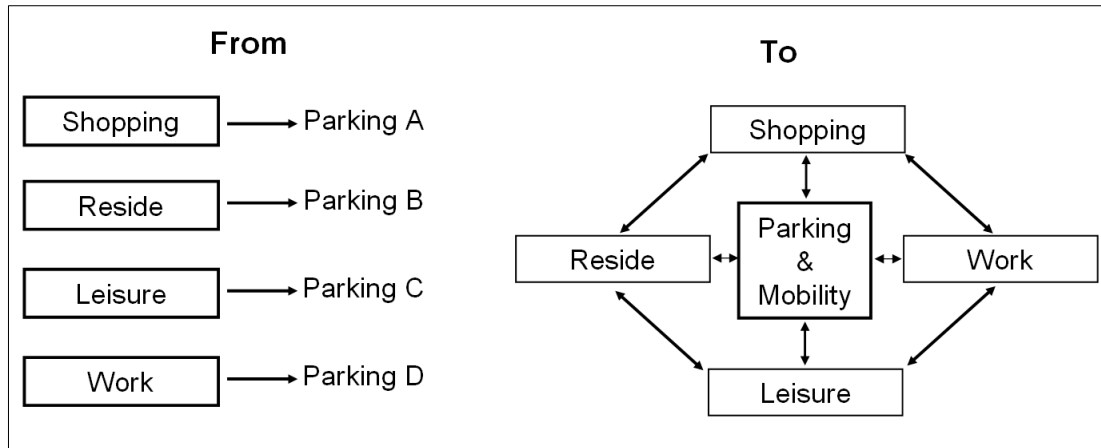


Figure 1.1: *Parking as element of urban dynamics (based on CROW, 2002)*

The activities of the government are transformed into local and regional planning. Parking is an essential link in both local and strategic (national and regional) planning. As Young (2008) stated in his overview of parking models: ‘the amount and the location of parking affect the level of service and congestion on access roads and internal city streets; the efficiency, effectiveness and financial performance of public transport; the amenity, safety and environmental integrity of the city and its surrounds; and the form and functioning of the metropolitan region as a whole’.

Parking is one of the available land uses in all type of areas such as residential, shopping and industrial areas, and in addition is related to all kind of trips such as commuting, shopping and leisure trips (Marsden, 2006). CROW (2002; 2004) advocates a more central role for parking and mobility management in the context of urban development. After a period of demand based (sixties) and guided (seventies, eighties and nineties) parking policies, the era of integrated parking policy started where parking challenges were not only parking facilities considered but also the land use and mobility characteristics of an area. Examples of parking measures in the context of mobility management are Park and Ride facilities, shared used of parking facilities, parking at distance (for residents), and maximum parking duration (to repress long term parking). The suggested integration of parking policy is illustrated in Figure 1.1. The figure shows the changing position of parking in the urban dynamics from a single orientation (separate parking) to a multiple (combined parking) orientation. In the past, parking was considered per type of land use and was mainly based on parking standards. There was limited attention paid to the relationship between parking choice and other travel decisions. In the new orientation, parking is more considered in relation to mobility management (different travel choices) that also integrates different land use requirements.

Special attention is asked for parking in shopping areas. In this context, municipalities mainly focus on the number and location of parking facilities in relation to stores (e.g., Rye *et al.* 2008). The role of parking in the context of mobility management is made more explicit for shopping areas by Van Huffelen & Van Voorst (2008). Based on extensive and repeated consumer studies, they conclude that the attractiveness of shopping centers is primarily dominated by the size and the quality of the center.

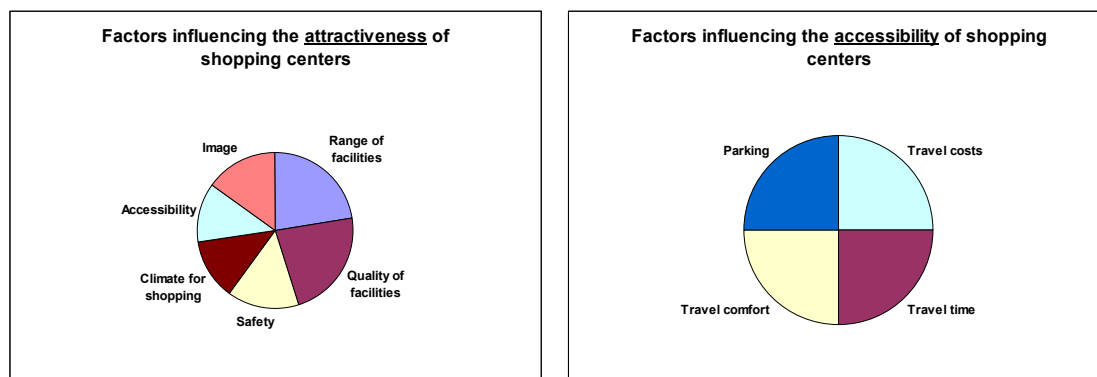


Figure 1.2: *Factors influencing the attractiveness and accessibility of shopping locations (Van Huffelen & Van Voorst, 2008)*

Figure 1.2 gives an indication of the importance of different shopping center characteristics including accessibility that is more or less equally divided in parking, travel costs, travel comfort, and travel time. It appears that accessibility and parking are not the most dominating factors but might become more important in the case that competing shopping centers are more similar. However, the authors do not give any details how the relation between parking and destination choice works. Therefore, parking is an interesting instrument to reduce car use and to optimize the use of scarce parking spaces in the context of shopping. The same holds for the influence of parking on for example route choice, departure time choice, and destination choice. Insights into the effects of changes in the parking situation on traffic flows and parking use are still limited and fragmented (see section 1.2).

1.3 Parking in shopping areas

In the context of shopping trips, the car is still a considerable travel mode, both for weekly and non-weekly shopping (Table 1.1). This holds especially for the Dutch context where central shopping areas are highly congested because of the high level of car use. Therefore, infrastructure that facilitates car trips plays an important role in the accessibility and, in addition, in the attractiveness and economic performance of shopping centers (e.g., WPM Consultants, 2002). Planners are aware of this and try to optimize the parking facilities in the surroundings of shopping centers. This optimization concerns not only the number of available parking spaces but also the quality and the price of the parking spaces. The availability of parking spaces can be manipulated by various measures such as increasing or decreasing the number of spaces, assigning parking spaces to specific user groups or introducing a paid parking regime (see also section 1.1). In addition, improvements in the quality of parking facilities can be financed by parking tariffs. Increasingly more municipalities introduce paid parking at the parking facilities in the surrounding of shopping centers.

The introduction and changes in paid parking may influence different aspects of residents' shopping behavior. Different travel related choices such as the choice of travel mode, departure time, shopping destination, visit duration, parking location and route can be affected by the introduction of paid parking.

Table 1.1: *Modal split for weekly and non-weekly shopping trips (Rijkswaterstaat, 2009)*

<i>Aspect</i>	<i>Total</i>	<i>Car driver</i>	<i>Car passenger</i>	<i>Other</i>
Distance traveled per person per day (km)	2.90	1.31	0.83	0.76
Number of trips per person per day	0.60	0.19	0.09	0.32

The CROW (2001) concludes that customers are more likely to change shopping destination than to change travel mode. A change to an alternative shopping destination is stimulated if the alternative shopping destination is a competing destination and near the shopping destination under study (Marsden, 2006). Hu & Saleh (2005) found that the main barriers for people to visit city centers are the access to and the availability of parking spaces. Regarding travel mode, it appears that in the context of non-commuter trips (a limited number of) customers are changing from car to public transport or bicycle (e.g., Hensher & King, 2001).

The discussion concerning the effect of parking and parking measures is still going on. In some studies the relation between parking facilities surrounding a shopping center and shopping behavior could not be determined, while other studies show changes in shopping behavior are related to certain parking measures. Rye, *et al.* (2008) found that in the case of Edinburgh 16 percent of the respondents indicated that the reason why they visited the city center less and shopping malls more was related to parking. The study of Van Huffelen & Van Voorst (2008) showed that the move of parking spaces from the city center to the borders of the city center and the periphery (P&R facilities) had a considerable negative impact on the economic performance of the city center. This holds especially for small and medium sized city centers. The negative effects can partly be compensated by additional measures such as better public transport and bicycle facilities. After a period of 3 to 6 months the effect is smoothed. Van Huffelen & Van Voorst (2008) also concluded that doing nothing is not an option because of the increasing congestion in the city center. Van der Waerden *et al.* (2009) evaluated the introduction of paid parking in a regional shopping center in the Netherlands. They found that at least at the short term, customers' shopping frequency, expenditure and duration decrease substantially for both weekly and non-weekly shopping trips. Also the use of different travel modes changed significantly. The findings have to be considered in the Dutch context where often several shopping opportunities are available at a short distance because of the existing hierarchy of shopping centers. Danwen *et al.* (2010) presented a study regarding the impact of parking rates on residents' travel behavior in the city of Nanjing. Based on a parking charge survey in the center of Nanjing, they concluded that 'the share rate of car travel would drop by 0.75 percent with an increase of parking rate of 1.00 percent'.

In contrast, Mingardo *et al.* (2009) investigated the relation between travel mode and parking, and consumers' expenditures in a neighborhood supermarket. Their study showed that at least in this context, the car is not as dominant as generally is assumed. In addition, there were no differences found in the (weekly) expenditures of users of different travel modes. The researchers admitted that these findings cannot be

generalized to other types of shopping centers. In 2005, Sharp found similar results in the city of London where car drivers and bus users spend the same amount of money per week, while those who walk to the city center spend 1.5 times more.

1.4 Trends in parking

Several publications indicated that the increase in the number of cars in the near future continues (e.g., CROW, 2004; Van de Coevering *et al.*, 2008; Van Luipen *et al.*, 2008). The expected increase in cars stimulated all kinds of organizations to intensify their attention for parking. CROW (2004) identified the following trends regarding transportation in general and parking in particular. The first trend deals with the rise of mobility management with parking as an important part. The second trend deals with the introduction of information and computer technology for both management (optimizing use) and (cashless) payment. Professionalizing the parking industry is another trend. This holds for both (private) enforcement and parking management. Parking is considered more and more as a product that has to be sold. Another (fourth) trend deals with a change from on-street (ground level) parking to off-street (garage) parking. The final trend that is described by CROW deals with change in the structure of shopping trips. Besides the direct trip from home to the shopping center, increasingly more shopping trips are divided into two parts: from home to an outside the center located transfer point (e.g., Park and Ride and Park and Bicycle locations) and from this transfer point to the shopping locations *visa versa*.

Van de Coevering *et al.* (2008) discussed some trends regarding parking in residential areas. They predicted an increase in car ownership from approximately 7.6 million cars in 2007 to 10.5 million cars in 2030 resulting in a huge task for municipalities to accommodate these cars. They suggested that the increase of the parking demand can be accommodated by a better usage of public space and extending parking capacity. A better use of public space can be achieved by redesigning roads and opening parking facilities for multiple users (e.g., residents, workers, and visitors). The 'double' use of parking facilities by different user groups is also suggested by Lamens *et al.* (2008). To make expensive parking garages in residential areas profitable the garages can be used by both residents (night) and workers (day). In the near future also the use of private property will be stimulated (Matthijssen & Vissers, 2008). New parking facilities can be created by redesigning existing parking facilities, building parking garages in residential areas including mechanical parking facilities.

In Van Luipen *et al.* (2008) the expected increase of cars is considered in the broader context of central business areas, residential areas, and industrial areas. New ideas are presented to handle the increasing demand for parking like a new structure of parking costs (pay for actual construction and maintenance costs), new parking standards (including parking at own property), new parking policy regarding short-term and long term parking (where to park, different costs), and new promotion campaigns (information). They also promote the introduction of a parking agent who tunes parking demand to parking supply resulting in equal distribution of parked cars.

Recently, some attention is paid to the issue of parking information (in relation to car navigation systems) and the design of parking guidance systems (e.g., Van der Waerden *et al.*, 2010a; Van der Waerden *et al.*, 2011). In both cases car drivers'

preferences were investigated with respect to the presentation and moment of providing parking information is presented. The delivery of information can influence car drivers' knowledge of a city's parking situation and, in addition, car drivers' travel and parking choice behavior. The studies show that car drivers prefer parking information when searching for a suitable parking place. Most relevant information concerns parking tariffs and occupancy rates.

In the specialist journals 'Parkeer24' (www.parkeer24.nl) and 'Vexpansie' (www.vexpan.nl) several authors pay attention to the fact that car drivers are changing from a 'low-interest' consumer to a critical consumer. Car drivers become more and more aware of the services that are or have to be provided by operators of parking facilities. Required services cover different aspects of parking facilities such as quality, maintenance, security, price, payment, and information.

1.5 Research aim

The call for detailed and reliable insights will increase in the near future because of the increase in car ownership and car use, and the decrease of available space in cities. Also the increasing 'competition' between cities and regions to attract economic activities like shopping, asks for better insights in the effects of parking policy. This call makes it necessary to look for a tool that is able to provide insights into effects of parking policy in general and parking measures in particular. The tool can be used to support decision makers when evaluating different planning alternatives for their city or region. Also residents and other stakeholders (shopkeepers, developers, etc) could use the tool to get insight in the effects of parking measures on their personal circumstances. Because of the range of policy goals, possible parking measures, and potential users the tool has to meet the following requirements:

- Showing the effects of parking measures on different aspects of residents' travel behavior such as destination choice (resulting in information concerning traffic flows), mode choice (resulting in information concerning car use), and parking choice (resulting in information concerning the distribution of cars across parking facilities);
- Including different parking measures related to parking location (where), design (what), and costs (how much);
- Easy access for both transportation planners and decision makers.

The studies described in the previous sections show a fragmented and sometimes limited view of effects of parking measures on individuals' travel behavior. This holds especially for shopping trips to major shopping areas like city centers. All studies are set up as evaluation studies after the implementation of one or more parking measures. To evaluate the effect of different parking measures on travelers' decision making before the measures are implemented, special evaluation tools are required. The availability of tools to evaluate different parking measures in the context of shopping is limited (see for an overview chapter 2). The tools that are available are not easily accessible because they are owned by consultants or specialized research institutes, and because the tools are complex and data intensive. In his overview of parking studies Marsden (2006) concluded that there is relatively limited evidence on the behavioral response of non-commuters on parking policies in the context of commercial and leisure uses. Rye *et al.* (2008) concluded from their study on the

relationship between parking policy and market research, that there is a requirement to take user opinions into account when developing a car parking strategy. Market research delivers insights into users' requirements and support regarding the contents of the parking strategy.

The study presented in this thesis aims to develop a parking analysis model at the scale of city and region that can easily be used for planning purposes, such as retail planning. The models predict traveler's choice decisions concerning travel mode, destination and parking/bicycle stall, focusing on the shopping context. The model is given the acronym **Pamela** which stands for a **P**arking **A**nalysis **M**odel for predicting **E**ffects on **L**ocal **A**reas. As I will discuss in chapter 2, there are only a limited number of examples of combined choice models that connect parking choice behavior to more than one other aspect of travel behavior such as destination, travel mode, and route choice. Especially in the context of shopping, such models are limited. The approach used in existing studies differs from the presented study in that (i) the existing models are mainly based on revealed preference and choice data, (ii) the individual parking facilities in combined choice models are mostly specified by average scores on various parking characteristics, and/or (iii) the various models are estimated separately and implemented in an overall simulation framework as will be shown in the next chapter of this thesis. The models in this study are based on stated choice data, include characteristics of individual parking facilities, and integrate different travel choices considering the role of the parking situation at destinations.

Although most empirical work related to the model presented in this thesis has been conducted in the context of shopping behavior, this is not a necessity in the sense that it can be easily calibrated or extended to other kinds of activities. The model allows planners to predict and simulate the effects of a variety of parking measures at the level of local areas such as city centers, shopping centers, and individual parking facilities. The system is dynamic in that it allows the prediction of changes in the parking system across the day.

1.6 Outline

The thesis is subdivided into 8 chapters. After this introduction, chapter 2 presents a general overview of parking models that have been developed by several researchers in the past. Special attention is paid to the components of car drivers' parking behavior that are also part of **Pamela**: the modeling of the car drivers' parking consideration set, the combined choice of destination, travel mode, and parking facility, and adaptive parking choice behavior. Next, the conceptual framework of **Pamela** is described in chapter 3. In addition, attention is paid to the theories (individual choice behavior and random utility theory) and techniques (mixed logit and stated choice) that are underlying the framework. In chapter 4, the models used in **Pamela** and the data collection method are explained in more detail. The stated choice experiment and the questionnaire that is used to collect data are described. Chapter 5 presents the results of both the descriptive and model analyses. The chapter also includes a brief description of the sample used for the analyses. In chapter 6, the external validation of the choice set model and the combined travel choice model is described. The two choice models are used to predict and evaluate residents' choices in a real world situation. The synthesis of the various components of **Pamela** is

described in chapter 7. In this chapter, attention is paid to a simulation that is set up to illustrate the working of the various components of *Pamela*. The thesis ends with conclusions about the estimation and application of the models included in *Pamela*, a discussion of the research findings, and suggestions for future research.

CHAPTER 2

Parking analysis models

2.1 Introduction

To get insight into the impacts of parking policy, in the past a variety of parking models has been developed. This chapter aims to give a brief overview of the scope and structure of existing parking models and the characteristics used to develop parking models for supporting parking policy. Attention is paid to existing parking models in general, models that describe parking choice behavior and parking choice set generation in particular. Special attention is paid to parking choice behavior in the case car drivers face a fully occupied parking facility which often occurs in (congested) shopping areas.

In the next section (section 2.2) attention is paid to the different scales parking models have been applied and to different types of parking models developed in the past. For the aim of this study, the next two sections describe in more detail existing parking choice models (section 2.3) and combined travel choice models (section 2.4). Next, attention is paid to the generation of choice sets in general and parking choice sets in particular (section 2.5). Section 2.6 describes existing information concerning adaptive parking choice behavior. The chapter ends with an enumeration of suggested improvements for the new to be developed parking model.

2.2 Overview of parking models

Various authors have presented overviews of parking models that have been developed (e.g., Feeney, 1989; Martens *et al.*, 2008; Young, 2008). Two major approaches are used to classify existing parking models: the inclusion of real world settings and the scale of the (parking) problem. Martens *et al.* (2008) used the first approach and made a distinction between spatially implicit models and spatially explicit simulations. Spatially implicit models cover the first generation of parking models in which parking choice is based on a car driver's preference for characteristics of the urban parking situation. In these models, car drivers choose from a set of available parking alternatives (based on individual parking facilities), parking types (based on groups of parking facilities with similar characteristics), or parking spots (based on groups of parking facilities at the same distance from destinations). The spatial distribution of parking facilities is included in these models by characteristics such as 'distance to destination' and 'location vis-à-vis car drivers' origin'. Most models are static in nature, and assess drivers' preferences using a logit model (e.g., multinomial and nested logit) in order to explain and predict drivers' choice of parking. In contrast, spatially explicit models simulate car drivers search behavior in a real world context consisting of off-street parking facilities (parking lots and garages) and several on-street segments.

In the overview of Young (2008) who adopted the second approach, a hierarchy of parking models based on the scale of the problems the models tackle is presented. Young distinguished four different spatial levels of models in policy analysis: (level i) parking site or lot analysis, (level ii) sub-center or regional modeling, (level iii) area wide or metropolitan modeling, and (level iv) land use/transport/environment modeling. Models that replicate detailed movements of cars in parking facilities belong to the first group of parking models. Models from the second level of the model hierarchy concentrate on allocating parking to the space provided in the vicinity of an activity center such as the Central Business District and district centers. The third level models look at metropolitan or sub regional transport systems including several activity centers. In these models not only parking choice is included but also other types of travel choices such as mode and destination choice. Models belonging to the fourth level relate to the indirect impact parking has on urban vitality, and the location of choice of businesses and households. When developing a parking analysis model in the context of shopping behavior the third level of the hierarchy of Young seems to be most interesting.

In addition to the hierarchy of parking models, Young (2008) gives an overview of different types of parking models illustrating their position in the hierarchy of spatial levels.

- a. *Parking design models (spatial level i)*, focusing on performance of the parking system at the parking site level (e.g., AS, 2004);
- b. *Parking allocation models (spatial levels ii and iii)*, focusing on the allocation of a fixed number of arrivals to the parking stock at the sub-center and regional level (e.g., Taylor *et al.*, 2000);
- c. *Parking search models (spatial level ii and iii)*, focusing on the process of gathering information about the parking systems in order to make a parking decision at the area or metropolitan level (e.g., Thompson & Richardson, 1998);

- d. *Parking choice models (all spatial levels)*, focusing on car drivers' reactions to changes in the supply, price, and operation of parking facilities at the area and metropolitan level (e.g., Axhausen & Polak, 1991);
- e. *Parking interaction models (spatial level iv)*, focusing on representation of the behavioral response (e.g., mode choice, time of travel choice) of travelers to parking policies at the land use level (e.g., Loudon *et al.*, 1989).

2.3 Parking choice models

As described in the previous section, parking choice models focus on car drivers' requirements regarding the parking situation at the destination of a car trip. These models can be used to analyze and simulate the effects of parking measures on different car drivers' travel decisions and behavior. In the past, a variety of spatially implicit model studies have been set up to describe parking choice behavior of car drivers in different circumstances (Gillen, 1978; Van der Goot, 1982; Axhausen & Polak, 1991; Bradley *et al.*, 1993; Hunt & Teply, 1993; Miller, 1993; Van der Waerden *et al.*, 1995, 2006, 2010b, 2010c, 2010d; Van der Waerden & Borgers, 1995; Van der Waerden & Oppewal, 1995; Lambe, 1996; MuConsult, 1997; Tsamboulas, 2001; Guan *et al.*, 2005; Harmatuck, 2007; Borgers *et al.*, 2010; Ottomanelli *et al.*, 2011) In general, the adopted approaches differ from each other on the following features (for a detailed overview of the studies see Appendix A1).

- *Number and type of alternatives included in the model*

In these studies, the number of parking alternatives has been varied between 3 (Gillen, 1978) and 147 (Hunt & Teply, 1993). Different types of parking alternatives have been included in the studies: street blocks based on distance to final destination (Gillen, 1978), types of parking like free-on-street, charged-on-street, charged-off-street, multi-storage car parking and illegal parking (e.g., Axhausen & Polak, 1991; Ottomanelli *et al.*, 2011), groups of parking spaces (e.g., Van der Goot, 1982), and existing parking lots and garages (e.g., Van der Waerden & Borgers, 1995). In these studies little or no attention is paid to the fact that travelers in general and car drivers in particular are not familiar with or do not consider all available parking facilities in the vicinity of destinations.

- *Number and type of characteristics included in the model*

To describe parking alternatives a variety of characteristics has been used. In some studies, the number of characteristics used to describe the parking alternatives has been limited to 3 or 4 (e.g., Lambe, 1996; Guan *et al.*, 2005), while in other studies the number of characteristics was 9 or 10 (Hunt & Teply, 1993; MuConsult, 1997). The most frequently used parking characteristics are parking fee, walking distance/time between parking and final destination, and type of parking. Other characteristics such as parking time restriction, access and search time, location vis-à-vis home, and chance of free space have also been used regularly. The range of parking characteristics included in the studies seems to cover most requirements of planners and politicians when setting up parking management plans. However, some new developments should be considered such as the change from parking lots to parking garages, the introduction of new methods of payment, and developments around parking security.

- *Field of application*

Most parking studies have been conducted in the context of commuting and shopping trips. Recently, studies have been concerned with leisure trips (e.g., Anderson *et al.*, 2006; Beunen *et al.*, 2006), and with residential areas (e.g., Broaddus, 2009; Borgers *et al.*, 2010).

- *Type of data used to estimate the model*

The number of studies that used revealed choice data is more or less equal to the number of studies that used stated choice data. The collection of revealed choice data often occurs in situations in which a certain diversity of parking facilities and their characteristics exist. For example, Van der Goot (1982) concluded that ‘the most important question to consider in applying the model is whether there are other factors which could probably influence parking choice, but which did not exist in the present situation’. If a local situation misses diversity in alternatives regarding certain characteristics (e.g., no parking costs) it is also hard to investigate the effect of these characteristics. For example, Van der Waerden & Borgers (1995) investigated a situation in which parking costs were equal for all parking alternatives. In a stated choice approach the states of all (necessary) parking characteristics can be controlled.

- *Modeling approach*

In the past, the standard multinomial (MNL) and the nested logit (NL) models were very popular both at universities and in practice. Nowadays, practice is still working with the MNL en NL models, while universities more and more focus on more advanced multinomial mixed logit models (e.g., Hess & Polak, 2009; Borgers *et al.*, 2010). The variety of car drivers’ preferences regarding parking requires more sophisticated models such as mixed logit models (see section 3.4).

- *Findings*

The findings of the various studies can be summarized as follows. Most of the investigated parking characteristics influence car drivers’ parking choice behavior. It seems that especially in the context of shopping trips walking time and parking costs are the most influential parking characteristics. But also the size of the parking facility and occupancy rates are important characteristics. The size of the effects is related to trip purpose, day of the week, and local circumstances. For example, it was found that the ratings of walking egress and access time differs between work and shopping trips (Axhausen & Polak, 1991; Bradley *et al.*, 1993). It also appears that parking behavior on weekdays differs from parking behavior in the weekend (Guan *et al.*, 2005). Regarding differences in local circumstances, it was found that the effect of parking fee depends on the distance between parking facility and final destination (Gillen, 1978; MuConsult, 1997). The dependencies in the results as mentioned above require more research.

Some parking studies are limited to the stage of development and not yet applied in practice (Brown-West, 1996; Spiess, 1996; Griffioen-Young *et al.*, 2004; Liu & Lu, 2005; Ottomanelli *et al.*, 2011). The studies only present the method to investigate parking behavior without testing it with empirical data.

2.4 Combined travel choice models

In contrast to what most models presented above assume, parking choice is only one choice in a series of choices an individual has to make when he or she wants to participate in out-of-home activities such as shopping. Together with the choice of a parking facility various choices have to be made, including the choice of destination, travel mode, and time of departure. These choices are strongly interrelated: the outcome of one choice process might influence another choice process. As for the parking decision, motorists also have to decide which route to take to reach the parking facility, and how long to stay at the parking facility or final destination.

To get more insight into these combined travel choices, two different approaches have been described in the literature. The first approach deals with an overall framework with several sub-models. For example, Young & Taylor (1991) suggested a hierarchy of models to study the total range of parking problems. The models form a suite that can be used for parking design (PARKSIM: a model for vehicle movement through a parking lot) and policy analysis (TIP: a model for location choice of business and households). Bates *et al.* (1997) considered an alternative framework for travel choices. They developed TRAM (Traffic Restraint Analysis Model), a travel choice hierarchy that contains two levels of travel choice models: (i) incremental choice models (choice of frequency, destination, mode, and time of day) and (ii) absolute choice model (choice of parking type and location, and choice of public transport sub-mode and route). In the second approach, various travel choices were combined into an integrated model. In general, two different model structures have been presented to model the combined choice of destination, mode and parking. The first model structure assumes the choice of a destination is at the highest choice level (*a*), while the second structure assumes that the choice of a travel mode is at the highest choice level (*b*).

Polak *et al.* (1990) derived from the CLAMP-model (Computer-based Local Area Model of Parking behavior; Bates & Bradley, 1986) the following hierarchy of demand sub-models (Figure 2.1). These demand sub-models represent ‘the effect of changes in transport and parking system level of service variables on the choice of destination, mode and parking for travelers to the City Center’. The structure consists of three levels. The highest level deals with the choice of whether or not to travel to the City Center. The second level represents the choice between alternative travel modes (bus, train and car). At the lowest level, car travelers choose between alternative parking opportunities.

The data for the estimation of the model were derived from a stated preference experiment. Respondents were placed in a hypothetical situation where they had to choose a destination, travel mode and parking type. Each choice was presented in a separate choice task. Separate models were estimated for work and non-work journeys. The models were mainly based on time-related attributes like access time, search time, and egress time.

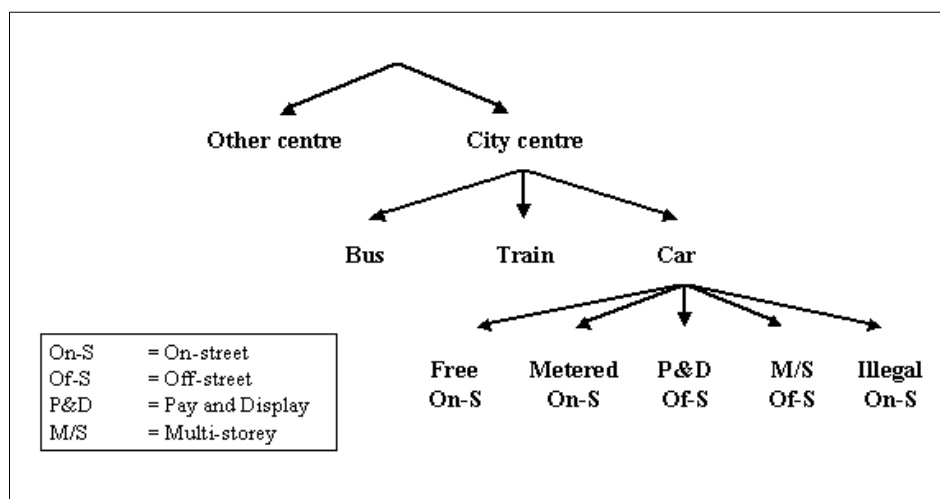


Figure 2.1: Structure of the demand sub-models according to Polak *et al.* (1990)

In the same tradition, Meurs *et al.* (1997a; 1997b) developed two choice models that describe the simultaneous choice of parking location, travel mode, and shopping destination for daily and non-daily shopping trips (Figure 2.2). The data for the model estimation were derived from four separate stated preference experiments where respondents had to rank profiles. The experiments contained the following choice tasks: one for destination choice, one for mode choice, one for parking choice, and one for the combined choice travel mode and parking.

Parking facilities were described by the attributes parking fees, maximum parking duration, number of parking spaces, occupancy rate, and walking distance between parking facility and shopping destination. Travel modes were described by the attributes travel time (for car, bus, and bicycle), travel cost (for car and bus), waiting time at bus stop, walking distance between bus stop and shopping destination, walking distance between bicycle stall and shopping destination, and level of security in bicycle stalls. A shopping destination was described by the following attributes: number of shops, distribution of shops, and availability of magnet store. The data of the separate choice experiments were pooled for parameter estimation. This approach implies that respondents are confronted with simple choice situations. The question is whether these simple choice situations (with one or two choices) are good representatives of the complex real world decision circumstances.

Looking to the two approaches described above, it seems that some things are missing or unclear. First, little or no attention is paid to the composition of the parking choice sets (see also section 2.5). Second, the use of a limited number of parking facilities or type of parking facility seems to be too simple in the context of central shopping areas. In reality, travelers face a complex choice situation. Third, it is unclear how the different choices are related to each other. For example, how does the parking situation in the vicinity of a destination influence the utilities of destinations and/or travel modes.

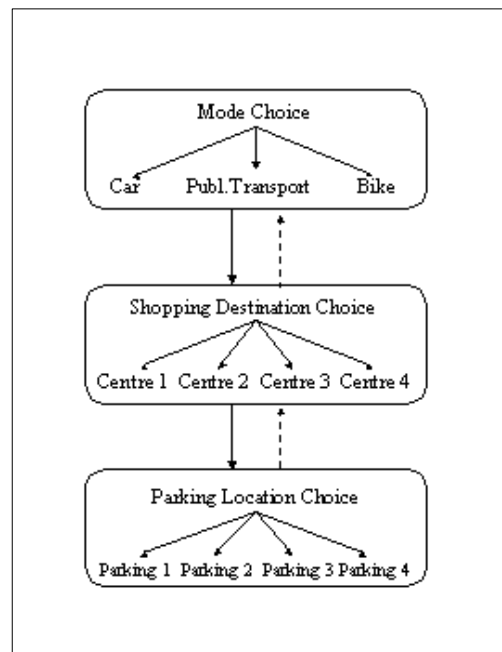


Figure 2.2: *Hierarchy in choice behavior of consumers according to Meurs et al. (1997b)*

More recently, some other less comprehensive combined travel choice models have been suggested, mostly related to network assignment. Tsamboulas (2001) developed two models describing the change of parking location and car mode change to other modes, because of parking fare increase. Respondents responded to different choice scenarios. In addition to other studies, he introduced additional variables to the ones usually employed, i.e. trip distance, walking distance and parking price. He added variables that describe the travelers' characteristics (income, age, gender) and trips (purpose, vehicle type). He also defined two separate models because, according to him, 'the importance attributed to the variables that capture drivers' behavior is not the same for parking location and travel mode choice'.

Sattayhatewa & Smith (2003) developed a joint parking lot destination choice and assignment model based on the concepts of user equilibrium traffic assignment. The parking lot choice is derived using a logit function. The parking lot choice problem is divided into two travel activities, the driving activity from the origin to any parking lot and the walking activity from the chosen parking lot to the final destination. Therefore, the utility of a parking lot consists of three components: the in-vehicle (driving) costs, the parking costs, and the walking time.

Lam *et al.* (2006) proposed a time-dependent network equilibrium model that simultaneously considers traveler's choice of departure time, route, parking location, and parking duration. The travel and parking choices follow a hierarchical decision-making process which means that travelers first make choices based on the time at which they will depart from the origin and how long they will park at their destination. Next, the travelers select a desirable parking location that will minimize their travel costs from origin to destination. Finally, they choose the shortest route to reach the chosen parking location. In this process, the following costs components

were considered: the travel time from origin to parking location, the searching time delay for parking, parking charge at the parking, and walking distance from the parking location to the final destination.

Balijepali *et al.* (2008) specified a joint model for parking location and traffic assignment using an equilibrium approach. The choice of parking is assumed to depend on the travel time between origin and destination, search time in the car park, parking charge, and distance to the final destination. Search time depends on the net flow into the car park and the capacity of the car park.

2.5 Parking choice sets

A special point of interest related to (parking) choice modeling concerns the set of available choice alternatives. In general, the individual choice set refers to the set of discrete alternatives considered by an individual in the decision process. Mostly, the individual choice set is a subset of the universal choice set that consists of all alternatives available to the decision maker (e.g., Pagliara & Timmermans, 2009). Pagliara & Timmermans (2009) reviewed different choice set generation approaches starting with the work of Thill (1992). Before describing various studies in detail, they state that the dominant literature suggests a hierarchical choice process in which consumers systematically reduce the number of alternatives on the basis of different mechanisms, and the very few compared immediately prior to the choice make up the choice set. This hierarchy is illustrated in Figure 2.3 (Bovy & Stern, 1990). In practice the formation of choice sets is done by using heuristics or deterministic choice set generation rules, using observed choice set information, or using random choice sets (e.g., Ortúzar & Willumsen, 2001).

Over the years, researchers have developed various so-called deterministic and probabilistic choice set formation rules. Examples of deterministic rules are ‘leaving out all illegal alternatives’, ‘exclude all alternatives outside the 500 meter range’, and ‘include only observed alternatives’.

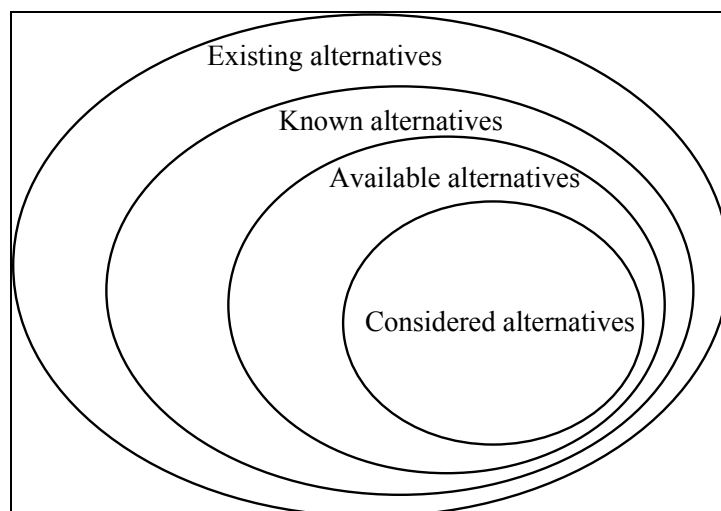


Figure 2.3: Hierarchical series of choice sets of a given choice situation (Bovy & Stern, 1990)

According to Pagliara & Timmermans (2009) ‘the accuracy of choice set specification – and, consequently, the accuracy of the parameter estimates – depends strongly on the analysts’ professional judgment, the empirical context and the size and the quality of the sample used for model estimation’. Stochastic or probabilistic choice set formation models are considered as more advanced approaches. Probabilistic models predict the probability that an alternative will be included in a choice set. Pagliara & Timmermans (2009) present a detailed overview of stochastic choice set formation approaches including strengths and weaknesses of the approaches. The overview starts with the approach suggested by Manski (1977) who proposed a stochastic, exhaustive and explicit approach to choice set formation. He suggested a two-stage approach where the probability that an individual chooses an alternative is related to the probability that an individual chooses an alternative given a certain choice set C and the probability that the choice set of the individual is equal to C . Later more advanced approaches based on Manski’s ideas were presented by several researchers (for an overview see Pagliara & Timmermans, 2009). Most recent study presented by Pagliara & Timmermans concerns the study of Zheng & Guo (2008) who developed a probabilistic choice model for destination choice analysis based on the concept of distance constraint and the assumption that decision makers perceive a spatial choice set as a contiguous collection of zones centered on their trip origin.

Also in the context of modeling parking choice, the choice set is important. The choice of a parking facility will be influenced by a person’s familiarity with the existing parking facilities. Individuals are not necessarily familiar with all parking facilities available in a particular area and a motorist often makes an explicit utility comparison or cost-benefit trade-off before making a choice (e.g., Mehta, *et al.*, 2003). The recent developments regarding the contents and distribution of parking information (see section 1.4) will also change car drivers’ familiarity with parking facilities.

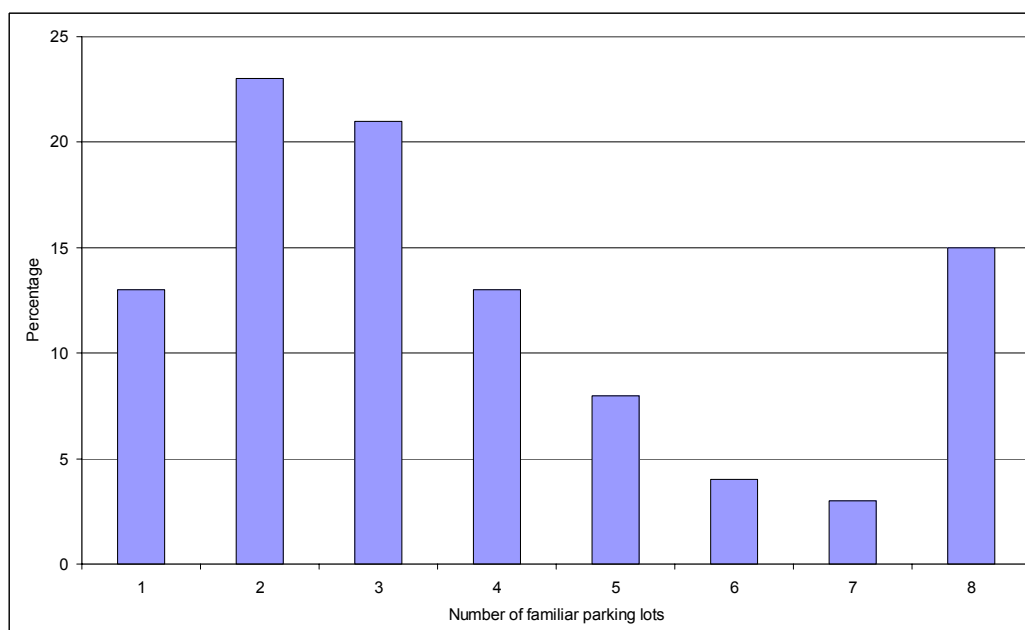


Figure 2.4: Car drivers’ familiarity with parking facilities, $N=438$ (Van der Waerden & Borgers, 1995)

Little attention has been paid to the size and composition of choice sets for parking choice behavior. Most researchers have either assumed that choice sets contain all available parking facilities at a shopping center (e.g., May, *et al.*, 1989) or only the parking facilities individuals are familiar with (e.g., Van der Waerden & Borgers, 1995; Matsumoto & Rojas, 1998; Rye *et al.*, 2008). Only a few empirical studies of choice set composition in the context of parking have been published. In a study of car drivers' familiarity with the parking situation in a regional shopping center, Van der Waerden & Borgers (1995) found that most car drivers are familiar with 2 or 3 parking lots. Only 15 percent of the car drivers were familiar with all 8 available parking lots (Figure 2.4). Rye *et al.* (2008) investigated respondents' familiarity with the parking situation in the city center of Edinburgh. They found that 33 percent of the respondents did not know any parking facility, 48 percent indicated that they knew 1 to 8 parking facilities, while only 3 percent knew all 19 available parking facilities in the city center. Rye *et al.* indicated that this lack of knowledge is likely to put pressure on the well-known parking locations.

In the past some models to generate parking choice sets have been tested. Most examples simulate the choice set in combination with the final parking choice. Richardson (1982) and Thompson & Richardson (1998) determined both the size and the composition of the choice sets endogenously. They assumed that initially motorists are aware of all on-street parking facilities within the Central Business District (CBD). This initial choice set is extended with off-street parking facilities that are encountered while searching for a parking facility or observed when walking to the final destination. The search process is influenced by the capacity of parking facilities, the fee rate, and the duration limit. The final choice set of an individual is known when his or her search process ends. Almost the same strategy was followed by Arnott & Inci (2006), and Arnott & Rowse (2009) who developed a downtown parking model that integrates traffic congestion and saturated on-street (curbside) and off-street (garages) parking. In the model, car drivers drive around the city streets and park immediately if a vacant parking spot is available and otherwise cruise around the destination block until a spot opens up.

Recently, Ji *et al.* (2007) presented a two-phased parking choice model that simulates the search for all available parking options and the selection of the optimal parking alternative. In the first phase, the search of available parking options is based on a maximum acceptable walking distance from parking to destinations (maximum of 300 meter) and available parking space (time variant). In the second phase, a multi-object decision making model is used to rank parking options identified in the first phase. The ranking of parking alternatives and the selection of the most optimal alternative are based on indices including walking distance, safety, convenience, cost, and accessibility.

Another example of combining choice set generation and parking choice was presented by Martens *et al.* (2008) who specified an agent-based model of parking search. In the model driving is represented as a sequence of decisions made by the car driver: (1) at each junction a driver makes a decision regarding the next segment to drive, and (2) within the search area a driver makes a recurring decision whether or not to occupy a free parking place. The choice of the segment at a road junction is based on an agent's estimate of the distance between each of the next junctions and the destination. Driving towards the destination, at a certain distance, the driver starts

to estimate the fraction of free parking places and starts considering to park. The driver decides to park or not, based on her expectations of the number of free spaces between the driver and the destination.

In contrast to the endogenous generation of the choice set one could use an exogenous approach where the choice set is generated separately from the actual parking choice. For example, Van der Waerden & Borgers (1995) presented a model for motorists' awareness with parking facilities. Their model suggested that the probability that a parking facility is part of the motorists' awareness or choice set is significantly related to the distance between home and the parking facility, the number of parking spaces, and the distance to alternative parking facilities.

2.6 Adaptive parking choice behavior

In several cases, especially in central shopping areas, car drivers are confronted with congested or fully occupied parking facilities. This situation stimulates car drivers to reconsider their first chosen parking facility. In this study, reconsidering a parking choice is called adaptive parking choice behavior. Very few studies have examined such adaptive behavior.

A first attempt to deal with the issue of adaptive parking choice behavior has been discussed in Van der Waerden *et al.* (1993). To investigate car drivers' reactions when facing a fully occupied parking facility a stated choice experiment was developed. In addition, different circumstances were defined using the following variables: expected waiting time, number of parking facilities visited before, number of cars waiting, travel time to an alternative parking facility, probability of a free space on the alternative parking facility, parking costs on the alternative parking facility, space present for illegal parking, and chance of getting a parking fine. Drivers were invited to indicate what they would do when facing a fully occupied parking facility and the circumstances defined by the eight variables. Four reactions were available: wait for a free space, leave current parking facility and search for an alternative parking facility elsewhere, park the car illegally, and none of these. The study showed that most of the selected variables influence the probability of choosing one of more reactions.

Spiess (1996) presented a logit parking choice model in which an explicit capacity is associated with each parking lot. The model includes an additional impedance (or weighted cost) which increases the attractiveness of alternative parking lots when a parking lot reaches its capacity. Car drivers adapt their parking choice behavior by selecting an alternative parking lot. The model describes the car drivers' parking lot choice in the context of park and ride trips.

More recently, Bonsall & Palmer (2004) investigated car drivers' reactions on en-route information concerning the occupancy of parking facilities. More specifically, car drivers were faced with a queue of 15 vehicles when arriving at one of the parking alternatives. The car drivers could choose from two alternatives: queue up or go to one of the other parking alternatives. A model was estimated to show how pre-trip parking guidance information (PGI) influences car drivers to revise their choice of car park. It appears that the pre-trip PGI influences car drivers' choice of parking. The FULL sign in PGI has a greater effect on car drivers' intention to revise their first

parking choice than showing the number of spaces. Also the price of the parking alternatives influences car drivers' intentions. No effect was found for driving time.

2.7 Conclusion

This chapter presented an extensive overview of simple and more complex parking related models ranging from models that describe the choice of parking facilities to models that describe different travel choices including travel mode, destination, and parking choice. The existing models cover various characteristics of destinations, the transport system, and parking facilities and bicycle stalls and are applied for different trip purposes. Looking to the nature of shopping trips, where parking is contemplated as an essential element in several choices individual shoppers make when traveling to a shopping destination, an individual choice model type is considered as the most optimal model type for our research aim. The model not only has to include shoppers' choice of parking but also other shopping trip related choices such as destination and travel mode choice. Also attention has to be paid to situations in which a car driver faces a fully occupied parking facility which often happens in congested shopping areas. For example, Litman (2006) mentioned a 90 percent occupancy rate during peak hours in Central Business Districts. Arnott & Inci (2006) stated that 'during business hours half the cars on downtown streets in large cities are cruising for parking.

For the development of 'an easy accessible parking analysis model (see chapter 1)' that is able to describe the complexity of travel behavior during a certain time period in the context of shopping in the Netherlands, we felt that several changes on existing model approaches were necessary. Firstly, in the existing approaches where the traveler's choice behavior is investigated, limited attention is paid to the composition of choice sets. This especially holds for the parking choice set. It is shown that car drivers are not fully aware of or do not consider all available parking facilities when they choose a parking facility to park their car. Secondly, it appears that in the context of shopping the main focus is on walking distance between parking and shopping destinations and parking costs. For planning purposes also other characteristics have to be included like size of parking, presence of security, and parking egress time.

The overview of parking studies presented in this chapter shows several limitations of the adopted approaches that are necessary to consider when looking for improvement of existing parking models.

- *The inclusion of bicycle as a means of travel and bicycle stalls as facility*

In contrast to existing international studies, in the Dutch case, the bicycle is an important travel mode. Parking measures can stimulate bicycle use and, in addition, the demand of parking facilities. It is important to include the bicycle in modeling approaches in terms of travel time and bicycle stall facilities. Policy makers want to stimulate the use of the bicycle by providing adequate bicycle stalls (see section 4.3).

- *Adaptive parking choice behavior*

Little attention has been paid to the situation a car driver faces a fully occupied parking which especially in shopping centers happens often. An extension of the planning tool in this direction is necessary to get insight into the actual visits of shopping centers and the actual use of parking facilities (see section 4.4).

- *Data collection*

It appears that revealed choice data are used in situations with diversity in parking alternatives. The data collection approach is also useful in the case only one or two choice decisions are considered. Stated choice data seem to be more useful if the local situation is not diverse and in the case complex decisions have to be unraveled (see chapters 4 and 5) or new policy measures have to be explored.

- *Accessibility and integration*

Most of the existing models are not easy to access because they are owned by private companies, they require a lot of detailed data, or they are based on specific software. There is a need for a platform that makes the models easy accessible and integrates the separate models (see chapter 7).

- *Improved model estimation*

Most travel choice behavior is explained using multinomial or nested logit models. Improvements in the efficiency of simulation-based estimation processes provide easy accessible tools to estimate more sophisticated models such as the mixed multinomial logit model (see section 4.4). For example, Hess & Polak (2009) showed that in the context of parking choice a mixed multinomial logit model performs better than a simple multinomial logit model.

- *Validation*

Most parking modeling studies do not pay any attention to the external validation of estimated models which is one of the most difficult issues related to modeling. Only few attempts have been described in more detail (see section 6.1). Mostly, models are only validated using the data they are based on or data that is collected at the same time/place (internal validation). Setting up an external validation requires a lot of effort (new data collection) and is mostly not carried out.

CHAPTER 3

Background of *Pamela*

3.1 Introduction

In the previous chapters, several aspects of parking policy and parking modeling have been discussed in more detail. The discussion shows that necessary insights into the effects of shopping area related parking policy are still limited. It also appears that parking models that intend to provide these insights are limited in terms of the shoppers' travel choices they cover and in terms of the parking and bicycle stall alternatives they consider. In most studies, parking choice is typically modeled as a function of parking facility attributes and distance from the parking facilities to the shopping center. Such an approach breaks down when motorists cannot find the parking space originally intended. In that case they have to adapt their parking choice behavior.

Based on the findings of previous studies, a conceptual framework for *Pamela* was developed. Basically *Pamela* is a parking analysis model that covers different travel and parking decisions from the moment an individual has decided to leave home until the moment the individual has completed his activity and leaves the parking facility. The input of the model can be the activity-travel patterns of any activity-based model of travel demand or the trip generation results of the more traditional four-step model approach.

This chapter is organized as follows. First, the general framework underlying *Pamela* will be explained including a description of all the decisions incorporated in the suggested approach (section 3.2). The models included in the framework are based on

the theory of individual choice behavior that is described in section 3.3. In addition, the theory of the model type used in the study, the Mixed Multinomial Logit model is outlined (section 3.4). Finally, some issues of the data collection method are described in more detail.

3.2 Conceptual framework underlying *Pamela*

The specific components of the conceptual framework underlying *Pamela* is presented in Figure 3.1. During the last several years, the components have been made operational and empirically tested. This thesis focuses on the parts of the framework that cover the parking consideration set, combined travel choice, and adaptive choice behavior.

The input to the model is an estimate of the number of individuals leaving their home for shopping across various days of the week. These numbers can be generated by any activity, trip or tour-based model of transport demand, but in this study it is linked to *Albatross*, a learning-based transportation oriented simulation system developed by Arentze and Timmermans (2000). The system simultaneously generates activity schedules for individual household members, in which activity selection of one adult household member depends on the activity schedule of the other adult, if any, in the household. The core component of the system is the scheduling engine. This component controls the scheduling process in terms of a sequence of steps that intends to stimulate the way individuals solve scheduling problems. The scheduler engine produces an individuals' activity schedule (including travel party, activity start time, and activity duration) and tours (including travel mode and location).

If such a link with a model of transport demand is not available, *Pamela* can be used to produce the choices of destination, travel mode, and parking facility (if the chosen mode is car). The outcome of this model is a prediction of parking demand for each available parking facility surrounding a particular destination at different times of the day. Theoretically, it is assumed that individuals will derive some utility from the combined choice of destination, travel mode and choice of parking facility. However, individual choice behavior is restricted: individuals are not necessarily familiar with all parking facilities in the environment of the shopping center. It is assumed that from the existing alternatives, only some may be known and not all are available. Hence, a choice will be made from the subset of considered alternatives. The choice of a parking facility will not only depend on the attributes of the facility, but also on its location in relation to the destinations to be visited and the purpose of the visit.

After a driver has arrived at the parking facility, the next decision involves finding a free parking space. This decision will be influenced by the exit point of the parking facility to the destinations to be visited and the location of the parking meters (unless payment is on exit). However, drivers may not be able to see all vacant lots if other cars have already been parked. Hence, finding a parking space may involve a search process. If the parking facility is fully occupied, the motorist will need to decide what to do: wait until a parking space becomes available (wait), park illegally (illegal), or perhaps leave the parking facility and go to another parking facility (search), shopping destination (else), or even break off the trip and go home (home).

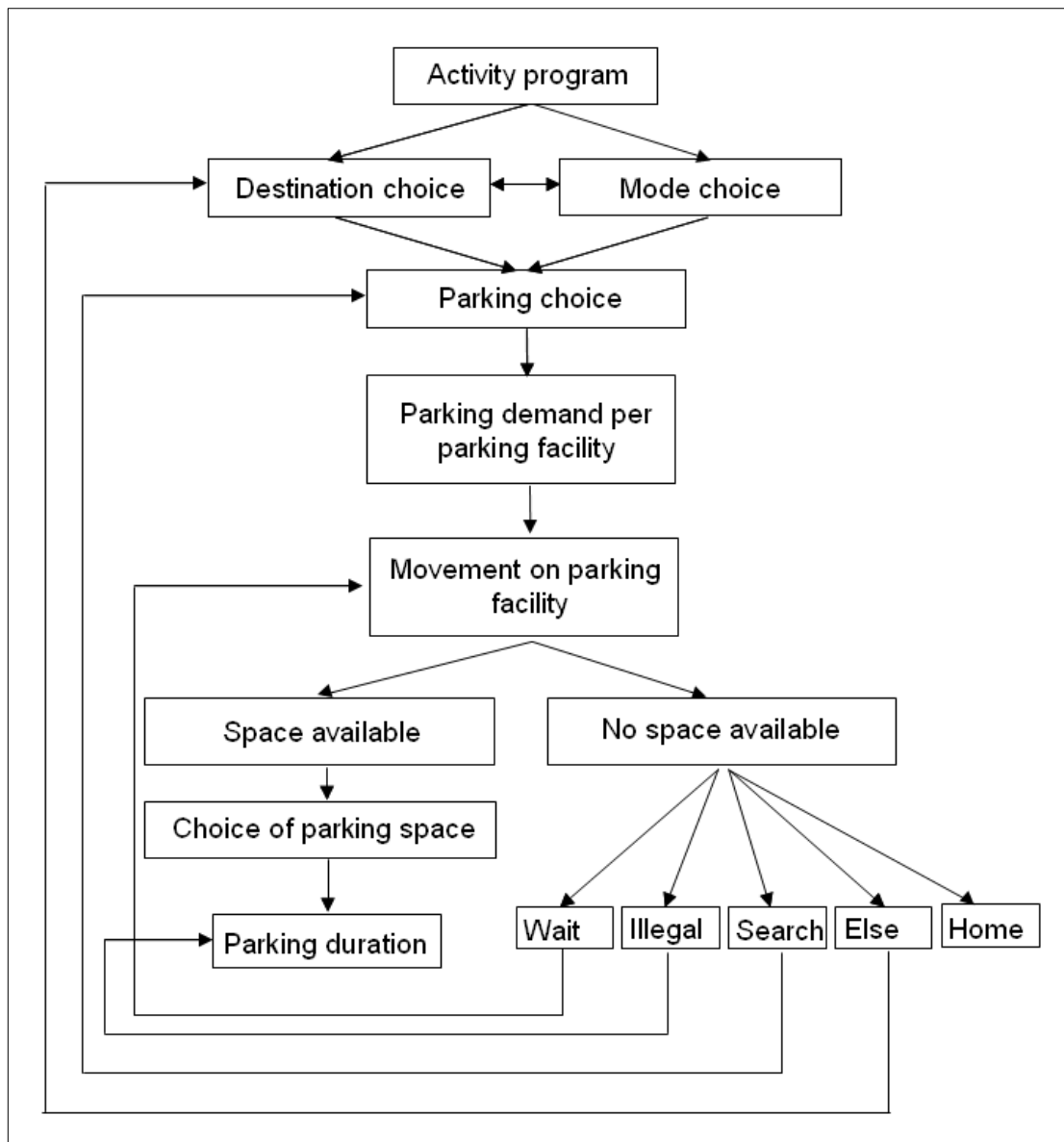


Figure 3.1: *Conceptual framework of Pamela*

A final decision, which of course will influence the decision previously described, concerns parking duration. The duration of parking may be dictated by the time required to conduct the activity or activities. For example, the shorter the duration, the less time there may be to search for a parking space unless the individual is willing to reschedule his or her activity program. Duration may also be influenced by maximum parking duration, time of payment, parking costs, and travel time (e.g., Van der Waerden *et al.*, 2000a).

3.3 Individual choice behavior

Parking choice models assume a process description of parking behavior, embedded in the larger context of activity-travel decisions. Individuals are assumed to make a set of sequential or simultaneous choices such as where to go, how late to leave, what mode to use, and, if the car is used, where to park the car. This implies that classical

theories of individual choice behavior (see e.g. Luce, 1959 for an overview) are potentially relevant for the parking simulation tool to be developed as well. A traveler's or individual's choice process consists of a sequence of decisions, leading to the ultimate choice (e.g., Louviere *et al.*, 2000). Six stages in this process can be distinguished (Figure 3.2). The traveler first becomes aware of needs and/or problems to be solved. Next, a period of information search is followed in which the traveler learns about alternatives that can satisfy the needs or solve the problems. During this period the traveler forms beliefs about which alternatives are available to obtain his/her objectives, attributes of alternatives relevant to a choice and attributes offered by alternatives, as well as any associated uncertainties. When the traveler is sufficiently informed he/she starts to valuing and trading off attributes that matter in the decision. Next, travelers develop a preference ordering for products based on the beliefs. Based on the ordering, the travelers make a choice for one of the alternatives. Louviere *et al.* (2000) also indicate that the traveler can wait until the right service is offered or the optimal price holds.

When setting up a choice model describing the choice process at least the following two aspects are important: the generation of the set of available alternatives (choice set) and the determination of the actual choice (behavior). The generation of the choice set is important because of the possible influence of the choice set on parameter estimates, and because of the possible dependency of the choice set on the prediction of market shares or externalities (e.g., Pagliara & Timmermans, 2009). In the context of parking, the issue of not choosing (post-choice evaluation) is related to adaptive parking choice behavior in which the traveler can not directly use the chosen parking alternative and has to adapt his/her parking choice.

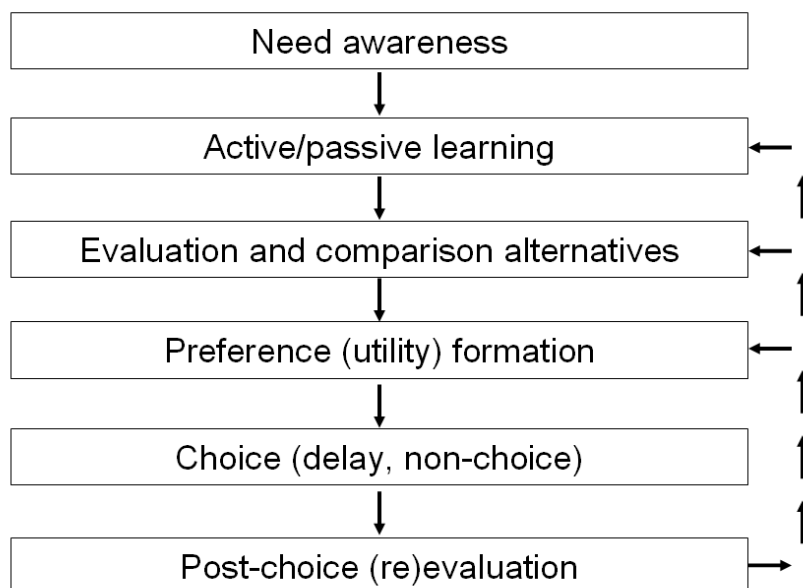


Figure 3.2: *Individual choice process (e.g., Louviere et al., 2000)*

Although differences between theories exist, they have some concepts and assumption in common and can be amalgamated into a more comprehensive conceptual framework as suggested by Timmermans (1982), who presented a conceptual model of individual decision making that underlies many theories and associated models of individual choice behavior (Figure 3.3). Choice alternatives (say parking facilities) are perceived as bundles of attributes, which may take on different values or levels. Individuals are assumed to derive a utility from the attributes of the choice alternatives (e.g., Lancaster, 1971). It is assumed that they derive a part-worth utility form each attribute. This involves a subjective trade-off among the perceived attribute levels. These part-worth utilities are combined according to some combination rule to arrive at an overall utility value for each choice alternative. Individuals choose alternatives from sets that may contain all the relevant alternatives or, if there are many potential alternatives, some comprehensive subset that is derived from pre-processing or screening of alternatives. Finally, given the utilities of the alternatives available in the choice set, a decision rule is used to select one (optimal) alternative from the set of available alternatives.

The relation between physical environment and spatial behavior can be approached differently. For example when using a revealed preference approach all stages presented in the marked frame of Figure 3.3 can be included in the data collection and analysis. In contrast, in the case of stated preference and choice approaches the physical environment is directly related to respectively the preferences and the spatial choice of an individual. In this case, the cognitive environment is not included in the process.

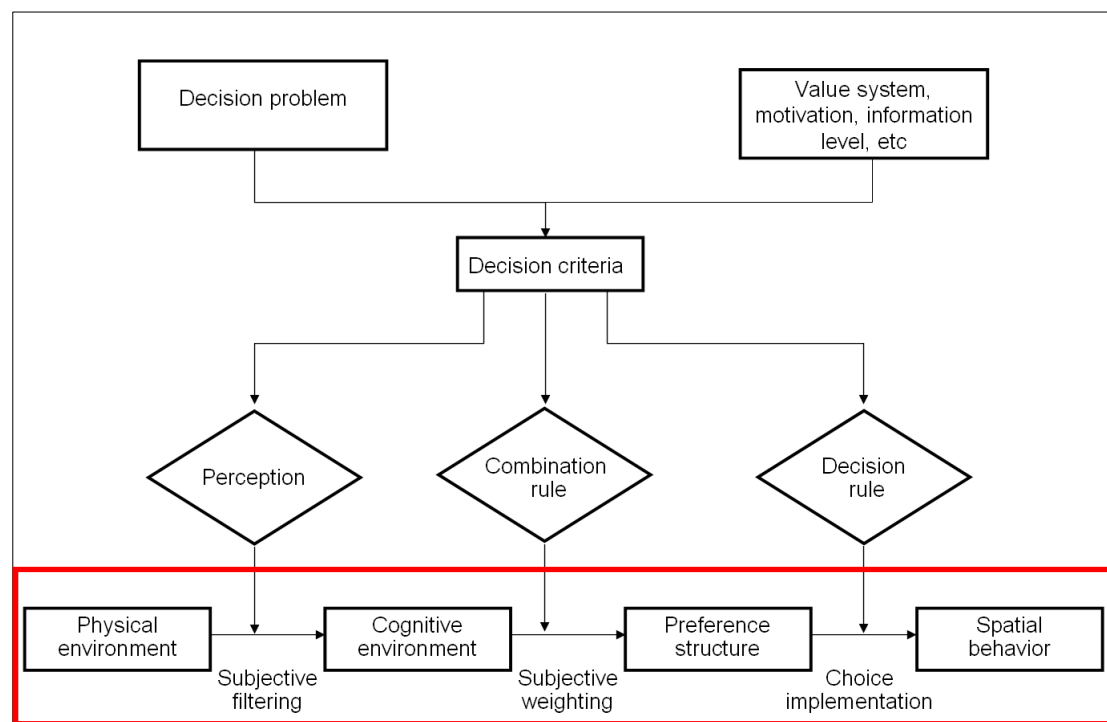


Figure 3.3: *Conceptual model of individual choice behavior*

In the utility theory two types of decision rules can be used to derive choice probabilities from the utilities of alternatives available: *strict utility theory* (Luce, 1959) and *random utility theory* (Torgerson, 1958). The first theory implies that the probability of choosing an alternative is directly proportional to its utility and inversely proportional to the total utility of alternatives in the choice set. Strict utility theory is probabilistic and can handle choice situations with multiple alternatives. However, it assumes that utilities can be expressed and measured perfectly, moreover, that utilities are fixed entities. These are not feasible assumptions in practical situations, where there is always measurement error and where people cannot be expected to exactly know and remember utility values of alternatives. Random utility theory accounts for various sources of variation by assuming that utilities can be decomposed into a systematic or deterministic component and a random or error component. The systematic component depends on the way in which individuals combine their part-worth utilities. Typically, a linear compensatory model is assumed, which means that low evaluations of a particular attribute may be compensated by high evaluations of one or more of the remaining attributes. The random component reflects inconsistencies exhibited by individuals and factors that cannot be measured by researchers. By making different assumptions about the distribution of the random component, a variety of discrete choice models can be formulated such as probit models (normally distribution, see Thurstone, 1927) and logit models (Gumbel distribution; see McFadden, 1974).

3.4 Mixed multinomial logit models

Various operational models have been suggested and applied in the context of individual choice behavior. These so-called discrete choice models differ in terms of operational decisions made with respect the specification of the utility function and error terms, if any. Discrete choice models describe an individual's choice of one option from a finite set of options (e.g., Ortúzar & Willumsen, 2001). Traditionally, the Multinomial Logit (MNL) model has been used to analyze discrete choices. The MNL model assumes that the random components are independently and identically double exponential (or Gumbel) distributed. The double exponential distribution is convenient because, in contrast to the normal distribution, it leads to a closed, hence tractable, model form as presented in equation 3.1 (e.g., Hensher & Johnson, 1981; Ben-Akiva & Lerman, 1985).

$$P_{qi} = \frac{e^{\mu V_{qi}}}{\sum_j e^{\mu V_{qj}}} \quad (3.1)$$

where,

P_{qi} is the probability that alternative i is chosen by individual q from a set of J alternatives;

V_{qi} is the systematic (or representative) utility of alternative i (see equation 3.2);

μ is a scale parameter, usually assumed to be equal to 1.0.

$$V_{qi} = \sum_k \beta_k \cdot X_{qik} \quad (3.2)$$

where,

x_{qik} represents the value of attribute k of alternative i for individual q ,
 β_k is a parameter indicating the contribution of attribute k to the utility of each alternative.

The MNL model is easy to estimate, but the model is not able to differentiate between individuals' tastes. Random taste variation across decision makers gives a more accurate representation of real world behavior than assuming the same taste for all decision makers (e.g., Hess & Polak, 2009). In contrast to MNL models, Multinomial Mixed Logit (MMNL) models or random parameter logit models allow for random taste variation in the population of decision makers. The models are flexible enough to completely relax the independence and identically distributed error structure of the MNL (Bhat *et al.*, 2008). Several examples show that MMNL models perform better than MNL models. For example, Hess & Polak (2009) compared several MNL parking choice models with MMNL models and concluded that MMNL models can lead to important gains in modeling parking behavior. Similarly, Borgers *et al.* (2010) found a substantial improvement in their study on residential parking choice behavior.

The MMNL models involve the integration of the MNL equation (equations 3.3 and 3.4) over the distribution of unobserved random parameters (e.g., Train, 2003; Bhat *et al.*, 2008):

$$P_{qi}(\theta) = \int_{-\infty}^{+\infty} P_{qi}(\beta) f(\beta | \theta) d(\beta), \quad (3.3)$$

where

$$P_{qi}(\beta) = \frac{e^{\sum_k \beta_k \cdot x_{qik}}}{\sum_j e^{\sum_k \beta_k \cdot x_{qjk}}} \quad (3.4)$$

where,

P_{qi} is the probability that individual q chooses alternative i ;
 x_{qik} represents for each individual q the value of each attribute k of alternative i ;
 β_k represents parameters of attribute k which are random realizations from a density function $f(\cdot)$;
 θ is a vector of underlying moment parameters characterizing $f(\cdot)$.

The structure of the MMNL model can be derived from a need to accommodate unobserved heterogeneity across individuals in their sensitivity to observed exogenous variables. It is related to the so-called random-parameters structure model and it is mostly used because of its compact formulation (Bhat *et al.*, 2008). In the case of random-parameters structure, the utility that an individual q derives from alternative i is written as (equation 3.5):

$$U_{qi} = \sum_k \beta_k' x_{qik} + \varepsilon_{qik} \quad (3.5)$$

where

- x_{qik} represents the value of attribute k of alternative i for individual q ,
- β_k represents parameters of attribute k which are random realizations from a density function $f(\cdot)$;
- ε_{qik} is assumed to be an independent and identically distributed (across alternatives) type I extreme value error term.

The density $f(\beta)$ is a function of parameters θ that represents, for example, the mean and (co)variance of the β 's in the population. In previous applications $f(\beta)$ has been specified to be normal or lognormal: $\beta \sim N(b, \sigma)$ or $\ln \beta \sim N(b, \sigma)$ with parameters b and σ that are estimated. For a large selection of parameters the normal distribution is a valid choice. The lognormal distribution is useful when the parameter is known to have the same sign for every decision maker, such as a price parameter that is known to be negative for everyone (Train, 2003). Also other distributions can be used such as uniform, triangular, and gamma distribution.

The specification of the MMNL model can be generalized for repeated choices by each sampled decision maker (see Train 2003). Repeated choices are common practice in stated preference surveys. The utility of alternative i in choice situation t by person q is presented in equation 3.6.

$$U_{qit} = \beta_k x_{qikt} + \varepsilon_{qikt} \quad (3.6)$$

with ε_{qikt} being independent and identically distributed extreme value over individual, alternative, attribute, and choice situation. The only difference between a MMNL with repeated choices and one with only one choice per individual is that the integrant involves a product of logit formulas, one for each choice, rather than just one logit formula.

The assumption of independent error terms may be invalid in the case of similar alternatives. Then, the error components may be correlated. This can be measured by the MMNL model as well. Such a mixed logit model does not exhibit independence from irrelevant alternatives (IIA) or the restrictive substitution patterns of logit (Train, 2003). To avoid IIA in a mixed multinomial logit model an additional random variable can be included with zero mean and standard deviation σ (equation 3.7). The estimated standard deviation (σ_γ) of this random component is a measure that represents the correlation between similar alternatives (e.g. parking facilities in the vicinity of a shopping destination or different car alternatives to the included shopping alternatives). This model is known as the *random component logit model* and enables including nested structures.

$$U_{qi} = \sum_k \beta_k' x_{qik} + \varepsilon_{qik} + \gamma_{qjk} \quad (3.7)$$

A major disadvantage of the MMNL model is its dependency on simulations due to the absence of a closed-form solution for the integral representing the choice

probabilities (Hess & Polak, 2009). The dimensionality of the integral (equal to the number of random parameters) will generally be sufficiently large to lead to a costly simulation process. To make the simulation process more efficient a variety of so-called quasi-random number sequences has been developed. A sequence often used in transportation is the Halton sequence that offers important savings when used in low-dimensional (≤ 9 dimensions) integration exercises. A high number of draws per individual and per dimension leads to very stable estimation results. The optimal number of draws is not known exactly and depends on the data, specification and type of draw. Chiou and Walker (2007) stated that it is critical not to stop at 200 (pseudo random, Halton or shuffled Halton) draws. Louviere *et al.* (2000) shows that model parameters become significant when the number of draws increases from 100 to 500. Hess & Polak (2009) and Bhat *et al.* (2008) suggest 1,000 draws. Borgers *et al.* (2010) found similar estimation results for 500 and 1,000 draws.

To evaluate the model estimates, the log-likelihood function can be used. The log-likelihood function of the model (equation 3.8) with the optimal β -parameters is defined as (e.g., Hensher & Johnson, 1981):

$$LL(\beta) = \sum_q \sum_i y_{qi} \ln(p_{qi}) \quad (3.8)$$

where q identifies a respondent. The value of y_{qi} is equal to unity if respondent q was observed to choose alternative i . For the evaluation of a model, the calculated $LL(\beta)$ is compared with the log-likelihood value of the model where all parameters are set to zero, the log-likelihood for the so-called equal shares (or null) model: $LL(0)$. The function of the $LL(0)$ is defined as (equation 3.9):

$$LL(0) = \sum_q \sum_i y_{qi} \ln(S_{qi}) \quad (3.9)$$

where S_{qi} is equal to $1/N_q$, where N_q is the number of alternatives in individual q 's choice set. The estimated model can be tested against this null-model using the Log-likelihood Ratio Statistic (LRS) (e.g., Ortúzar & Willumsen, 2001). The LRS is asymptotically χ^2 distributed with r degrees of freedom, where r is the number of linear restrictions. Rejection of the null hypothesis implies that the model with optimal parameters performs better than the model with parameters equal to zero. The LRS is defined as follows (equation 3.10):

$$LRS = -2[LL(0) - LL(\beta)] \quad (3.10)$$

In addition to the LRS, an index called McFadden's Rho-Square, can be calculated based on $LL(\beta)$ and $LL(0)$. The index is defined as follows (equation 3.11).

$$Rho^2 = 1 - [LL(\beta)/LL(0)] \quad (3.11)$$

Basically, the value of McFadden's Rho² varies between 0 (no fit) and 1 (perfect fit). Values between 0.2 and 0.4 are considered to be indicative of 'extremely' good model fits (Louviere *et al.*, 2000). According to Hensher, *et al.*, (2005), a Rho² of 0.3 or higher represents a 'decent' fit for a discrete choice model.

3.5 Revealed versus stated choice data

To estimate the model discussed in the previous section, various types of data and data collection methods can be used. The alternate approaches measure individuals' preferences or choices in different ways. Figure 3.4 shows an overview of various methods that have been used in the past, differentiating between revealed and stated preference/choice data. A main difference between revealed and stated data is that revealed data concern observations in real world situations, whereas stated preference/choice data refer to observations in controlled hypothetical situations. Preference data refers to ranking or rating alternatives while choice data refers to a choice of an alternative (e.g., Hensher *et al.*, 2005). In several studies the stated choice approach is adjusted to a so-called stated adaptation approach where choice alternatives are worked out as adaptation strategies (e.g., D'Arcier *et al.*, 1998; Arentze *et al.*, 2004; Kelly & Clinch, 2006).

The pros and cons of revealed and stated modeling approaches have been discussed in detail by several researchers (e.g., Louviere *et al.*, 2000; Ortúzar & Willumsen, 2001; Hensher *et al.*, 2005). The main characteristics of both approaches can be summarized as follows. Revealed preference data depict the world as it is now, possess inherent relationships between attributes, have only existing alternatives as observables, embody market and personal constraints on the decision maker, have high reliability and face validity, and yield one observation per person at each observation point. The following main limitations of the revealed preference approach are mentioned by the researchers.

- Observations of actual choices may not provide sufficient variability for constructing good models for evaluation and forecasting;
- The observed behavior may be dominated by a few factors making it very difficult to detect the relative importance of other variables;
- Exploratory factors of alternatives in the real world may correlate;
- It is difficult to collect responses regarding policies which are entirely new or contain new (never applied) planning measure;
- Observational data are time consuming and expensive to collect.

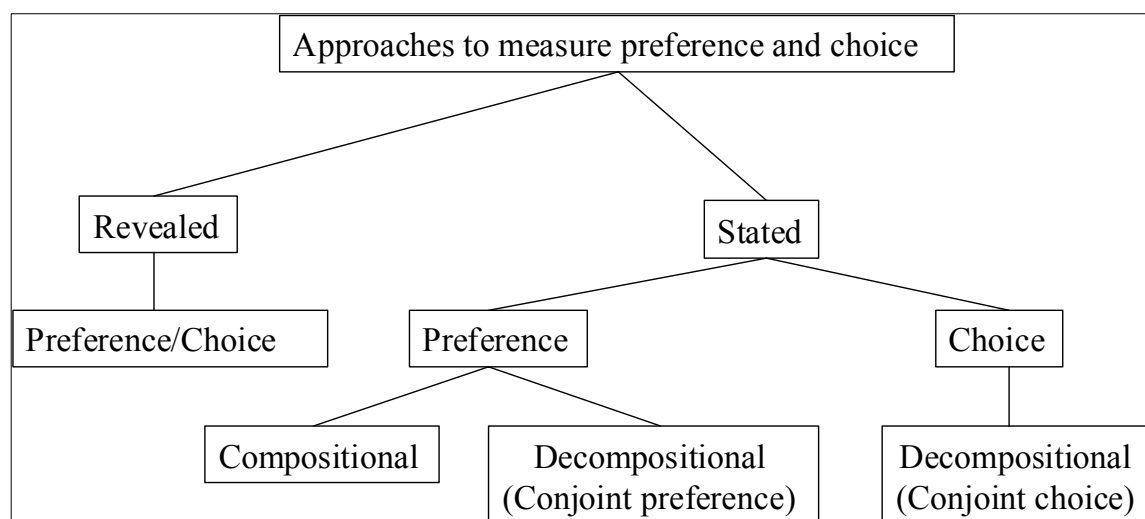


Figure 3.4: An overview of preference and choice measurements approaches (based on Kemperman, 2000)

In contrast, stated preference data describe hypothetical decision contexts and controls relationships between attributes, which permits mapping of utility functions with technologies different from existing ones, can include existing and/or proposed and/or generic choice alternatives, cannot easily represent changes in market and personal constraints effectively, seem to be reliable when respondents understand, are committed to and can respond to tasks, and can yield multiple observations per respondent at each observation point. A basic problem with stated preference data collection is how much faith we can put on individuals actually doing what they stated they would do when the case arises. Due to improved data collection methods the difference between predicted and actual choice decreases (e.g., Louviere, 1988; Timmermans *et al.*, 1992). Van der Waerden *et al.* (2000b) found similar results when applying the stated choice approach in the context of modeling the composition of consideration sets. Their study also learned that it is important to consider the context or real world experience of respondents when analyzing the stated choice behavior. In addition to these findings, Ortúzar & Willumsen (2001) give an overview of guidelines to achieve a higher degree of realism in the responses when conducting a stated choice experiment. One has to focus on specific rather than general behavior in a realistic choice context. The constraints of choice required have to be retained to make the context realistic. When describing alternatives, it is necessary to include all relevant attributes and use existing (perceived) levels of attributes. The respondents' perception of what is possible can be used to limit the attribute levels. The choice options have to be clearly and unambiguously defined. Allow respondents to opt for a response outside the set of experimental alternative. Include an option like 'None of these' or 'Keep current choice'. Despite the complex reality it is necessary to design the choice experiments as simple as possible.

The set up of the different stated choice experiments follows the stages as suggested by Ortúzar & Willumsen (2001).

- Identification of the key attributes of each alternative and construction of the 'packages' constituting the choice options;
- Design of the way in which the options will be presented to the respondents and how they will be allowed to express their preferences;
- Development of a sampling strategy to be followed to ensure a rich and representative data set;
- Appropriate conduct of the survey including supervision and quality-assurance procedures;
- Use of model estimation techniques;
- Elaborate an internal and external validation.

3.6 Conclusion

In this chapter, the conceptual framework underlying the parking analysis model *Pamela* including the theoretical bases of the framework, have been presented. *Pamela* intends to include the decision process of residents starting at the moment residents decide to go out for shopping and ending at the moment residents leave the chosen parking facility and go home. Therefore, the framework is set up as a sequence of models that describe the generation of residents' parking choice sets, the combined choice of shopping destination, travel mode, and parking/stall choice, the movement

of cars on the chosen parking facility, the adaptive parking choice when a fully parking facility is faced, and the duration of parking.

The chapter gives an overview of the theories the framework is based on. The choice decisions included in the framework are embedded in the theory of individual choice behavior. To describe the choice behavior in a formal way the use of discrete choice models is suggested. More specifically, the mixed multinomial logit model is introduced as the most suitable modeling technique in this context. Because of the complexity of the decision process, the requirement of controlling the attributes, and the absence of variety in certain parking attributes, the data to estimate the model will be collected using stated choice experiments.

Most choice decisions are at the macroscopic level (destination, travel mode and parking choice, and adaptive parking choice) while other choices are more at the microscopic level such as the choice of parking space. The following models of **Pamela** will be worked out in this thesis (see chapter 4): parking choice set composition, combined travel choice behavior consisting of destination, mode, and parking choice, and adaptive parking choice behavior. The models will be implemented in a multi-agent system covering all actions of **Pamela** except the movement of car on the individual parking lots.

CHAPTER 4

Models of *Pamela*

4.1 Introduction

In this chapter, the suggested models of *Pamela* will be described in more detail. As mentioned in the previous chapter, the study focuses on the following three major models: the composition of the traveler's parking consideration set, the traveler's combined choice of travel mode, destination, and bicycle stall/parking, and traveler's adaptive parking choice behavior when she/he faces a fully occupied parking facility. For all three models, a separate stated choice experiment is constructed that was included in a mail back questionnaire.

The remainder of the chapter is organized as follows. First, the structure of stated choice experiment for the traveler's parking consideration set is described (section 4.2). The section includes an overview of the selected parking attributes and an example of a choice task as it was included in the questionnaire. In section 4.3, the experiment for the combined travel choice is explained in more detailed. Again, attention is paid to the selected attributes and an example of the choice task. In the next section (4.4), the set up of experiment for car drivers' adaptive choice behavior is explained. The selected attributes and the choice task as it appeared in the questionnaire are presented. In section 4.5, attention is paid to the implementation of the stated choice experiments in the written questionnaire that was distributed in the town of Veldhoven (closely located to the city of Eindhoven) and a part of the city of Eindhoven. The chapter ends with the conclusions (section 4.6).

4.2 Consideration set model

As described before, most car drivers are not aware of or do not consider all parking facilities surrounding shopping destinations (e.g., Van der Waerden & Borgers, 1995; Thompson & Richardson, 1998). As it is difficult to judge which parking lots are considered by the car drivers, it was decided to conduct a stated choice experiment. In this experiment, respondents were asked to state whether they would consider several ‘hypothetical’ parking facilities for their trip. Respondents had to assume that they used the car for a weekly or non-weekly shopping trip. Based on findings in previous studies (see Appendix A2) and local circumstances the parking facilities were specified using the following set of attributes: size of the parking facility (number of spaces); chance of finding a free parking space; parking costs per hour (in Dutch Guilders, 1 DFL is equal to 0.45 Euro); maximum allowed parking duration; average time needed to leave the parking facility (egress time); availability of driving space in the parking facility; type of parking facility; type of security; the location of the parking facility vis-à-vis the individuals’ residence; location of the parking facility vis-à-vis other parking facilities; and the distance to the closest supermarket or department store. Each characteristic was defined at three levels (Table 4.1).

The definition of the different attribute levels fits in the tradition of previous studies (see chapter 3, section 3). Some levels were described in a very precise manner (minutes, meters, etc.), while other attributes were described more crudely.

The availability of driving space refers to the space surrounding parking spaces that can be used to maneuver the car into the parking spaces. For type of parking only two levels are specified. Because all other attributes are specified using three levels, for type of parking one of the levels is used twice in the design for the choice task. The residential location of the car driver was defined as follows: if the parking is located between residence and shopping center, the level is ‘Favorable’. If the parking is located behind the shopping center, the level is ‘Unfavorable’ and if the parking facility is located at the same distance and in the same direction from home as the shopping center, the level is ‘Neutral’.

Table 4.1: *Attributes and attribute levels for the consideration set task*

<i>Attributes</i>	<i>Levels</i>		
Size of the parking facility	50 spaces	250 spaces	450 spaces
Chance of finding a free parking space	25 %	50 %	75 %
Parking costs per hour	free	DFL 1.00	DFL 2.00
Maximum parking duration	unlimited	max 3 hours	max 1 hour
Average egress time	0 minutes	2 minutes	4 minutes
Driving space in the parking facility	limited	average	spacious
Type of parking facility	parking lot	-	parking garage
Type of security	none	video	guards
Location in relation to residence	favorable	neutral	unfavorable
Location in relation to other parking facilities	close	neutral	at distance
Distance to supermarket/department store ¹	50 meters	150 meters	250 meters

¹dependent on type of purchases: weekly (supermarket) and non-weekly (department stores) goods

<i>Attributes</i>	<i>Parking facility</i>
Size of the parking facility	250 spaces
Chance of a free parking space	25%
Parking cost per hour	DFL 1.00
Maximum parking duration	maximum of 3 hrs
Average egress time	2 minutes
Driving space in the parking facility	spacious
Type of parking facility	parking lot
Type of security	none
Location in relation to origin	neutral
Location in relation to other parking facilities	at distance
Distance to supermarket	150 meter
Would you consider this parking facility for weekly shopping?	<input type="radio"/> Yes <input type="radio"/> No

Figure 4.1: Example of the parking consideration task for weekly shopping

Regarding the levels of the location vis-à-vis other parking facilities, the following strategy was followed. Parking facilities close to each other and at the same side (relative to the residential location) of the shopping center were classified as ‘Close’. Parking facilities that can be reached within a few minutes were classified as ‘Neutral’ and parking facilities that are at some distance at the opposite site of the shopping center were classified as ‘At distance’.

Parking profiles were generated, by varying the defined attribute levels according to a fraction of the 3^{11} full factorial design consisting of 27 different profiles. Figure 4.1 shows an example of the choice task as it was included in the questionnaire. The stated choice experiment was designed as follows. After a short introduction of the context (‘Image that you are going to make a trip for weekly shopping ...’), the relevant attributes of the parking facilities, and a full description of an example task were presented. For every choice task, the respondent was asked to indicate whether he or she would consider a predefined parking facility for a (weekly or non-weekly) shopping trip.

Before starting the actual experiment, the respondent was invited to carefully evaluate the example task. This action was included to give each respondent the same basic knowledge of the stated choice experiment. In the actual experiment, each respondent was invited to evaluate three randomly selected parking facilities from the set of generated alternatives.

4.3 Combined travel choice model

The core component of *Pamela* covers three different travel choices: the choice of destination, travel mode, and bicycle stall/parking. The studies of Polak *et al.* (1990) and Meurs *et al.* (1997a; 1997b) show that these three travel choices are strongly related to each other. Therefore, it is decided that the three travel choices are investigated in combination. Respondents had to choose specific combinations of destination, mode and parking facility. For the choice of shopping destinations two attributes were included in the model: the supply of shops and the distribution of shops across the shopping area (Table 4.2). The supply of shops was described by the following three levels: limited, average, and broad. The levels were briefly explained

in the questionnaire. Limited was defined as ‘there is only one shop or department in each type of shop and only one supermarket’. Average was described as ‘there is only one shop or department in each type of shop and there are two supermarkets/department stores’, while Broad was defined as ‘in each type of shop there are more shops or departments present in the shopping center’. The distribution of shops focuses on the location of shops vis-à-vis other shops and buildings like houses and offices, in the shopping area. The attribute levels were scattered, concentrated, and dense. Also these attribute levels were defined in more detail in the questionnaire. Scattered was defined as ‘shops are widely scattered along different roads surrounded by houses and offices’. Concentrated was described as ‘shops are close to each other along several roads, only a few houses or offices are present’. Dense was defined as ‘shops are close to each other along a limited number of roads and almost no houses and offices are present’. For all attribute levels an example of a shopping center in Veldhoven (selected study area, see section 5.2) was added to the description.

The travel time of the various modes was included in the model to describe the choice of a mode. The travel time for the car included the time needed to find a parking space while the travel time for the bicycle included the time needed to store the bicycle. The travel time for the bus included the walking time from home to bus stop, the waiting time at the bus stop, and the walking time from bus stop to final destination.

Individuals, who had chosen for the car, had to choose a parking facility from a set of parking facilities. These facilities were described by means of three attributes: the walk distance from the parking facility to a specific shop (closest supermarket for daily shopping and closest department store for non-daily shopping), the parking costs, and the maximum parking duration. Shoppers, who had chosen for the bicycle, had to decide whether they will use a bicycle stall or not. The bicycle stalls were characterized by the following attributes: level of security, storage charges, and the walking distance from the bicycle stall and a specific shop.

Table 4.2: *Attributes and attribute levels for the combined travel choice task*

<i>Alternatives</i>	<i>Attributes</i>	<i>Attribute levels</i>
Shopping destinations	Supply of shops Distribution of shops	limited, average, broad scattered, concentrated, dense
Travel modes	Travel time Car Travel time Bicycle Travel time Bus	5, 15, 25 minutes 10, 20, 30 minutes 10, 15, 20 minutes
Parking facilities	Walking distance to final destination Parking costs Maximum parking duration	50, 150, 250 meter free, DFL 1.00/hour, DFL 2.00/hour unlimited, max 3 hours, max 1 hour
Bicycle stalls	Level of security Storage charge Walking distance to final destination	secured, unsecured free, DFL 0.50/time, DFL 1.00/time 25, 75, 125 meter

The attributes and attribute levels were used to define choice tasks. Each choice task consisted of three destinations with each three modes and a certain number (4, 2, or 1) of parking facilities and one bicycle stall. Each shopping center was combined with three travel modes. The car alternative was accompanied by a different number of parking facilities depending on the involved shopping destination. For the bicycle alternative respondents could choose for using a specified bicycle stall or not. There was no choice included between different bicycle stalls within one shopping center. Thus, the respondent had to choose from 16 alternatives or combinations (see Figure 4.2).

The levels of the 34 attributes of the first two shopping centers (shopping center I and II) and accompanying modes (car, bicycle, and bus) and parking facilities were varied according to a fraction of the 3^{34} fractional factorial design (developed by D. Anderson, e.g., Anderson *et al.*, 1992). This fractional design consisted of 81 different choice profiles. The third shopping destination (shopping center III) was added to the profiles and served as a constant base alternative which means that the attribute levels of the shopping center, travel modes, parking facility, and bicycle stall were fixed for all choice tasks and respondents at the levels as presented in Figure 4.2.

This experiment was included in the written questionnaire. The experiment was structured as follows. After a brief introduction of the choice task, the involved attributes of the shopping destinations, the travel modes, the parking facilities, and the bicycle stalls were presented to the respondent. Next, a detailed description of an example task was given. Each respondent was invited to read the description carefully, and to fill out the example by choosing one of the choice alternatives. Finally, each respondent was asked to evaluate three randomly selected choice profiles. This decision resulted in 27 different sets of combined travel choice tasks.

4.4 Adaptive parking choice model

As presented in the conceptual framework of *Pamela*, after entering the chosen parking a car driver might not find any free space to park. In this case, it is assumed that the car driver reacts by adapting his/her parking behavior. To get insight in car drivers' adaptive parking choice a stated choice experiment was designed. In this experiment, five different adaptive choices were distinguished. First, motorists may choose to wait until a parking space becomes available. Motorists are likely to adopt this strategy when they feel it takes less time to wait than to drive to another parking facility. Second, motorists may choose to park illegally, especially when they think the risk of being fined is small. Third, motorists may decide to go to another parking facility and continue their search for a free space at that parking. This strategy seems most likely for motorists who do not want to risk a parking fine and who find that the waiting line is too long. Fourth, motorists can decide to shop elsewhere a strategy that is most likely in the case of large congestion in the vicinity of the shopping center. Of course, the car drivers also can decide to terminate their shopping trip and return home.

SHOPPING CENTER- ATTRIBUTES supply of shops distribution of shops	SHOPPING CENTER I limited scattered				SHOPPING CENTER II broad scattered			SHOPPING CENTER III broad dense							
travel time	CAR 10 min				BICYC LE 10 min	BUS 10 min	CAR 15 min			BICYC LE 20 min	BUS 20 min	CAR 20 min		BICYC LE 30 min	BUS 20 min
PARKING FACILITIES distance to supermarket parking costs/hour max. parking duration	P1 150 m free max 1hr	P2 50 m DFL 2.00 unlimited	P3 250 m free unlimited	P4 50 m DFL 1.00 max 3hrs			P1 150 m free unlimited	P2 50 m DFL 1.00 max 3hrs			P1 250 m DFL 2.00 max 1hr				
BICYCLE STALLS level of security storage charge/time distance to supermarket					F1 unsecured DFL 0.50 25 m				F1 secured free 25 m				F1 secured DFL 1.00 125 m		
CHOICE, <u>check only one box</u>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Use bicycle stall <input type="checkbox"/> yes <input type="checkbox"/> no	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Use bicycle stall <input type="checkbox"/> yes <input type="checkbox"/> no	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Use bicycle stall <input type="checkbox"/> yes <input type="checkbox"/> no	<input type="checkbox"/>	<input type="checkbox"/>

Figure 4.2: Example of the choice task for combined travel choice

Table 4.3: *Attributes and attribute levels for the adaptive parking choice task*

<i>Attribute</i>	<i>Levels</i>		
Expected waiting time	2 minutes	5 minutes	8 minutes
Number of parking facilities visited before	none	one	two
Number of cars waiting	2 cars	4 cars	6 cars
Travel time to an alternative parking facility	2 minutes	5 minutes	8 minutes
Probability of a free space on the alternative lot	25%	50%	75%
Parking costs on the alternative lot	free	DFL 1.00	DFL 2.00
Space present for illegal parking	verge	footpath	road
Chance of getting a parking fine	25%	50%	75%

It is assumed that the probability of implementing one of the strategies depends on attributes of the parking situation faced by the car driver, the trip history of the car driver, and the location and price level of alternative parking facilities. The parking situation was defined by the set of attributes presented in Table 4.3.

The attribute levels were combined to formulate possible scenarios of parking situations. An orthogonal fraction consisting of 81 scenarios was selected from the 3^8 full factorial design. This design allows the estimation of all main effects and a set of first order interaction effects. The design of the 81 scenarios was randomly split into 27 sets of adaptive parking choice tasks. Each respondent received one set, implying that respondents were asked to identify their likely adaptive behavior for 3 scenarios. Figure 4.3 shows an example of a scenario as it appeared in the questionnaire. Again, the tasks were preceded by a brief introduction of the choice task, an explanation of the included variables, an example choice task, a detailed description of this example, and the invitation to evaluate the example task.

4.5 Questionnaire

The stated choice experiments were included in a written questionnaire that was distributed across households in Veldhoven and Eindhoven (Figure 4.4). The questionnaire consisted of an introduction letter and a set of questions.

<i>Attributes</i>	<i>Parking facility</i>
Expected waiting time	5 minutes
Number of parking facilities visited before	One
Number of cars waiting	2
Travel time to an alternative parking facility	2 minutes
Probability of a free space on the alternative facility	25%
Parking costs on the alternative facility	free
Space present for illegal parking	sidewalk
Chance of getting a parking fine	75%
What will be your reaction if the chosen parking facility is fully occupied?	<input type="radio"/> Wait for free space <input type="radio"/> Illegal parking <input type="radio"/> Search another facility <input type="radio"/> Shop elsewhere <input type="radio"/> Go home

Figure 4.3: *Example of adaptive parking choice task*

The introduction letter described the research goals of the study and invited residents to participate. The questions of the questionnaire were grouped into 5 parts. The first part of the questionnaire focuses on different characteristics of the respondents' travel behavior: shopping destination, visit duration, visit frequency, and most common visiting part(s) of the day. Also some questions were asked concerning the respondents parking consideration set and parking choice. These questions were only asked to respondents who use the car when visiting one of the major shopping centers in the region. Three shopping centers were included in the questionnaire: Veldhoven City Center (Figure 4.5); Eindhoven City Center (Figure 4.6); and Eindhoven Shopping Center Woensel (Figure 4.7). Veldhoven City Center is a regional shopping center consisting of approximately 120 shops including shoe and clothing stores, supermarkets, appliance and department stores. The Shopping Center Woensel, located in the northern part of Eindhoven, is also a regional shopping center. The shopping center consists of approximately 160 stores including local, national, and international operating stores. The Eindhoven inner city area consists of more than 500 stores. All shopping centers are surrounded by several parking facilities, bicycle stalls, and bus stops.

The second, third, and fourth part of the questionnaire cover the stated choice experiments as described before. The final part of the questionnaire deals with the respondents' reaction to the introduction of paid parking at the Veldhoven City Center.

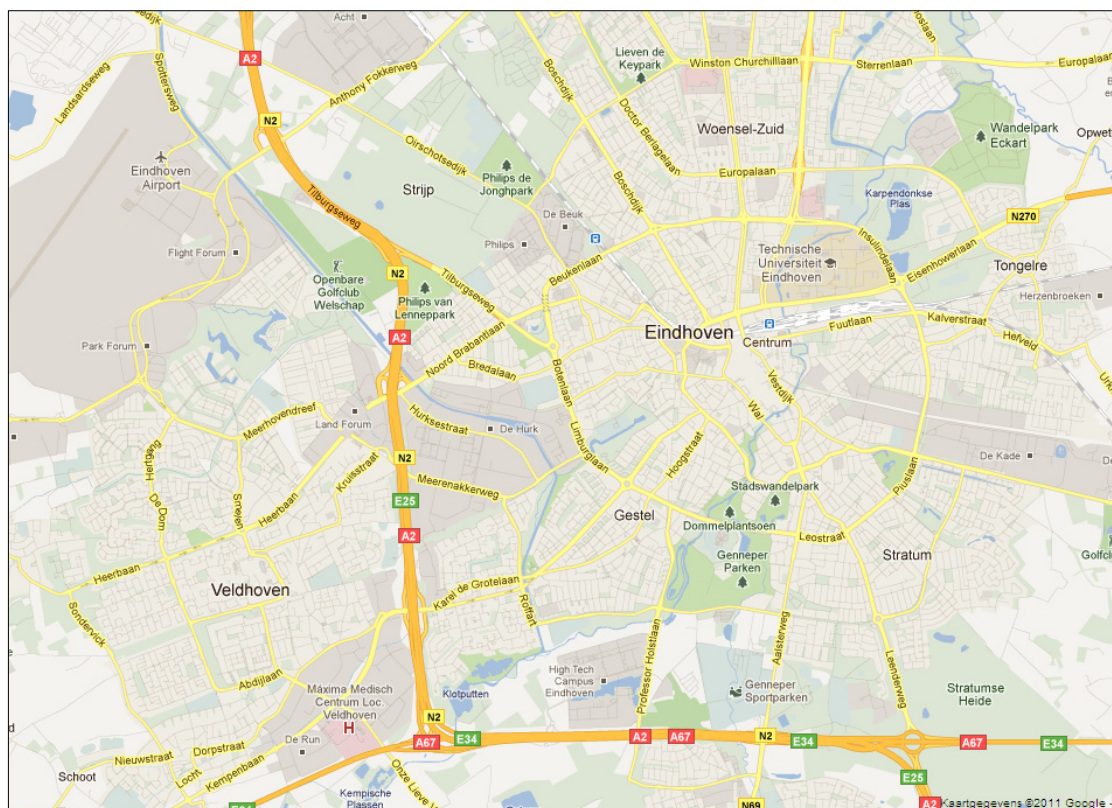


Figure 4.4: Map of Veldhoven and Eindhoven (source: Google Maps)

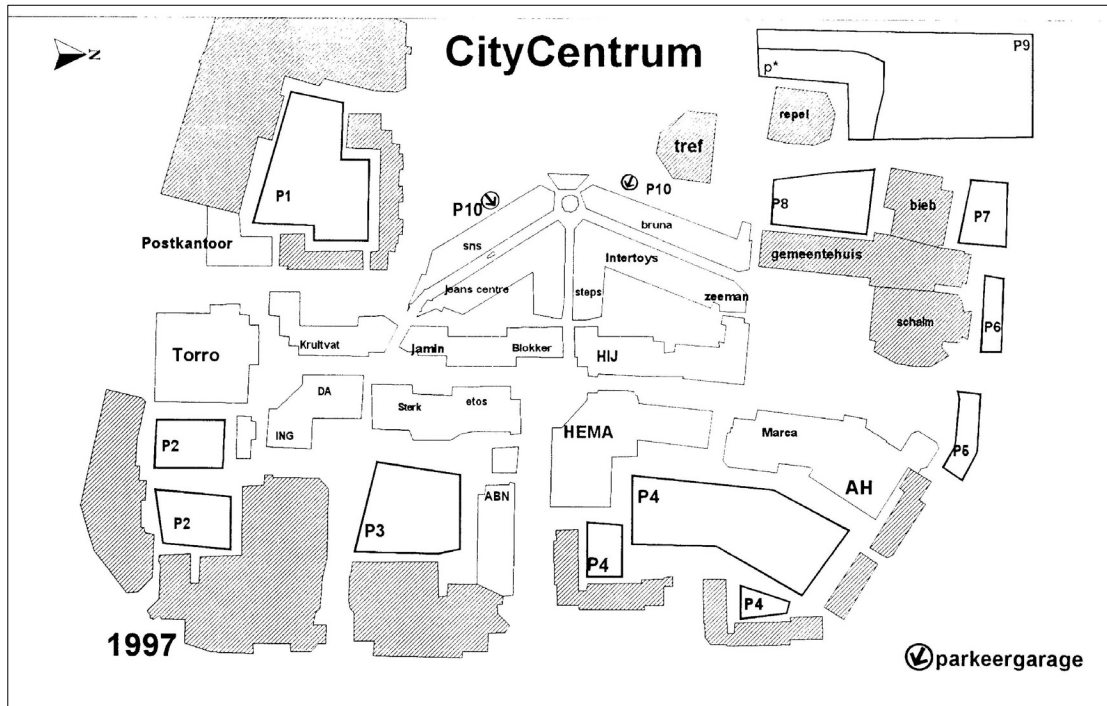


Figure 4.5: Map of the shopping center Veldhoven City Center (scale 1:4400) as included in the questionnaire

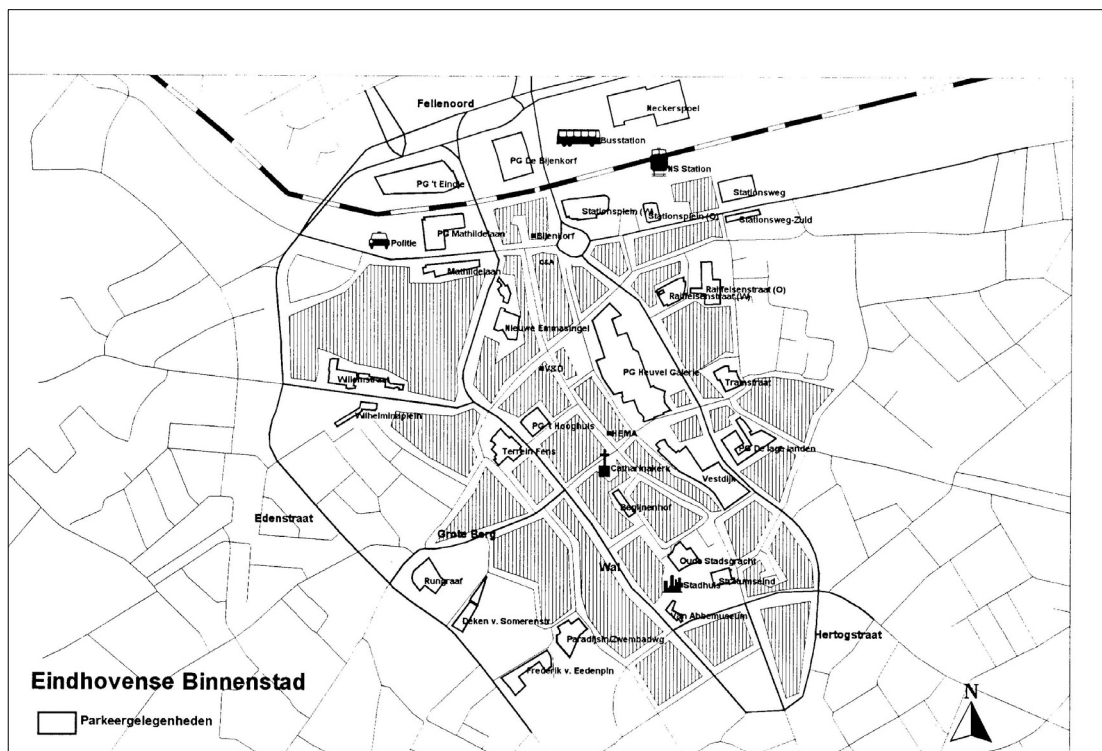


Figure 4.6: Map of the shopping center Eindhoven City Center (scale 1:17400) as included in the questionnaire

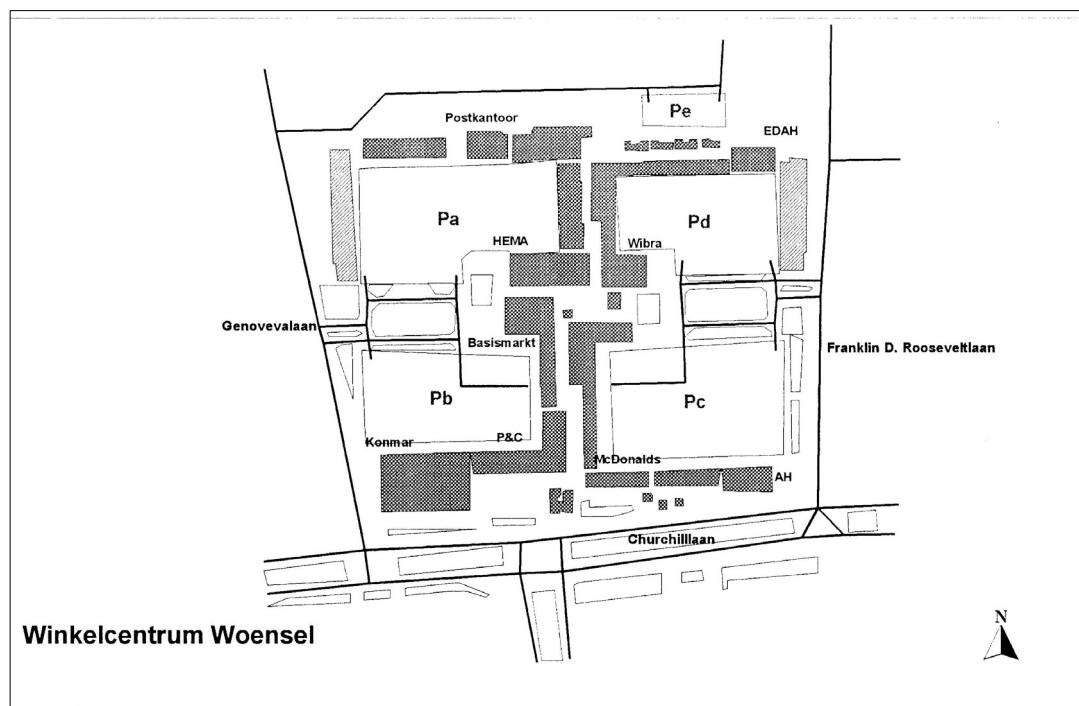


Figure 4.7: Map of the Shopping Center Woensel (scale 1:7000) as included in the questionnaire

Because of expected differences in travel choice behavior two different questionnaires were developed. One group of respondents was asked to fill out the questionnaire for weekly shopping trips (weekly purchases of food, cleaning material, personal care, etc.). In their choice tasks, the distance between parking facility and shopping destination is represented by the distance from the parking facility to the closest supermarket in the shopping center. The other respondents were asked to fill out the questionnaire for non-weekly shopping (purchases of clothes, shoes, appliance goods, etc.). In this case, the distance between parking facility and shopping destination is represented by the distance between parking facility and the closest department store in the shopping center.

In total, 54 different versions of the questionnaire were generated; 27 for weekly shopping trips and 27 for non-weekly shopping trips. For each shopping type a questionnaire consisted of three combined travel choice tasks (27 times 3 gives 81 profiles, see section 4.3). The 27 sets of three combined travel choice tasks were subdivided into three groups of 9 sets. Within each group of 9 sets, three randomly selected parking consideration tasks were added to each set of combined travel choices (9 times 3 gives 27, see section 4.2). Finally, three randomly chosen choice tasks from the adaptive parking choice experiment (section 4.4) were added to each set of combined travel and parking consideration task (Figure 4.8).

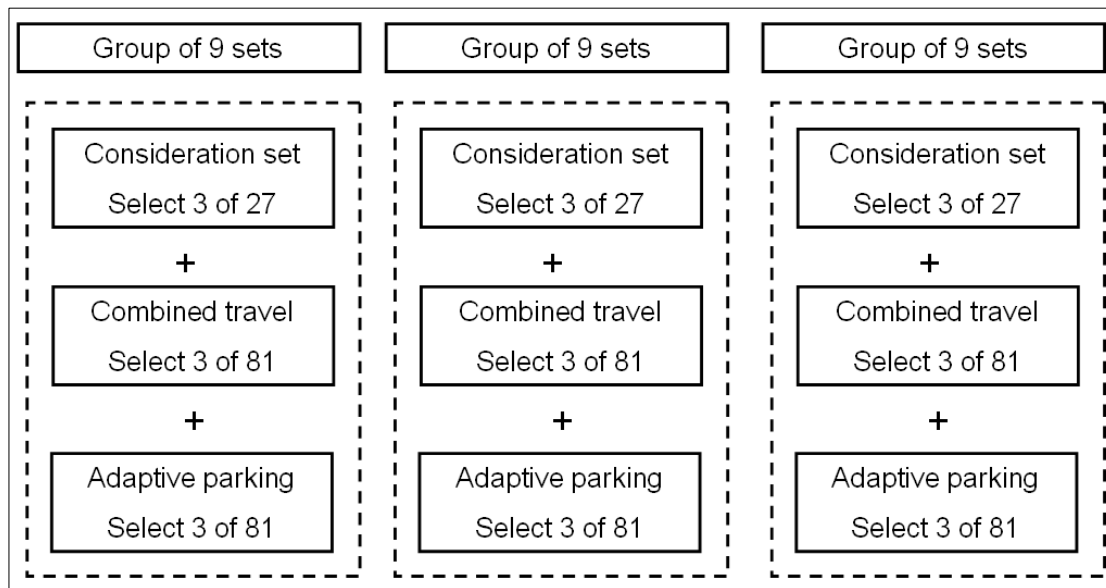


Figure 4.8: *Combination of different choice tasks*

4.6 Conclusion

In this chapter the three major models of the parking analysis model *Pamela* were described in detail. More specifically, the stated choice experiments to investigate the generation of parking choice set, combined travel choice including destination, travel mode and parking/stall choice, and adaptive parking choice behavior were presented including all the attributes used to describe the choice situation of shoppers. In the choice task for the consideration set, parking facilities were defined using eleven different attributes with three attribute levels each (except type of parking that ranges over two attribute levels). Each respondent was asked to evaluate three predefined parking facilities. The alternatives in the combined travel choice task were defined using thirty-four attributes: four for destination alternatives, six for travel mode alternatives, eighteen for parking alternatives and six for bicycle stall alternatives. The attributes were included alternative specific for two destinations, six modes, six parking facilities, and two bicycle stalls. The respondents' task consisted of making a choice out of 16 choice alternatives (including 4 base alternatives, see section 4.3). Again respondents were asked to evaluate three different choice tasks. The final task included the adaptive parking choice behavior. The choice situation was defined using eight attributes with each 3 levels. Respondents were asked to evaluate three choice situations by choosing one of the five options: wait, park illegally, search, go elsewhere, and go home. The developed stated choice experiments were included in an extensive mail back questionnaire that also included questions regarding the respondents' revealed choice behavior. The maximum number of choice tasks (81 tasks in the combined travel and adapted parking choice part) resulted into 27 different questionnaires for each trip purpose (weekly and non-weekly shopping).

CHAPTER 5

Data collection and model estimation

5.1 Introduction

As explained in chapter 4 (section 4.5), the data used for the estimation of the different sub-models of *Pamela* were gathered in the town of Veldhoven (all neighborhoods) and the city of Eindhoven (four neighborhoods adjacent to Veldhoven), two municipalities in the South of the Netherlands. The number of inhabitants of Veldhoven is approximately 45,000. Approximately 15,000 residents live in the neighborhoods of Eindhoven that are included in this study.

In this chapter, attention is paid to the set up of the data collection (section 5.2). Next, the response is described in more detail. Attention is paid to the composition of the sample, and respondents' shopping and parking behavior. The chapter continues with the presentation of the results of the model estimation process (section 5.3). In section 5.4, the findings of the model estimation process are summarized and discussed.

5.2 Data collection

In the spring of 1997, a total of 11,000 reply cards were distributed door-to-door in Veldhoven and a part of Eindhoven (Figure 5.1). Approximately 1500 residents returned the reply card by mail indicating that they were willing to participate in the study. These residents received one of the versions of the developed questionnaire. The versions were randomly distributed across the respondents. Residents who filled out the questionnaire had a chance of winning one of the 10 gift vouchers of DFL

50.00 (approximately 23.00 euro's). A total of 1024 inhabitants who frequently visit the main shopping centers of Veldhoven and Eindhoven returned the final questionnaire. The number of respondents who filled out the questionnaire for weekly shopping trips is equal to 529, while 495 respondents filled out the questionnaire for non-weekly shopping trips.

Table 5.1 presents some characteristics of the respondents per type of shopping trip. It appears that for the characteristics age and home location, the respondents are well distributed across the distinguished levels. The distribution across characteristic levels of the other characteristics is not equal. For the characteristics drivers' license and car availability the observed distribution is what one can expect in the two cities. The distribution of the respondents across gender is equal to findings in other shopping related studies (e.g., Borgers & Vosters, 2011).

To get some more background information, additional information concerning the respondents' shopping and parking behavior was collected. In particular, the following data were collected: average visit duration per trip, annual visit frequency, most frequent visiting day, most used travel mode, and most visited shopping center. Table 5.2 presents an overview of the structure of the respondents' shopping behavior. The distribution across the different characteristic levels is according to general expectations. It appears that for weekly shopping the respondents stay less than or equal to 60 minutes, while for non-weekly shopping the majority of respondents stays more than 90 minutes. Most weekly shoppers visit the shopping center once a week for weekly shopping and less than less than once per week for non-weekly shopping. The most frequent shopping day for both weekly and non-weekly shopping appears to be a weekday. The car is the most frequently used travel mode for both weekly and non-weekly shopping. Almost all respondents visit the Veldhoven city center or one of the neighborhood centers for weekly shopping. For non-weekly shopping, respondents visit the centers of Veldhoven and Eindhoven.

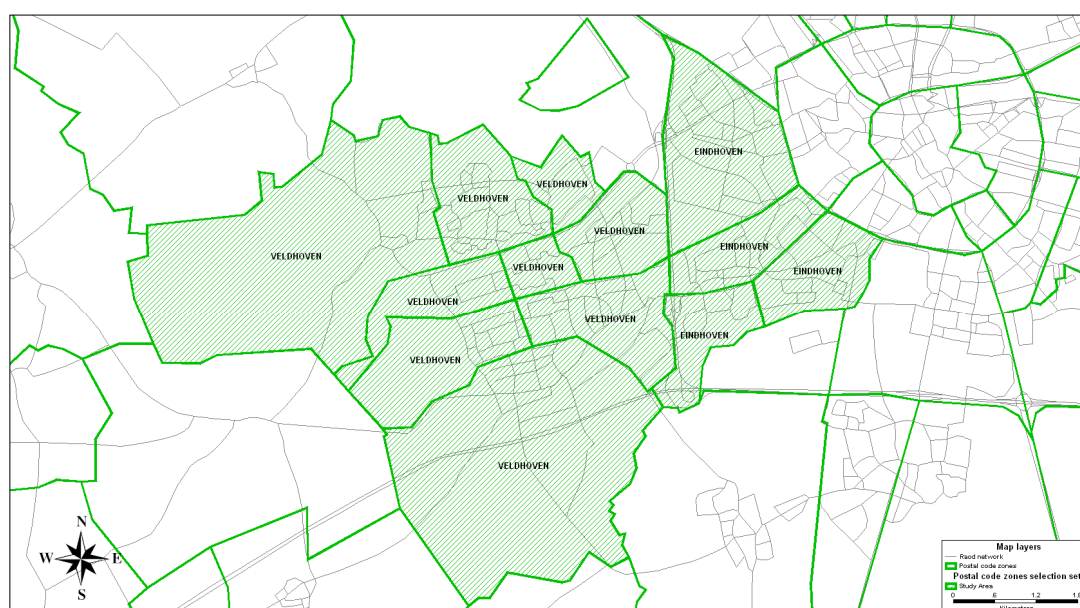


Figure 5.1: Study area: Veldhoven and part of Eindhoven

Table 5.1: *Characteristics of the respondents per type of shopping trip (percentages)*

Characteristic	Levels	Shopping trip	
		Weekly	Non-weekly
Gender	Male	27.8	25.5
	Female	71.8	74.1
	Unknown	0.4	0.4
Age	Younger than 40 year	38.9	41.6
	Between 40-56 year	33.6	32.5
	Older than 55 year	27.2	25.1
	Unknown	0.2	0.8
Residential location	Center of Veldhoven	41.8	41.3
	At some distance from center	57.6	57.1
	Unknown	0.6	1.6
Drivers License	Yes	93.4	92.1
	No	6.4	7.3
	Unknown	0.2	0.6
Car availability	Yes	95.1	90.7
	No	4.7	8.7
	Unknown	0.2	0.6
Number of respondents		529	495
Percentage of total (N=1024)		52	48

Regarding revealed parking choice behavior, for each respondent the parking facility he/she regular uses is identified for the three major shopping centers in the study area (Veldhoven city center, Eindhoven city center, and Eindhoven Woensel). Table 5.3 presents the respondents' parking choices for the most frequently used parking facilities. For the Veldhoven city center, it appears that parking P1 is very popular, followed by parking facilities P4, P2, and P10 (see figure 4.4). Parking facility Mathildelaan (see figure 4.5) is the most popular in the case a respondent visits Eindhoven city center. In the case of Woensel the respondents distribute across parking facilities P_b and P_a (see figure 4.6).

Table 5.2: *Shopping characteristics of respondents per type of shopping trip (percentages)*

Shopping characteristic	Level	Type of shopping trip		Total
		Weekly	Non-weekly	
Visit duration (N _w =525) (N _{nw} =489)	Less than or equal to 60 minutes	58.3	22.7	41.1
	Between 60 and 90 minutes	28.0	21.1	24.7
	More than 90 minutes	13.7	56.2	34.2
Visit frequency (N _w =526) (N _{nw} =489)	Less than once per week	5.1	64.0	33.5
	Once a week	61.8	23.3	43.3
	More than once per week	33.1	12.7	23.3
Visiting day (N _w =523) (N _{nw} =491)	Weekday	56.8	49.5	53.3
	Weekend	16.6	28.3	22.3
	Mixed	26.6	22.2	24.5
Travel mode* (N _w =245) (N _{nw} =325)	Car	53.9	65.5	60.5
	Bicycle	33.1	22.8	27.2
	Walking	13.1	11.7	12.3
Most visited shopping center (N _w =527) (N _{nw} =494)	Veldhoven city center	52.4	59.3	55.7
	Eindhoven city center	0.0	26.7	12.9
	Eindhoven Woensel	0.2	2.6	1.4
	Other (neighborhood centers)	47.4	11.3	30.0

*This data was collected in a separate shopping behavior related questionnaire (developed by A. Borgers, 1997)

Table 5.3: Respondents' parking choice for three major shopping centers

<i>Veldhoven city center</i>		<i>Eindhoven city center</i>		<i>Eindhoven Woensel</i>	
<i>Parking*</i>	<i>Percentage</i>	<i>Parking*</i>	<i>Percentage</i>	<i>Parking*</i>	<i>Percentage</i>
P1	29.6	Mathildelaan	50.4	P _b	38.4
P4	19.3	Heuvelgalerie	9.3	P _a	37.2
P2	17.4	Meckerspoel	3.3	P _c	12.3
P10	15.3	De Bijenkorf	2.9	P _d	12.0
P3	6.6	PSV stadion	2.7		
N	817	N	452	N	341

*For numbers see Figures 4.4, 4.5, and 4.6

Table 5.4: Respondents' consideration sets for three major shopping centers

<i>Veldhoven city center</i>		<i>Eindhoven city center</i>		<i>Eindhoven Woensel</i>	
<i>Number of parking facilities</i>	<i>Percentage</i>	<i>Number of parking facilities</i>	<i>Percentage</i>	<i>Number of parking facilities</i>	<i>Percentage</i>
1	6.6	1	18.8	1	22.5
2	13.8	2	23.2	2	23.4
3	11.3	3	13.1	3	6.1
4	11.6	4	11.7	4	44.8
5	9.3	5	9.5	5	3.2
More than 5	47.4	More than 5	23.7		
N	817	N	452	N	341

Table 5.5: Overview of response per component of *Pamela*

<i>Choice</i>	<i>Trip</i>	<i>Respondents</i>	<i>Number of tasks per respondent</i>				<i>Total tasks</i>
			<i>0 tasks</i>	<i>1 task</i>	<i>2 tasks</i>	<i>3 tasks</i>	
Consideration	Weekly	529	32	13	1	483	1464
	Non-weekly	495	40	7	9	439	1342
Combined travel	Weekly	529	159	14	3	353	1079
	Non-weekly	495	217	2	2	274	828
Adaptive choice	Weekly	529	40	8	2	479	1449
	Non-weekly	495	46	4	1	444	1338

To get insights into the consideration sets of respondents, respondents were asked to indicate which parking facilities they consider to use when visiting one of the investigated shopping centers. It appears that the majority of respondents, who visit Veldhoven city center, consider 5 or more parking facilities when they visit the shopping center by car (Table 5.4). In the case of Eindhoven city center, the size of the consideration set is more diverse, ranging from 1 parking facility to more than 5 parking facilities. A similar picture is found for the shopping center Eindhoven Woensel.

For each model included in this thesis, the response used to estimate the model parameters are presented in Table 5.5. A large number of the respondents have filled out the stated choice parts for consideration set and adaptive choice behavior (more than 90 percent). The number of respondents who have completed the combined travel choice task is limited (70 percent in the case of weekly shopping trips, and 56 percent in the case of non-weekly shopping trips). This might be caused by the complexity of the choice task. Most of the respondents have evaluated all three tasks that were presented in the questionnaire.

5.3 Model estimation

The data of the respondents were used to estimate the parameters of the mixed multinomial logit (MMNL) models that describe the various components of the respondents' choice behavior. As mentioned in section 3.4 MMNL models allow checking for heterogeneity across respondents and substitution effects between alternatives which might improve estimation results. The program NLOGIT (Greene, 2007) was used to estimate the parameters. Unfortunately, the program has some limitations. The maximum number of parameters that can be estimated simultaneously is equal to 100. The Halton method, as it is implemented in NLOGIT allows the estimation of a maximum of 25 random parameters. For most models the result of these restrictions is a stepwise estimation process. To cancel out inaccuracies for all models, the number of draws was set to 1000 as suggested by different researchers (see section 3.4).

The models estimated in this thesis are specified as follows. Consider a travel choice situation of multiple residents who want to go out for shopping. Let $q = 1, 2, \dots, Q$ denote the individuals involved. A choice alternative i ($i=1, 2, \dots, I$) is considered to consist of a set of K attributes, $k = 1, 2, \dots, K$, represented by vector X_i . Assume that the utility of a choice alternative i for resident q is some function of the preference or part-worth utility of that individual for its attributes (equation 5.1). Then:

$$U_i^q = f^q(X_i) \quad (5.1)$$

In general, f may be a non-linear, non-additive, context-dependent function of attributes. Realizing that every attribute k with L_k levels can be coded in terms of L_k-1 indicator variables, a general form for equation (1) can be expressed as shown in equation 5.2. In this study effect coding is used to represent all effects of the attribute levels.

$$U_i^q = \beta_{io}^q + \sum_{k=1}^K \sum_{l=1}^{L_k-1} \beta_{kl}^q(X_{ikl}) \quad (5.2)$$

In the equation, the component β_{io}^q represents the base utility of individual q for choice alternative i . For each β -parameter, the standard deviation of a distributed random component was estimated (the σ -parameter, see section 3.4) using the Normal distribution offered by NLOGIT (see Train, 2003). The effect of repeated choice was included in the estimation process. For each individual one random number for each random variable was generated regardless the number of evaluated tasks.

Because of differences found in car drivers' behavior in the context of weekly and non-weekly shopping trips (Van der Waerden *et al.*, 2006) it was decided to include so-called context variables that cover the influence of type of shopping trip on the mean effects of the attribute levels. By creating context variables, additional parameters can be estimated to test for differences between subsamples of weekly and non-weekly shoppers. The context effects can be modeled as follows (equation 5.3):

$$U_i^q = \beta_{io}^q + \sum_{k=1}^K \sum_{l=1}^{L_k-1} \beta_{kl}^q(X_{ikl}) + \delta_{io} C^s + \sum_{k=0}^K \sum_{l=1}^{L_k-1} \delta_{kl} C^s(X_{ikl}) \quad (5.3)$$

Variable C^s indicates the subsamples: $C^1 = +1$ (weekly shopping) and $C^2 = -1$ (non-weekly shopping). The β -parameters measure the mean part-worth utility across contexts while the δ -parameters measure the deviation in part-worth utilities due to the subsamples. Note that in this thesis the models do not include individuals' taste variation for the context variables.

5.3.1 Consideration set model

The stated choice data of the consideration set model were analyzed using a mixed multinomial logit model with the consideration of a parking (yes or no) as the dependent variable and the selected attributes of the parking as independent variables: size of the parking facility, chance of finding a free parking space, parking costs per hour, maximum parking duration, average egress time, driving space in the parking facility, type of parking facility, type of security, location in relation to residence, Location in relation to other parking facilities, and distance to supermarket / department store. To find the optimal model, the following strategy was followed in the estimation process. First, a model with all mean (β) and context (δ) parameters, and standard deviations (σ) of the distribution functions of all mean parameters (β) was estimated. Then, step by step, non-significant standard deviations were removed from the model. This process ended with only significant standard deviations of parameter distributions. The estimation process shows that only for a selection of attributes the standard deviations could be estimated and appeared to be significant. An overview of the final estimation results is presented in Table 5.6.

The estimated model was tested against a model with all coefficients equal to zero (null-model) using the Log-likelihood Ratio Statistic (LRS). The LRS-value indicates that the estimated model performs significantly better than the model without parameters (null model). The LRS-value is equal to 781.310 while the critical Chi-square value for 51 degrees of freedom is approximately equal to 68.33 at the confidence level of 95 percent. With a Rho-squared value of 0.201 and an adjusted Rho-squared of 0.186, the model performs quite well. The presence of a parking facility in the consideration set is correctly predicted at 70.3 percent. It also appears that the MMNL model performs significantly better than the standard MNL model. The optimal log-likelihood of the MMNL model is equal to -1554.32 (51 degrees of freedom) while the optimal log-likelihood of the MNL model is equal to -1582.67 (44 degrees of freedom). The LRS is equal to 56.7 which is more than the critical Chi-square value for 7 (51 minus 44) degrees of freedom, that is equal to 14.07.

Regarding the effects of the *mean parameters* (β), it appears that at least one attribute level of each attribute is significant at the conventional level (95 percent), except for the attributes 'size of parking facility', 'type of security', and 'location vis-à-vis other parking facilities'. All significant parameters are in anticipated direction. On average, the probability of considering a parking facility increases with an increasing chance of finding a free parking space, lower parking costs, increasing maximum parking duration, lower average parking egress time, increasing driving space at the parking facility, favorable location vis-à-vis the residence, and lower distance to the nearest supermarket/department store in the shopping area.

Table 5.6: *Estimated mean and context parameters for the consideration of parking facilities*

Attributes	Levels		Parameters	
			Mean	Context
Constant		Mean	-0.1795	-0.4876
		Std Deviation		
Size of the parking facility	50 spaces	Mean	-0.0080	0.0343
		Std Deviation		
	250 spaces	Mean	0.1825	0.2149
		Std Deviation		
Chance of finding a free parking space	25 %	Mean	-0.8406	-0.0525
		Std Deviation	1.4184	
	50 %	Mean	0.1145	-0.0218
		Std Deviation		
Parking cost per hour	Free	Mean	1.6213	0.3431
		Std Deviation	1.4247	
	DFL 1.00	Mean	-0.0886	-0.0214
		Std Deviation	1.0014	
Maximum parking duration	Unlimited	Mean	1.3346	-0.4384
		Std Deviation	0.9356	
	Max 3 hours	Mean	0.4305	-0.0861
		Std Deviation		
Average egress time	0 minutes	Mean	0.2416	0.1025
		Std Deviation		
	2 minutes	Mean	-0.1625	-0.1054
		Std Deviation		
Driving space at the parking facility	Limited	Mean	-0.4159	-0.0062
		Std Deviation		
	Average	Mean	-0.0080	0.0915
		Std Deviation		
Type of parking facility	Lot	Mean	0.1610	-0.0423
		Std Deviation		
Type of security	None	Mean	-0.1192	0.0025
		Std Deviation	1.4057	
	Video	Mean	0.0713	0.1335
		Std Deviation		
Location vis-à-vis the home location	Favorable	Mean	0.4641	0.0816
		Std Deviation		
	Neutral	Mean	0.2829	0.0441
		Std Deviation		
Location vis-à-vis other parking facilities	Close	Mean	0.0166	-0.0108
		Std Deviation		
	Neutral	Mean	0.1623	0.0119
		Std Deviation		
Distance to supermarket/department store	50 meters	Mean	0.9145	0.4061
		Std Deviation	1.0604	
	150 meters	Mean	-0.0344	-0.0074
		Std Deviation	0.9319	
Goodness-of-fit				
Log-likelihood of the null model, LL(0)			-1944.971	
Log-likelihood of the optimal model, LL(B)			-1554.316	
LRS=-2[LL(0)-LL(B)]			781.310 (df 51)	
McFadden's Rho-Square ML			0.201	
McFadden's adjusted Rho-Square ML			0.186	
McFadden's Rho-Square MNL			0.186	
McFadden's adjusted Rho-Square MNL			0.173	

Bold: significant at 95-percent confidence level ($\alpha < 0.05$)

In addition, it appears that the assumption of heterogeneity is supported by a significant standard deviation for a number of attribute levels. This means that there is random variation across the respondents regarding these attribute levels. Note that in three cases (parking costs – DFL 1.00; security – none; distance to supermarket/department store – 150 meters) the standard deviation is significantly

different from zero, while the corresponding mean value is not. This suggests that preferences of individuals regarding these attribute levels fluctuate around zero (apart from context effects), cancelling out the neutral mean values (e.g., Borgers & Vosters, 2011).

Only four *context parameters* (δ) are significant at the conventional level: ‘Constant’, ‘Parking costs – free’, ‘Maximum parking duration – unlimited’, and ‘Distance to supermarket/department store – 50 meters’. The significant context parameter of the ‘Constant’ shows that car drivers who travel for weekly shopping do hardly consider the included parking facilities while car drivers who travel for non-weekly shopping do consider these parking facilities.

Regarding parking costs, it appears that for weekly shopping trips car drivers have a higher preference for free parking facilities than in the case they conduct non-weekly shopping trips. This effect is analogous to general expectations and can be explained by differences in the nature of weekly and non-weekly shopping trips (duration, frequency, and voluntariness). In the case of maximum parking duration, car drivers who visit the shopping center for non-weekly shopping trips have a higher preference for no duration restriction than car drivers who visit the center for weekly shopping trips. Finally, car drivers who visit the center for weekly shopping trips have a higher preference for car parks close to their (main) destination than car drivers who visit the shopping center for non-weekly shopping trips. The total effect of the attributes parking costs, maximum parking duration, and distance to supermarket/ department store is shown in Figures 5.2 a-c.

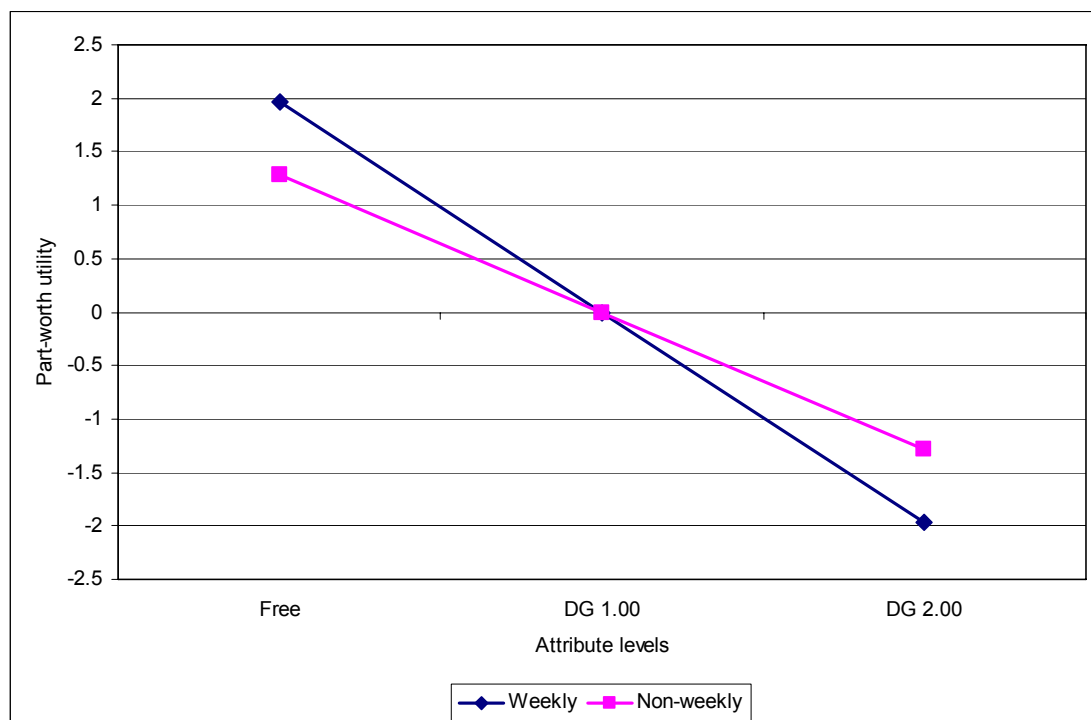


Figure 5.2a: Total effect of attribute ‘Parking costs’ (consideration set model)

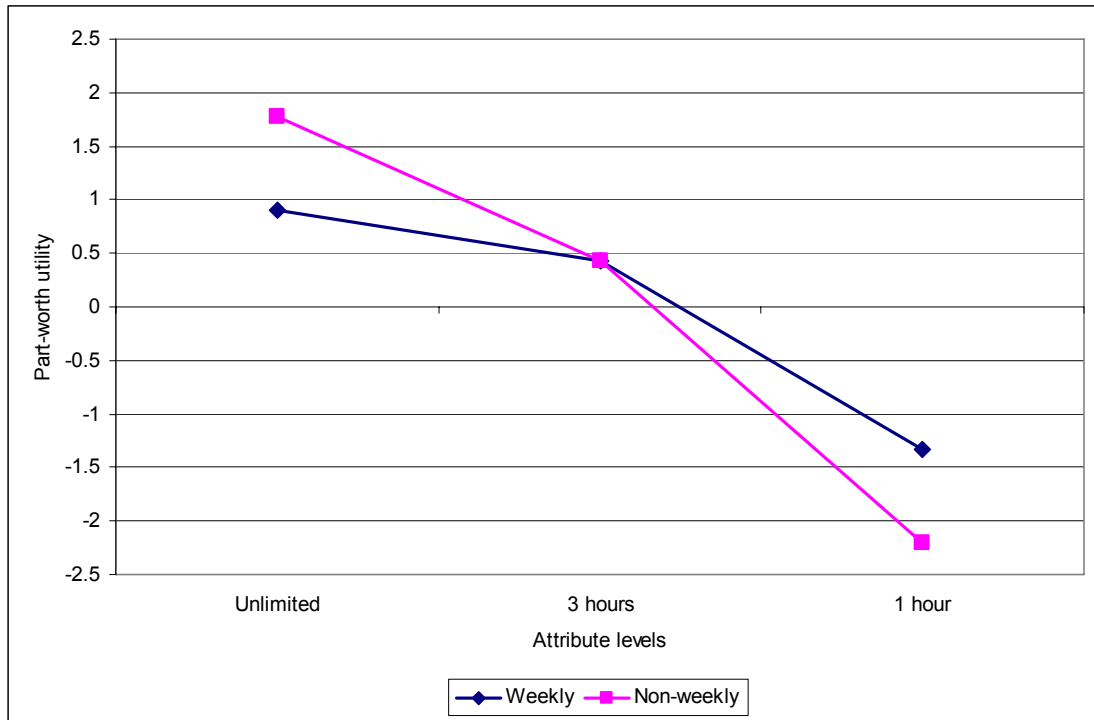


Figure 5.2b: Total effect of attribute 'Maximum parking duration' (consideration set model)

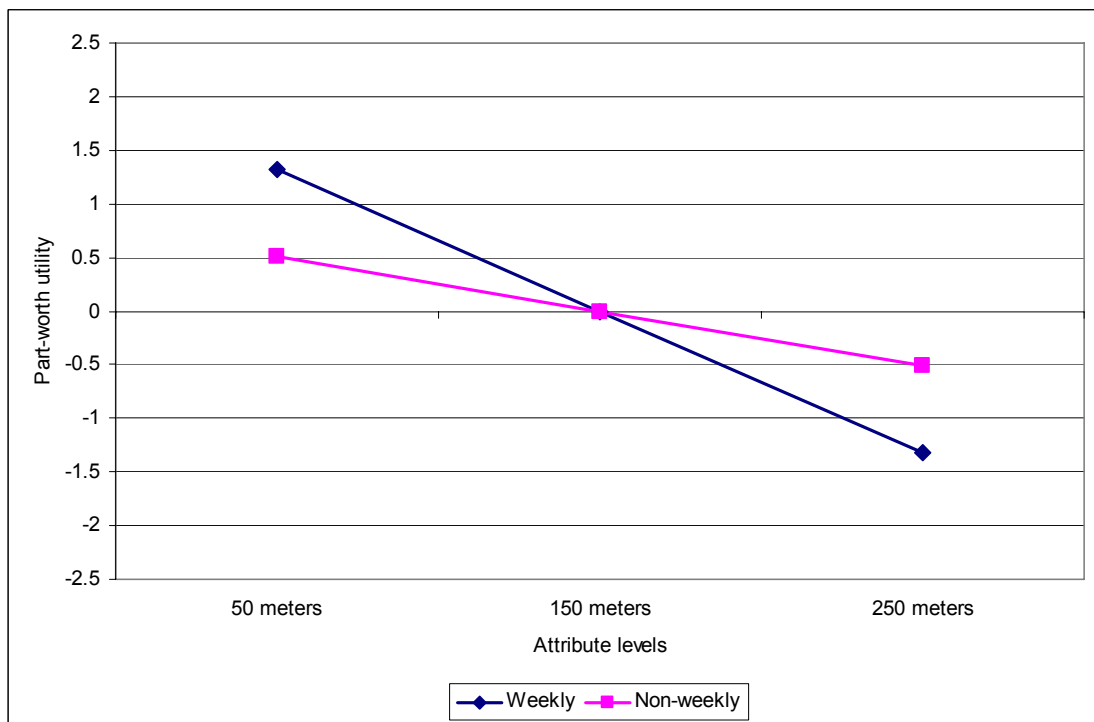


Figure 5.2c: Total effect of attribute 'Distance to supermarket/department store' (consideration set model)

For planners the results are interesting because it shows that there is a diversity of parking characteristics available to influence car drivers' consideration set. It appears that the most traditional characteristics (e.g., parking costs, parking duration, and walking distance) have the highest influence but also 'less conventional' characteristics such as chance of free space, egress time, driving space, and location vis-à-vis home can be used to change car drivers parking consideration set. The results also show that the effects of changes in the most influential characteristics are related to the visiting purpose (weekly or non-weekly shopping) of car drivers who visit the shopping center. A change in parking costs from free to DFL 1.00 has more effect on the part-worth utility of weekly shoppers (decrease of 1.96) than on the part-worth utility of non-weekly shoppers (decrease of 1.28). It is also interesting to see that the MMNL is able to include taste differences for the most influential parking characteristics. This helps the discussion concerning the influence of individual preferences that is not captured by the traditional parking models.

5.3.2 Combined travel choice model

The second model describes the residents' combined travel choices of shopping destination, travel mode, and parking or bicycle stall in the context of shopping trips. These choice data were also analyzed using a mixed multinomial logit model with the combined mode, destination and parking/stall choice (in total 16 choice alternatives) as dependent variable and the selected attributes of the shopping destinations, travel modes and parking/stall facilities as independent variables. The shopping centers are characterized by the variables supply of shops and distribution of shops. The travel modes car, bicycle, and bus are represented by the travel time of each mode. Parking facilities are represented using the variables walking distance from parking to supermarket/department store, parking costs, and maximum parking duration. The variables level of security, storage costs, and walking distance from bicycle stall to supermarket/department store describe the bicycle stalls. The model is completed with some constants. The first two constants represent the different number of parking facilities that surround the shopping centers compared to the base shopping center (4 and 2 parking facilities versus 1 parking facility). The third and fourth constants represent the base utility of the travel alternatives car and bicycle versus the alternative bus. In addition, the standard deviations of these constants provide insight into the level of similarities between car related alternatives and between bicycle related alternatives. Similar to the previous model, the included context parameters (δ) represent differences between weekly (+1) and non-weekly (-1) shopping trips.

Looking at the model performance, it appears that the model performs very well (Table 5.7). Both the Rho-square value (0.377) and the adjusted Rho-square value (0.376) show that the model is very well able to represent the combined travel choices of the residents. The percentage correctly predicted combined travel choice is equal to 36.2 that is considerably better than the percentage (100 percent divided by 16 alternatives resulting in 6.3 percent) of the null model. The LRS shows that the optimal model outperforms the null model (all parameters equal to zero). The LRS is equal to 3984.98. The Critical chi-square value for 60 degrees of freedom is at the confidence level of 95 percent approximately equal to 79.08.

Table 5.7: *Parameter estimates of the combined travel choice model*

<i>Attributes</i>	<i>Levels</i>	<i>Mean</i>	<i>Std.dev.</i>	<i>Context</i>
Constants	Shopping center (4 facilities)	0.2648	2.1382	0.9823
	Shopping center (2 facilities)	0.0773	1.4773	0.9431
	Car	7.4292	7.2295	3.6945
	Bicycle	2.0292	6.2128	2.8876
Supply of shops	Limited	-1.4933	1.4510	0.3307
	Average	0.2615	1.0416	0.0100
Distribution of shops	Scattered	-0.9954		0.1599
	Concentrated	0.4044		-0.1133
Travel time car	5 minutes	0.4999		0.2374
	15 minutes	0.1603	0.9183	-0.0757
Travel time bicycle	10 minutes	2.6921	2.4193	0.2904
	20 minutes	0.4359		0.1068
Travel time bus	10 minutes	1.6366		0.8668
	15 minutes	0.1628		0.4388
Walking distance from parking	50 meters	0.9119	1.1211	0.3334
	150 meters	0.0818		0.0152
Parking costs	Free	2.2919	1.5225	0.1820
	DFL 1.00/hr	-0.0292		-0.0482
Maximum parking duration	Unlimited	1.4208		-0.3994
	Maximal 3 hours	0.5608		-0.2360
Level of security	Secured	0.1882		-0.0409
Storage charge	Free	0.7203		-0.0419
	DFL 0.50/time	-0.3384		-0.0379
Walking distance from bicycle stall	25 meters	-0.0064		0.0753
	75 meters	0.2659		-0.1682
Goodness-of-fit				
Log-likelihood of the null model, LL(0)			-5287327	
Log-likelihood of the optimal model, LL(B)			-3294.837	
LRS=-2[LL(0)-LL(B)]			3984.980 (df 60)	
McFadden's Rho-Square ML			0.377	
McFadden's adjusted Rho-Square ML			0.376	
McFadden's Rho-Square MNL			0.191	
McFadden's adjusted Rho-Square MNL			0.190	

Bold: significant at 95-percent confidence level ($\alpha < 0.05$)

The MMNL model performs significantly better than the standard MNL model. The log-likelihood value of the optimal MMNL model is equal to -3294.84 (60 degrees of freedom) while the log-likelihood value of the optimal MNL model is equal to -3927.17 (50 degrees of freedom). The resulting LRS value of 1284.66 is higher than the critical Chi-square value of 18.31 (10 degrees of freedom).

The effects of the significant *mean parameters* (β) are all consistent with general expectations. The constants of car and bicycle show that in the context of shopping trips, these travel modes are more favorable than the bus. Concerning the supply of shops, it appears that the more shops are supplied, the higher the probability of a combined travel alternative will be. The effect of the spatial distribution of shops shows that the more shops are spatially concentrated, the higher the probability of the

destination will be. Regarding the travel time between home and shopping center, it appears that for all travel modes the effect is the farther away a shopping center is located, the less attractive it is. The most sensitive travel mode regarding travel time is the bicycle, followed by bus. In line with previous findings it appears that of investigated parking characteristics, parking costs have the highest effect on the attractiveness of parking. The lower the parking costs are, the higher the probability of parking. Also the maximum parking duration and the walking distance between parking and final destination influence the probability of parking considerably. For parking duration the effect shows that the shorter the allowed parking duration, the lower the attractiveness of parking. The effect of walking distance show that the larger the distance between parking and final destination the less attractive the parking will be. Regarding the bicycle stall characteristics it appears that residents prefer secured bicycle stall and free bicycle stalls.

In addition to the findings regarding the mean effects, it appears that the assumption of similarity is supported by a significant standard deviation (σ) for the constants included in the model that represent the random error components. The size of the standard deviations in relation to the means of the constants indicates that some alternatives are nested. In this case the car alternatives are nested (see section 3.4). This means that the car alternatives compete each other more than other alternatives. The same holds for the bicycle alternatives. There are also significant correlations between the four and two parking facilities of respectively the first and the second shopping center. In addition the assumption of heterogeneity between residents is supported for the characteristics supply of shops, travel time of car, travel time of bicycle, walking distance between parking and final destination, and parking costs. The effects show that also for the combined travel choice tastes differ across respondents.

The number of *context parameters* (δ) that are significant at the conventional level is limited. Significant context parameters are found for all constants and the characteristic levels 'Limited' (supply of shops), '50 meter' (walking distance between parking and final destination), 'Unlimited' and 'Maximum of 3 hours' (maximum parking duration). The effects of all characteristics are in accordance to general expectations. It appears that respondents who visit a shopping center for weekly shopping prefer shopping centers with 2 or 4 parking facilities more than respondents who visit the shopping center for non-weekly shopping. In addition, respondents who go out for weekly shopping have a higher preference for the car and the bicycle in relation to the bus than respondents who go out for non-weekly shopping. For supply of shops, residents who go out for non-weekly shopping trips prefer a broader supply more than residents who go out for weekly shopping trips. In contrast, shoppers for weekly purchases prefer more than shoppers for non-weekly purchases a short walking distance. Finally, shoppers for non-weekly purchases prefer a longer parking duration than shoppers for weekly purchases.

The consequences of the significant context effects are presented in Figures 5.3a-c. The part-worth utility is calculated using only significant mean and context parameters (the random effect is not included). Non-significant mean and context parameters are set to zero.

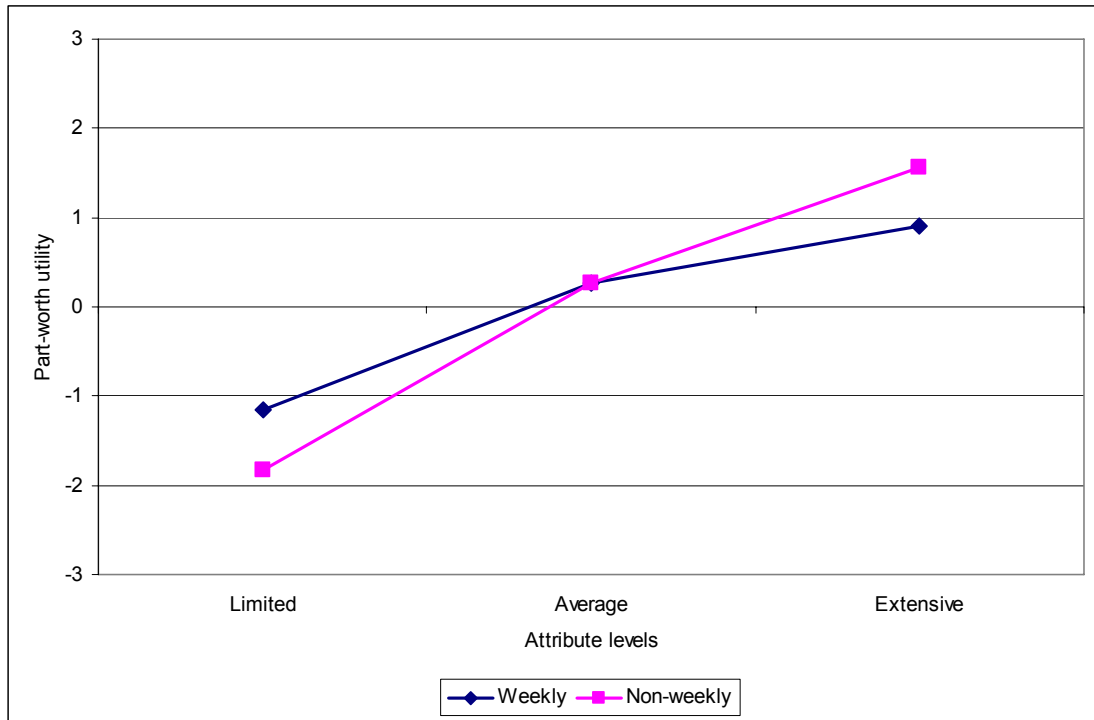


Figure 5.3a: Total effect of attribute 'Supply of shops' (combined travel choice model)

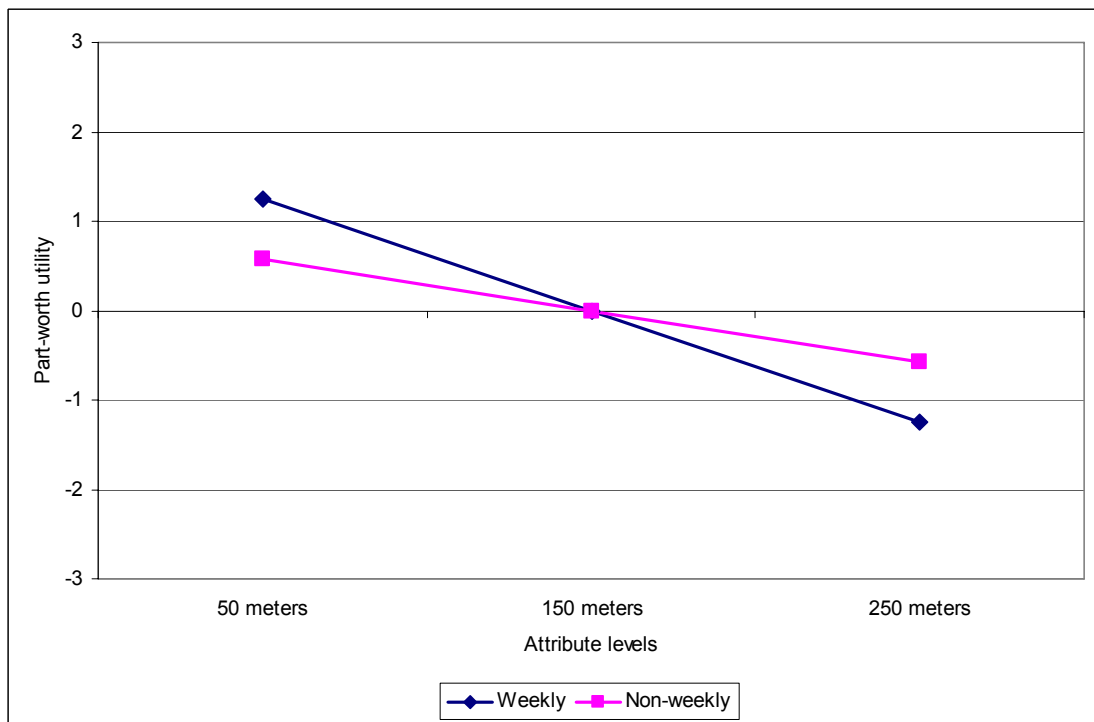


Figure 5.3b: Total effect of attribute 'Walking distance from parking' (combined travel choice model)

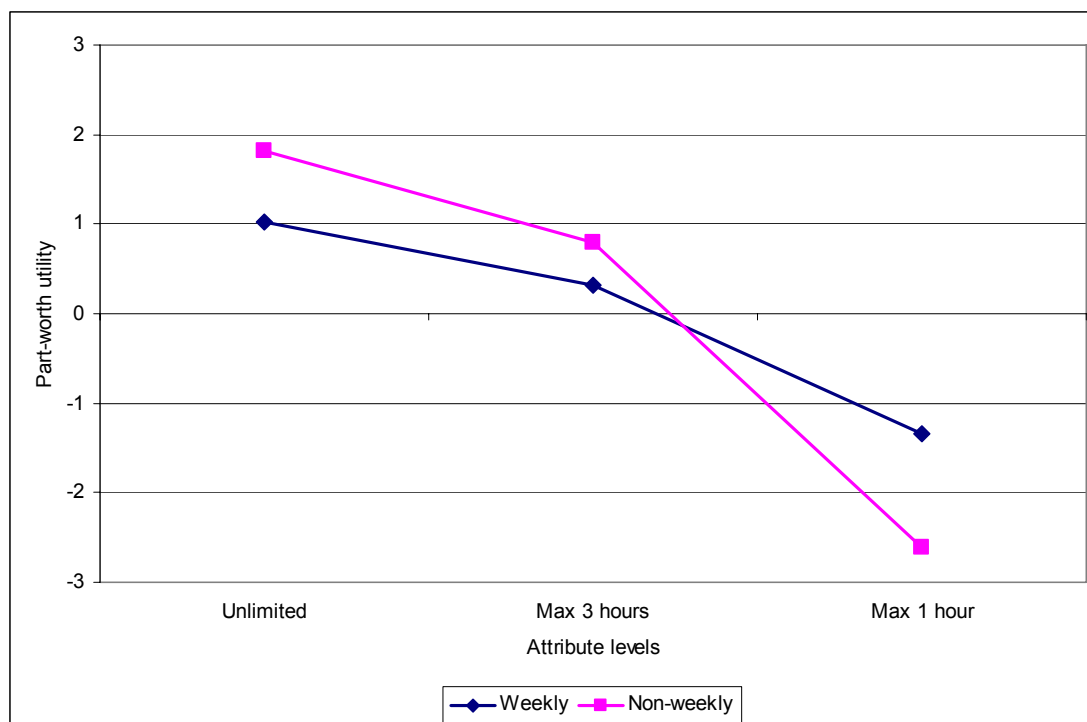


Figure 5.3c: Total effect of attribute 'Maximum parking duration' (combined travel choice model)

Similar to the findings for the consideration sets model, it appears that time and cost related characteristics have the highest influence on the travelers' travel mode and parking choices. It appears that the car is the most popular travel mode in the context of shopping. When planners want to reduce car use in favor of bicycle use, they have to reduce travel time by bicycle between home and shopping destination or change the parking costs or the maximum parking duration. The value of the context parameter related to these characteristics requires extra attention for differences between residents who travel for weekly shopping and residents who travel for non-weekly shopping. Finally, it appears that the effect of changes in travel time of cars, walking distance between parking facility and final destination, and the presence of bicycle stalls is limited.

5.3.3 Adaptive parking choice model

The final model that was estimated concerns the adaptive parking choice of car drivers when facing a fully occupied parking facility. Again the mixed logit multinomial model was used to describe the car drivers' reactions when they face a fully occupied parking facility. The reactions of the car drivers (wait for a free space, search another parking facility, park illegally, go shopping elsewhere, and go home) were used as the dependent variable. The reaction 'Go home' was used as the base alternative. The model included mean parameters and context parameters for weekly versus non-weekly shopping trips. The estimation results are presented in Table 5.8.

With a Rho-square value equal to 0.347 the model performs very well. This conclusion is supported by the LRS-value of 3111.84, which shows that the model

clearly outperforms the null model. The critical Chi-square value for 84 degrees-of-freedom is equal to 110. The percentage correctly predicted adaptive parking choice is equal to 48.7; that is considerably better than the percentage of the null model (20 percent). The parameter estimates for the constants show that searching for another parking facility is most favorable, while illegal parking is the least favorable option. The significant standard deviations indicate that differences between respondents exist. The MMNL performs significantly better than the standard MNL model. The log-likelihood value of the optimal MMNL model is equal to -2929.58 (84 degrees of freedom) while the log-likelihood value of the optimal MNL model is equal to -3378.49 (74 degrees of freedom). The resulting LRS value of 897.82 is higher than the critical Chi-square value of 18.31 (10 degrees of freedom).

Regarding the effects of the *mean parameters* (β), it appears that the probability of waiting is significantly influenced by the waiting time, the number of parking facilities visited before, the number of cars waiting, and the chance of getting a parking fine. As expected the probability of waiting increases when the expected waiting time at the chosen parking facility decreases. The same holds when the number of parking facilities visited before decreases and when the number of cars waiting for a free space decreases. The effect of the chance of getting a parking fine is less clear. The probability of waiting increases when the chance increases from 25 percent to 50 percent. This effect is not as what one might expect. After 50 percent the probability of waiting decreases. This effect is according to expectations. Maybe car drivers only start to think about this characteristic when the chance of getting a parking fine is 50 percent or higher.

The probability of searching for an alternative parking facility is significantly influenced by expected waiting time, number of parking facilities visited before, travel time to the nearest alternative parking facility, chance of a free parking space when going to an alternative parking facility, parking costs at alternative parking facilities, and chance of getting a parking fine. According to general expectations the probability of searching for an alternative parking facility decreases when the expected waiting time decreases and when a car driver has visited more parking facilities before arriving at the fully occupied parking facility. The effect of travel time to the nearest alternative parking facility is also as one might expect. The farther away an alternative parking facility is located, the less the probability will be that a car driver will search for an alternative parking facility. Regarding the effect of chance of a free parking space, it appears that the higher the chance of a free space the higher the probability that a car driver will search for an alternative parking facility. As expected, the probability of searching decreases when the parking costs at alternative parking facilities increase. Finally, the probability of searching increases when the chance of getting a parking fine on the chosen parking facility increases.

The probability of illegal parking is significantly influenced by expected waiting time, number of cars waiting, and chance of getting a parking fine. The effect of waiting time is partly as expected. As expected, when the expected waiting time increases from 2 to 5 minutes, the probability of illegal parking also increases. The effect between 5 and 8 minutes is not according to general expectations: the increase of expected waiting time results in a decrease of the probability of illegal parking. The effect of the number of car drivers waiting is surprising but not totally unexpected. The probability of illegal parking decreases when the number of car drivers waiting

for a free space increases. Finally, the effect of chance of getting a parking fine is as expected: the higher the chance the less the probability that illegal parking will be chosen.

In the case of the reaction ‘shopping elsewhere’ the characteristics number of parking facilities visited before and travel time to alternative parking facility have a significant influence. The effect of the first characteristic is unexpected. The probability of shopping elsewhere is higher when car drivers have visited one parking facility before and is lower when they visited two parking facilities before. The effect of the travel time to the nearest alternative parking facility is as expected; the farther away the higher the probability of going elsewhere.

Regarding the *standard deviations* (σ), it appears that heterogeneity between individuals exists for several characteristics. The standard deviations are significant for all constants included in the model. The same holds for the characteristic levels ‘2 minutes of waiting time’ (in the case of the alternative Wait); ‘4 cars waiting at the parking’ (alternative Wait); ‘2 and 5 minutes travel time to nearest alternative parking facility’ (alternative Search); and ‘Free and DFL 1.00 parking costs at alternative parking facility’ (alternative Search).

For only two characteristics the *context parameters* (δ) are significant at the conventional level: the number of parking facilities visited before and number of cars waiting (see also Figures 5.4a and 5.4b).

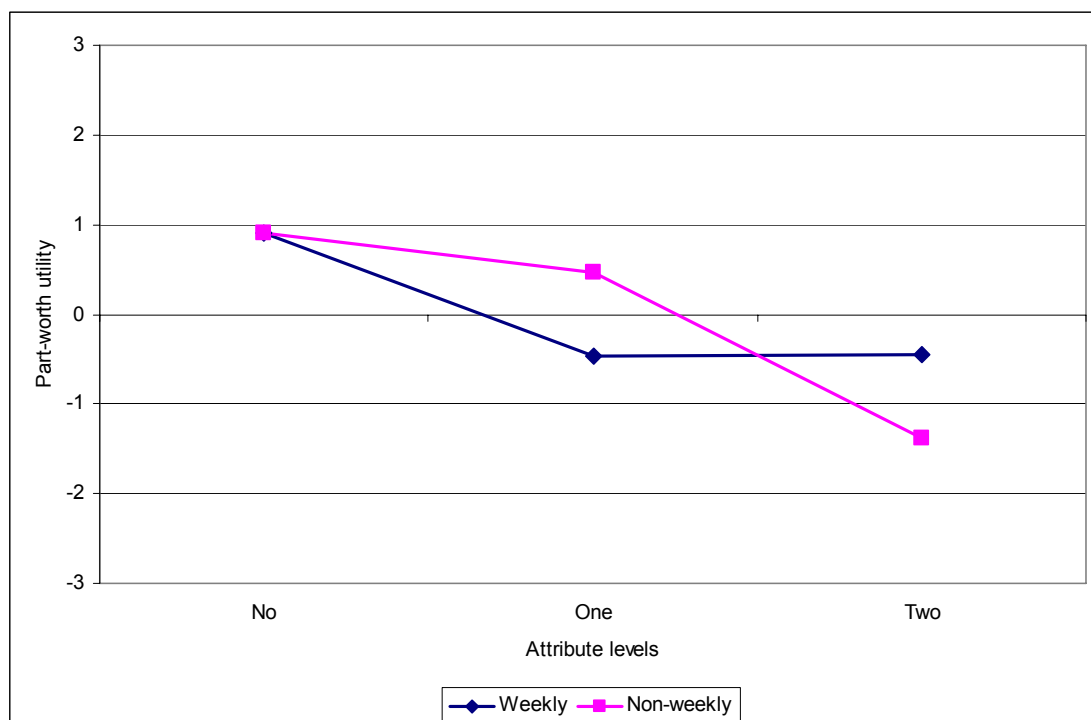


Figure 5.4a: Effect of attribute ‘Number of lots visited before’ on Search (adaptive parking choice model)

Table 5.8: *Parameter estimates of the model for adaptive parking choice behavior*

Attributes	Levels	Component	Adaptive choice behavior			
			Wait	Search	Illegal	Elsewhere
Constant		Mean	0.9665	1.8186	-8.0879	0.0014
		Std dev	4.6346	3.3817	4.9796	4.2432
		Context				
Waiting time	2 minutes	Mean	2.5436	-0.5676	-0.8773	-0.3122
		Std dev	1.9702			
		Context				
	5 minutes	Mean	0.7415	0.3590	0.9113	0.2975
		Std dev				
		Context				
# Lots Visited	No	Mean	0.5586	0.9088	-0.3265	-0.0600
		Std dev				
		Context				
	One	Mean	0.2317	-0.0477	0.0442	0.4526
		Std dev				
		Context				
# Cars waiting	2 cars	Mean	1.7360	0.1717	0.9217	0.0677
		Std dev				
		Context			1.0756	
	4 cars	Mean	-0.2880	-0.1562	-0.3400	-0.1401
		Std dev	1.4216			
		Context			-1.5574	
Travel time	2 minutes	Mean	-0.2734	1.1716	-0.1429	-0.4281
		Std dev		2.2663		
		Context				
	5 minutes	Mean	-0.1872	0.4378	-0.4770	0.1585
		Std dev		1.1901		
		Context				
Free space	25 percent	Mean	0.0403	-1.7427	0.3453	0.2986
		Std dev				
		Context				
	50 percent	Mean	0.0595	0.0993	-0.3032	0.1148
		Std dev				
		Context				
Parking costs	Free	Mean	-0.1883	1.9637	-0.2284	-0.2932
		Std dev		2.2586		
		Context				
	DFL 1.00	Mean	0.2858	0.1392	0.0320	0.1345
		Std dev		1.8450		
		Context				
Space available	Verge	Mean	0.1332	0.0645	0.2549	-0.3119
		Std dev				
		Context				
	Sidewalk	Mean	0.1548	-0.0920	-0.4844	0.0854
		Std dev				
		Context				
Chance of getting a parking fine	25 percent	Mean	-0.4129	-0.4981	2.6914	-0.1906
		Std dev				
		Context				
	50 percent	Mean	0.5795	0.3231	0.0319	0.3000
		Std dev				
		Context				
Goodness of fit			-4485.503			
Log-likelihood of the null model, LL(0)			-2929.584			
Log-likelihood of the optimal model, LL(B)			3111.839 (df 84)			
LRS=-2[LL(0)-LL(B)]			0.347			
McFadden's Rho-Square ML			0.342			
McFadden's adjusted Rho-Square ML			0.107			
McFadden's Rho-Square MNL			0.101			
McFadden's adjusted Rho-Square MNL						

Bold: significant at 95-percent confidence level ($\alpha < 0.05$)

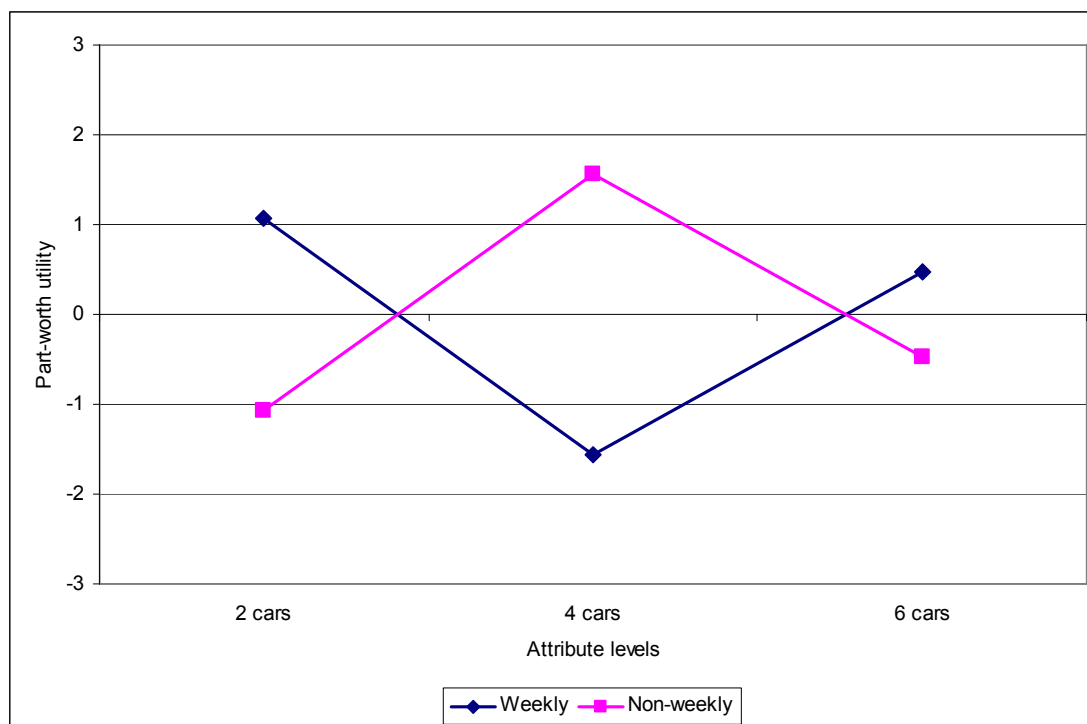


Figure 5.4b: *Effect of attribute ‘Number of cars waiting’ on Illegal parking (adaptive parking choice model)*

Regarding the number of parking facilities (Figure 5.4a) visited before it appears that for weekly shopping trips, the probability of the alternative searching is lower than for car drivers who visit the parking facility for non-weekly shopping trips. When two cars are waiting at the chosen parking facility (Figure 5.4b) the probability of illegal parking is higher for car drivers who visit the parking facility for weekly shopping trips than for car drivers who visit the facility for non-weekly shopping. In the case of 4 cars waiting, the opposite holds which is not as expected.

Overall, the results of the model estimation show that car drivers do not tend to change shopping destination or go home when facing a fully occupied parking facility (Table 5.8). A fully occupied parking facility mainly results into more cruising for a free parking space both at a parking facility (Wait) and the road network surrounding the shopping destination (Search). Especially the latter effect is not wanted by planners who want to optimize the use of the urban road network and limit the negative effects of cars (e.g., noise, pollution, and congestion) in city centers. To reduce this effect, planners can set up measures to reduce the expected waiting time, increase travel time to alternative parking facilities, and increase parking costs of alternative parking facilities. These parking measures will stimulate car drivers to use their first chosen parking facility.

5.4 Conclusion

In this chapter, the results of model estimations have been presented and discussed. Most estimation results are satisfactory indicating that the estimated models give a good representation of the respondents’ stated choice behavior. Looking to the

calculated Rho-square values, it appears that in all cases the mixed multinomial logit model performs significantly better than the traditional multinomial logit model. Most effects of the included model attributes are as expected. It appears that the probability that a parking facility is included in the shopper's parking consideration set is significantly influenced by the following characteristics: chance of finding a free parking space, parking costs per hour, maximum parking duration, average egress time, available driving space, type of parking facility, type of security, location vis-à-vis the shoppers' home location, and the distance between parking and nearest supermarket/department store. The effect of the characteristics parking costs, maximum parking duration, and distance to final destination differs significantly for weekly and non-weekly shopping trips. The probability is not influenced by the size of a parking facility and the location vis-à-vis other parking facilities.

Regarding the combined travel choice it appears that almost all investigated characteristics influence the probability of a combined travel choice alternative. No significant effect was found for the characteristic distance between bicycle stall and final destination. A significant difference between weekly and non-weekly shopping trips is found for the supply of shops, walking distance between parking and nearest supermarket/department store, and maximum parking duration.

The final model concerns shoppers' adaptive parking choice behavior. Regarding this model the following conclusions can be drawn. The probability of the choice alternative 'Wait for a free space' is significantly influenced by the characteristics expected waiting time, number of parking facilities visited before, number of cars waiting, and chance of getting a fine. The characteristics expected waiting time, number of parking facilities visited before, travel time to an alternative parking facility, chance of free parking space at alternative parking facility, parking costs at alternative parking facility, and chance of getting a fine influence the probability of the alternative 'Search for an alternative parking facility' significantly. The probability of the alternative 'Park illegally' is influenced significantly by the characteristics expected waiting time, number of cars waiting, and chance of getting a fine. Finally, the probability of 'Shop elsewhere' is influenced significantly by the characteristics number of parking facilities visited before and travel time to an alternative parking facility.

The analyses show that it is possible to describe the influence of both the general and actual parking situation in shopping areas on different components of shoppers' travel choice behavior using stated choice experiments and discrete choice models. It appears that not only the more 'traditional' parking characteristics like parking costs and walking distance are important in the context of travel behavior but also some 'less conventional' characteristics such as chance of free parking space, parking egress time, availability of driving space at parking facilities, and location of parking facilities vis-à-vis travelers' home location. It is interesting to see how car drivers react when they face a fully occupied parking facility. The model for adaptive parking choice behavior shows that changes in the regime of parking facilities affects car drivers' behavior which results in new parking demand at alternative parking facilities. Another interesting finding concerns the differences in shoppers' preferences related to type of shopping: weekly versus non-weekly. The influence of several characteristics on the utility of alternatives differs per type of shopping trip. The estimated models show that manipulating particular characteristics may be

effective in affecting travel behavior. It gives planners and decision makers handles to evaluate future transport policies for shopping areas.

CHAPTER 6

Validation of *Pamela*

6.1 Introduction

The parking analysis model *Pamela* has been developed to predict the effects of different parking measures on various travel choices in different time periods and/or places. To find out how well *Pamela* is able to predict these choices, an external validation study was conducted. According to Sacks *et al.* (2002), the external validation of computer simulation models is a crucial element in assessing their value in transportation policy. External validation concerns the question whether a model is able to reproduce actual preferences or observed behavior not used in the estimation (e.g., Orme *et al.*, 1997; Kroes, 1998). In the past, several external validation studies of stated preference models have been conducted to examine to what extent models based on stated preferences/choices can be validly used to predict the consumer behavior in actual markets (e.g., Timmermans *et al.*, 1992; Lusk & Schroeder, 2004). To examine external validity, first, an actual or new situation is defined and the estimated stated preference model is applied to this (new) situation. Next, the predicted behavior is compared with behavior that is observed in the (new) situation.

A study of Mahmassani & Jou (2000) dealt with the transferability of laboratory experiments to field surveys. First, they described four elements that have to be transferred from stated preference experiments to the actual systems. These elements are the principal theoretical constructs, the methodology for model specification and estimation, behavioral insights, and the model specification. Next, the predicted behavior was compared to actual or observed behavior. They found that the models based on stated preference experiments described actual behavior quite well. Looking

to individual parameter values, they found some differences between the stated experiments and the actual systems.

These studies seem to indicate that the number of good external validity studies regarding parking is limited. Most studies focus on the reliability (reproduction of preferences) and the internal validity (quality of the model) of the estimated models. One of the major problems is the lack of data concerning actual behavior. Also, the specification of the new situation (in time and/or place) where the actual behavior takes place is difficult. For example, Van Maarseveen (1985) met this problem when he designed a study to validate a parking simulation model in the city of Apeldoorn. The study covered a before and after situation. It appeared that insurmountable problems existed in research decisions such as differences in the definition of parking facilities, the levels of parking tariffs, and car drivers involved in the study. The study of Van Maarseveen was ended prematurely.

The models of **Pamela** are used to predict car drivers' travel choice behavior in the town of Veghel. The estimated parameters presented in chapter 5 are implemented in the models. For the first two levels of the characteristics, the estimated parameter is used. For the base level, the value of the parameter is calculated as follows. The mean values of the first and second level are summed and multiplied with -1 (effect coding). An assumption has to be made regarding the standard deviation of the base level is assumed to be equal to the root of the sum of squared standard deviations for the first and second level because the mixed logit model specified in this study assumes uncorrelated random parameter.

In the external validation only weekly shopping trips were considered. The validation focuses on the consideration set model and the combined travel choice model. There was no data available for the validation of the adaptive parking choice model. This chapter presents the set up and results of the external validation of the investigated parking consideration set and combined travel choice models. First, the case of Veghel is introduced by presenting the necessary details of the available shopping centers, parking facilities, and bicycle stalls. For the description of the shopping centers, parking facilities, and bicycle stalls, the predefined variable levels that were introduced in chapter 4, were used. Next, attention is paid to the data collection and the composition of the sample. In addition, the findings of the observed consideration sets and combined travel choices in Veghel are presented. The results of the validation are presented and discussed in sections 6.3 (consideration set) and 6.4 (consideration set and combined travel choice). The chapter ends with the conclusion regarding the validation of both models.

6.2 Case Veghel

The town of Veghel is located in the South of the Netherlands. Veghel is comparable with Veldhoven (see Section 5.2) in terms of size (approximately 40,000 residents) and spatial layout including the available shopping facilities (one major shopping center and several sub-centers). Also the surrounding bus and bicycle facilities are comparable. In fact, the shopping facilities consist of three major shopping centers: Veghel center, Boekt, and Bunders (Figure 6.1). Table 6.1 shows the characteristics of the shopping centers that are included in the models of **Pamela**.

The three shopping centers are surrounded by several parking facilities and bicycle stalls. The characteristics of the facilities that are included in the models of *Pamela* are presented in Tables 6.2 (Veghel Center) and 6.3 (Boekt and Bunders). In the center of Veghel, 13 official parking facilities are available for car drivers (Figure 6.2). The shops are scattered in the streets marked with ‘■’. The parking facilities are described using the characteristic levels that are included in the stated choice experiment that was applied in Veldhoven. Parking facilities 3 and 12 are close to the supermarkets, respectively Edah and Albert Heijn. All settings are presented in Table 6.2. All shopping centers are served by one or more bus lines.

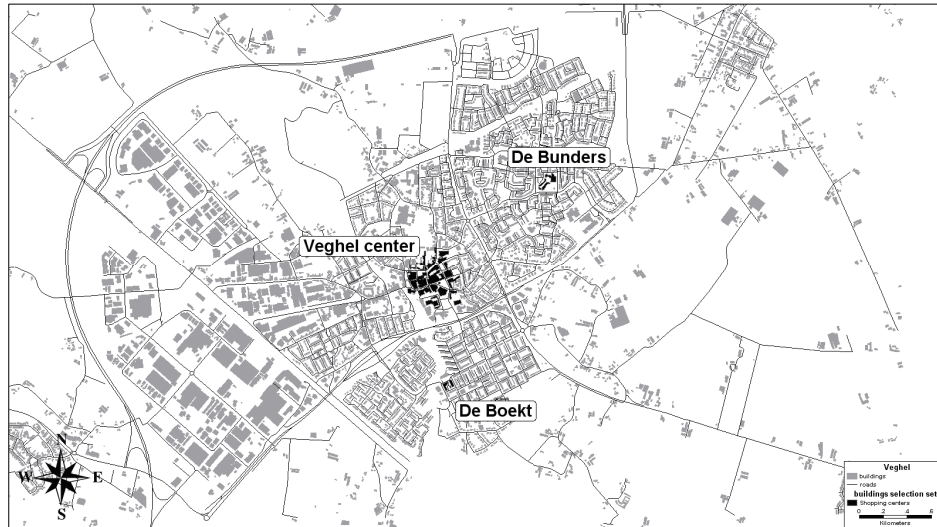


Figure 6.1: Veghel’s major shopping centers

Table 6.1: Description of the shopping centers included in the validation

Characteristics	Shopping centers		
	Veghel center	Boekt	Bunders
Supply of shops	Broad	Limited	Limited
Distribution of shops	Concentrated	Dense	Dense

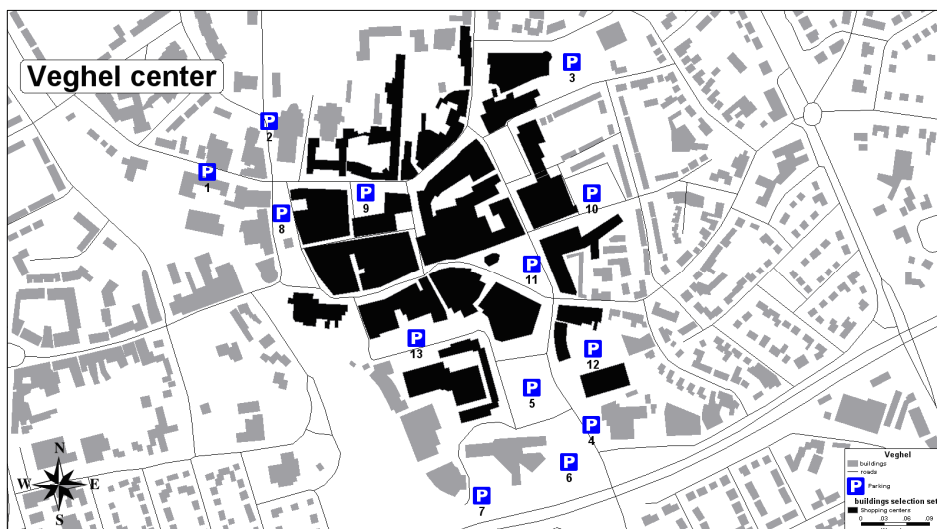


Figure 6.2: Parking facilities in shopping center ‘Veghel center’

Table 6.2: Description of the parking facilities, Veghel Center

Characteristics	Parking facilities						
	1	2	3	4	5	6	7
Size of parking facility	50	50	250	50	250	50	50
Chance of free space	50%	25%	75%	25%	50%	50%	75%
Parking costs	Free	Free	Free	Free	Free	Free	Free
Max parking duration	Unlim	Unlim	Unlim	Unlim	Unlim	Unlim	Unlim
Average egress time	4	4	4	2	4	4	4
Driving space	Aver	Aver	Aver	Aver	Aver	Limit	Limit
Type of parking facility	Lot	Lot	Lot	Lot	Lot	Lot	Lot
Type of security	None	None	None	None	None	None	None
Location home*	-	-	-	-	-	-	-
Location other parking	Far	Far	Neutral	Neutral	Close	Far	Far
Walking distance	250	250	50	150	150	150	250
<i>Parking facilities</i>	8	9	10	11	12	13	
Size of parking facility	50	50	50	50	250	250	
Chance of free space	75%	75%	50%	50%	75%	50%	
Parking costs	1.00	1.00	1.00	1.00	Free	Free	
Max parking duration	Unlim	Unlim	Unlim	Unlim	Unlim	Unlim	
Average egress time	0	0	2	2	4	4	
Driving space	Aver	Aver	Limit	Aver	Limit	Spaci	
Type of parking facility	Lot	Lot	Lot	Lot	Lot	Lot	
Type of security	None	None	None	None	None	None	
Location home*	-	-	-	-	-	-	
Location other parking	Close	Close	Far	Close	Neutral	Neutral	
Walking distance	150	150	50	150	50	150	

* depends on the home location of the respondent

The shopping centers Boekt and Bunders are both surrounded by respectively 3 and 2 parking facilities (Figure 6.3 and Table 6.3). It appears that within the centers there is a great similarity between the parking facilities especially when it concerns the parking characteristics that are included in the combined travel choice model; parking costs, maximum parking duration, and walking distance. This similarity makes the prediction of the parking consideration set unnecessary.

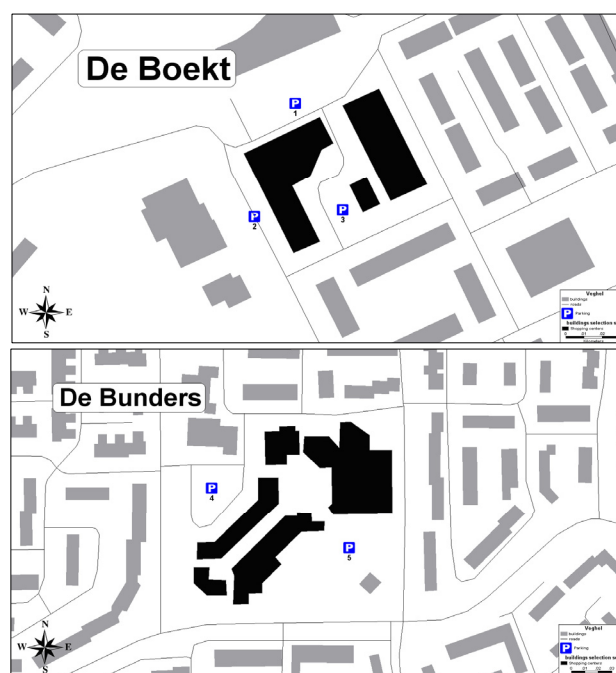
**Figure 6.3:** Parking facilities Boekt and Bunders

Table 6.3: Description of the parking facilities, Boekt (1 & 2) and Bunders (3, 4 & 5)

Characteristics	Parking facilities				
	1	2	3	4	5
Parking costs	Free	Free	Free	Free	Free
Max parking duration	Unlim	Unlim	Unlim	Unlim	Unlim
Walking distance	150	150	150	150	250

Table 6.4: Description of the bicycle stalls included in the validation

Characteristics	Bicycle stalls		
	Veghel center	Boekt	Bunders
Level of security	Unsecured	Unsecured	Unsecured
Storage charge	Free	Free	Free
Walking distance to stores	75 meter	75 meter	75 meter

In addition to the parking facilities, the available bicycle stalls are defined using the characteristics presented in the combined travel choice model (Table 6.4). Each shopping center is accompanied by one bicycle stall. In all centers the bicycles stalls have the same characteristics.

The data for the validation were collected in 2002 using a home sent questionnaire. The questionnaire consisted of several questions concerning weekly shopping trips, the parking consideration set, travel and parking behavior, and personal characteristics. Respondents were also invited to describe in more detail the last two weekly shopping trips to one of Veghel's shopping centers. In total 2000, questionnaires were randomly distributed across Veghel and surrounding villages Mariaheide, Eerde, Zijtaart, and Erp. Approximately 20 percent of the households returned the questionnaire, resulting in 441 completed questionnaires, including information of the residents' home location.

Table 6.5: Characteristics of the Veghel and Veldhoven sample, weekly shopping

Characteristic	Levels	Veghel	Veldhoven
Gender (significance = 0.476)	Male	30.8	27.8
	Female	68.3	71.4
	Unknown	0.9	0.4
Age (significance = 0.335)	Younger than 40 year	31.7	38.9
	41-55 year	37.3	33.6
	Older than 55 year	30.9	27.2
	Unknown	0.2	0.2
Educational level (significance = 0.308)	Lower level	30.1	31.2*
	Middle level	40.6	35.6
	Higher level	29.2	33.1
Home location (significance = 0.292)	City center	47.2	35.5
	Fringe	52.8	63.9
	Unknown	0.0	0.6
Drivers License (significance = 0.220)	Yes	96.1	93.4
	No	3.4	6.4
	Unknown	0.5	0.2
Car availability (significance = 0.299)	Yes	96.1	95.1
	No	2.5	4.7
	Unknown	1.4	0.2
Number of respondents		441	529

* Based on an additional data collection under 362 respondents

Table 6.5 presents some general statistics of the Veghel sample. It appears that for almost all characteristics, the distribution across the characteristic levels is comparable with the Veldhoven distribution of respondents who conducted weekly shopping trips. Differences in frequencies between the two samples were tested using the Chi-square test. For each characteristic there are no significant differences at the 95 percent confidence level.

In addition to the personal characteristics, respondents were asked to describe two recent weekly shopping trips. The following information about the shopping trips was collected: the departure time and the duration of the shopping trip, the shopping center that was visited, the travel mode that was used, the parking facilities that were considered when visiting the chosen shopping center by car, and the parking facility that was chosen to park the car. All respondents who used the bicycle for their weekly shopping trip used the available bicycle stalls. The 441 respondents described 700 weekly shopping trips. The information of all 700 weekly shopping trips was included in the validation.

Figure 6.4 provides some information concerning the size of the *observed consideration sets*. It appears that the consideration set of approximately 10 percent of the respondents is equal to zero. These respondents do not visit Veghel center by car or do not visit Veghel center at all for weekly shopping. For these respondents the car and parking alternatives for Veghel center are excluded. Approximately, 4 percent of the respondents consider only one parking facility. Figure 6.4 shows also that a large number of respondents consider 11, 12 or 13 parking facilities when visiting Veghel center.

The observed presence of parking facilities in the car drivers' consideration sets is shown in Figure 6.5. The total number of consideration sets that is observed is equal to 399 (441 respondents minus 42 respondents who have no parking consideration set). It appears that there are considerable differences between the parking facilities regarding the presence of the alternative in the car drivers' consideration sets. Some parking facilities like 3 and 5 are present in almost all consideration sets while parking facility 2 is only included in a small number of consideration sets.

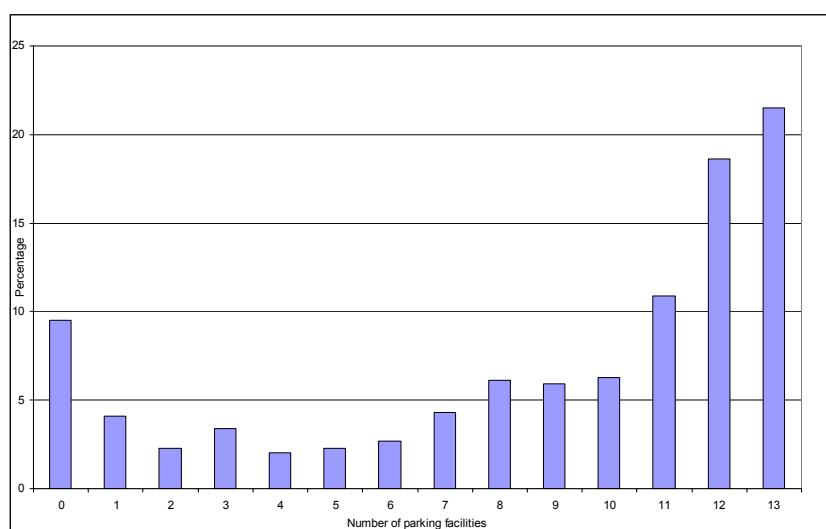


Figure 6.4: Observed size of the consideration sets, Veghel center (N=441)

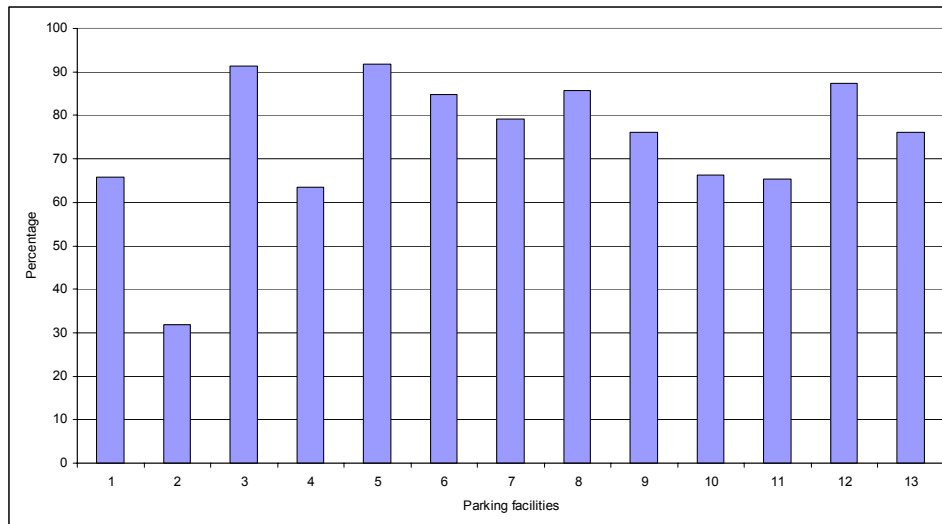


Figure 6.5: Observed presence of parking facility in the consideration sets (N=399)

The next part of the information that was used for the validation concerns the respondents' *combined travel choice* including the choices of shopping destination, travel mode, and parking/stall facility. The various choice options were combined into 24 combinations. Table 6.6 shows the possible combined travel choice combinations and the number of observations per combination.

Table 6.6: Observed combinations of travel choices

Shopping center	Number	Travel mode	Parking/stall facility	Frequency	Percentage
Veghel center	1	Car	1*	4	0.6
	2		2	1	0.1
	3		3	157	22.4
	4		4	6	0.9
	5		5	16	2.3
	6		6	35	5.0
	7		7	4	0.6
	8		8	8	1.1
	9		9	18	2.6
	10		10	27	3.9
	11		11	9	1.3
	12		12	120	17.1
	13		13	43	6.1
	14		Bicycle	Yes	117
	15	Bus		4	0.6
Boekt	16	Car	1**	10	1.4
	17		2	16	2.3
	18		3	16	2.3
	19	Bicycle	Yes	29	4.2
	20	Bus		-	-
Bunders	21	Car	1**	34	4.9
	22		2	7	1.0
	23	Bicycle	Yes	19	2.7
	24	Bus		-	-
Total				700	100.0

* See Figure 6.2, ** See Figure 6.3

In general, it appears that almost all possible combinations are present in the data set. Only the use of the bus for weekly shopping trips to the shopping centers Boekt and Bunders is not observed. The most often observed combination is the combination Veghel center, car, and parking facility 3 closely followed by the combination Veghel center, car and parking facility 12.

6.3 Consideration set model

The external validation as conducted for this thesis consists of two steps. In the first step the parking consideration set model is applied to the situation of Veghel center. The limited number of available parking facilities in the vicinity of the shopping centers Boekt and Bunders makes it not realistic to apply the consideration set model to these two centers. The model is only applied to Veghel center where 13 different parking facilities can be identified.

The decision to enter a choice alternative (parking facility) in the respondents' choice set is based on average probabilities combined with Monte Carlo simulation. The following steps were carried out (see Figure 6.6). First, to calculate the average probabilities of the parking facilities, for each respondent 1000 calculations of the choice probabilities (in or not in the consideration set) were made. For each calculation a random number was drawn for each parameter from the normal distribution with mean β_k and standard deviation σ_k . Next, for each parking facility, the 1000 calculated probabilities were summed and divided by 1000, resulting into an average probability for each parking facility. Finally, for each parking facility, Monte Carlo simulation was used to determine if the parking is added to the car drivers' parking consideration set or not. For each respondent this total simulation process is carried out once.

To test the quality of the predictions, three different measures were presented. The first two measures focus on the individual level: the Log-likelihood Ratio Statistic (LRS) and the percentage correctly predicted or hit rate (e.g., Orme *et al.*, 1997). The third measure is calculated at the aggregate level of parking facilities: the correlation coefficient of the predicted and observed presence of parking alternatives in the consideration set (similar to Figure 6.5).

First, the predicted average probabilities were tested against the null model (the model with all parameters equal to zero). The LRS takes into account the log-likelihood of the predicted probabilities and the log-likelihood of the probabilities calculated with the null-model ($-2*[LL_{\text{predicted}}-LL_{\text{null}}]$). The calculated value of the log-likelihood for the predictions is equal to -1061.76 and the log-likelihood of the null model is equal to -2676.24. The LRS-value is equal to 3228.96 while the critical Chi-square value for 51 degrees of freedom is approximately equal to 68.33 at the confidence level of 95 percent. The LRS-value shows that the predictions based on the estimated model outperform the predictions based on the null model. This means that it is better to use the estimated model than using equal choice probabilities.

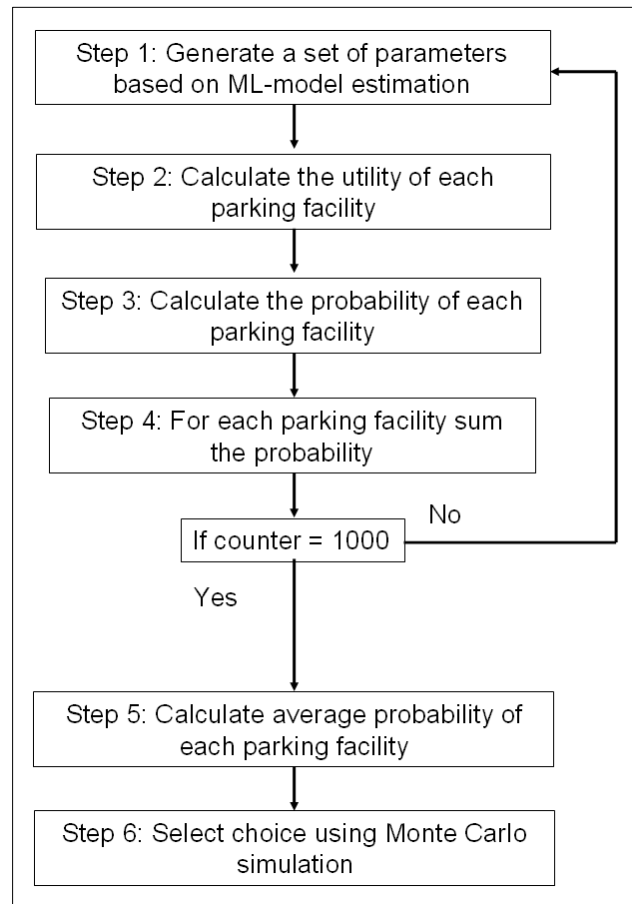


Figure 6.6: *Workflow of model prediction consideration set model*

Next, the predicted average probabilities were tested against the observed probabilities using the LRS. The log-likelihood of the observed probabilities is equal to -1056.83. The LRS-value ($-2 \cdot [LL_{\text{predicted}} - LL_{\text{observed}}]$) is equal to 9.86 while the critical Chi-square value for 51 degrees of freedom is approximately equal to 68.33. The LRS-value indicates that the predicted average probabilities do not differ significantly from the observed probabilities.

The second measure considers the number of correctly predicted present (1) or not present (0) in the car drivers' consideration sets. It appears that at least 54 percent of the cases the (non-) presence of parking facilities in the consideration set are predicted correctly. Figure 6.7 shows for each parking facility the percentage correctly predicted. The results differ considerably between the parking facilities and range between approximately 54 (parking facility 11) and 86 (parking facility 3) percent. Over all 13 parking facilities, the average percentage correctly predicted is equal to 67 percent.

The third measure concerns the correlation coefficient that describes the relation between the observed and predicted number of times an alternative is predicted in the car drivers' consideration sets ($N=399$). With a correlation coefficient (r) of 0.91 it appears that the model predictions come close to the observations (Figure 6.8).

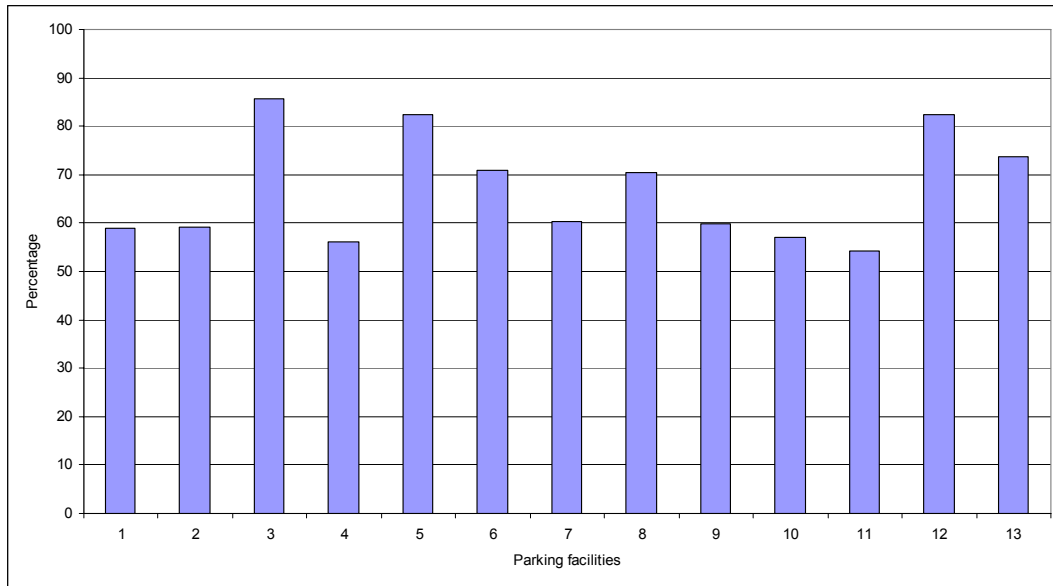


Figure 6.7: *Percentage correctly predicted per parking facility*

For example, the model predicts a 70 percent presence of parking alternative 1 in the consideration sets and the observation shows a percentage of approximately 66. The largest difference between prediction and observation is noticed for parking facility 13 (over-prediction of 17 percent).

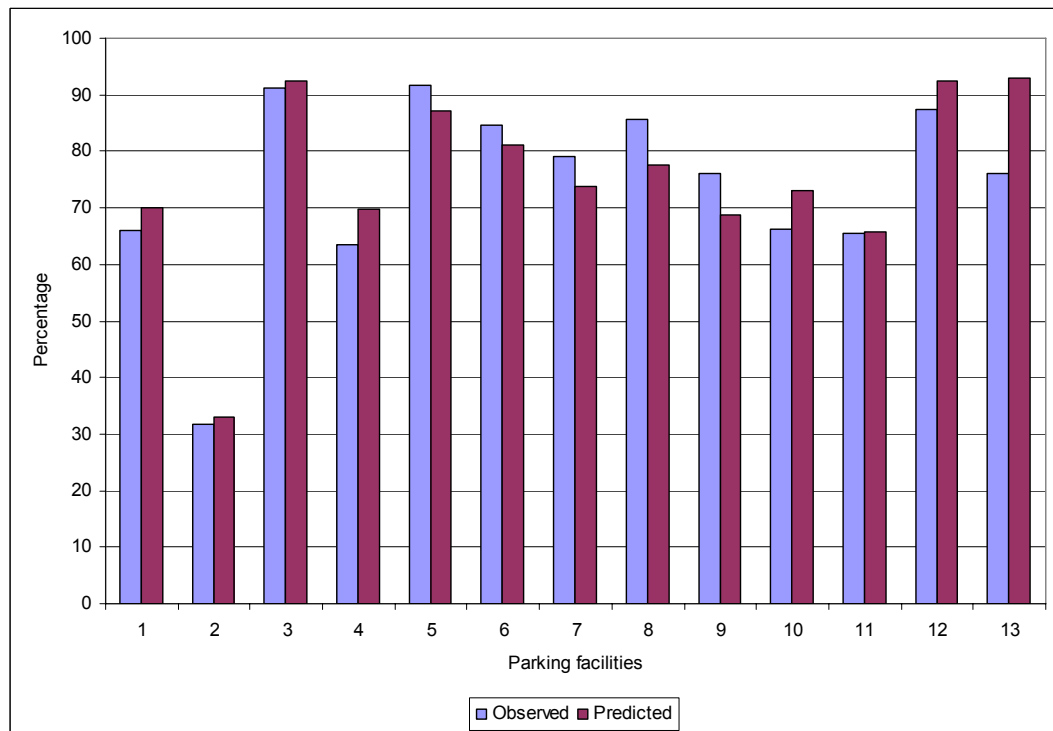


Figure 6.8: *Observed and predicted presence of parking facilities in consideration sets*

6.4 Consideration set and combined travel choice model

The second step in the validation concerns predicting the combined travel choice behavior of shoppers. The prediction of the combined travel choice includes the predicted parking consideration sets. It is assumed that shoppers consider all parking facilities that are located in the vicinity of the shopping centers Boekt and Bunders. Again, for each respondent 1000 simulations were carried out to derive the average probabilities (see Figure 6.9). The predicted choice alternative was selected using Monte Carlo simulation. Also in this validation step three different measures (two at disaggregate level and one at aggregate level) were calculated to test the quality of the predictions: the LRS, the percentage correctly predicted, and the correlation coefficient describing the relation between the totals of observed and predicted choices.

First, the predicted average probabilities were tested against the null model (the model with all parameters equal to zero). The calculated value of the log-likelihood for the predictions is equal to -2002.79 and the log-likelihood of the null model is equal to -2307.79. The LRS-value ($-2 \cdot [LL_{\text{predicted}} - LL_{\text{null}}]$) is equal to 610.00 while the critical chi-square value for 60 degrees of freedom is approximately equal to 79.08 at the confidence level of 95 percent. The LRS-value shows that the predictions based on the estimated model outperform the predictions based on the null model.

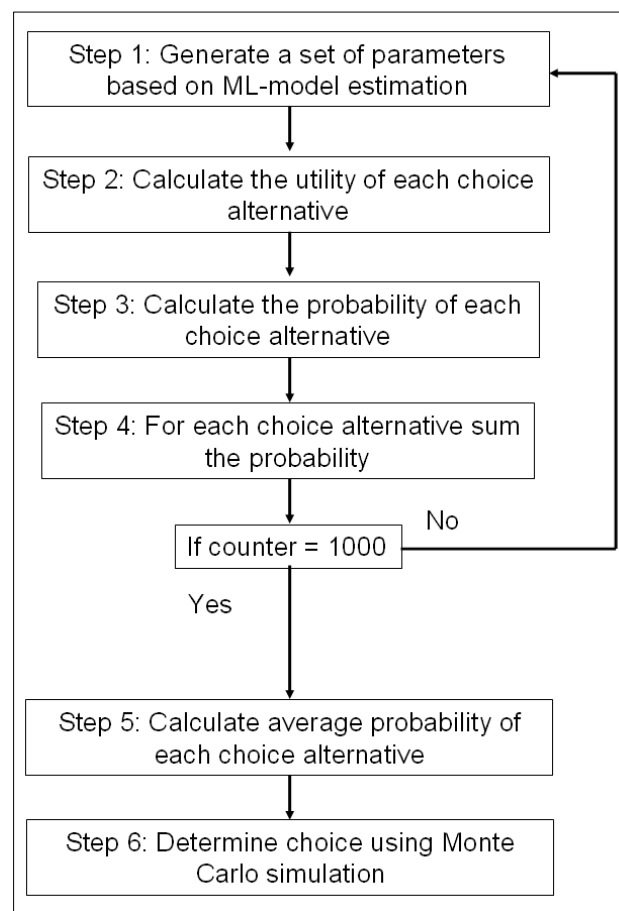


Figure 6.9: *Workflow of model prediction combined travel choice model*

Next, the predicted average probabilities were tested against the observed probabilities using the LRS. The log-likelihood of the observed probabilities is equal to -1911.43. The LRS-value ($-2*[LL_{\text{predicted}}-LL_{\text{observed}}]$) is equal to 182.72 while the critical chi-square value for 60 degrees of freedom is approximately equal to 79.08. The LRS-value indicates that the predicted average probabilities differ significantly from the observed probabilities.

For the combined travel choices the number of correctly predicted choices at the individual level is calculated. In line with the previous findings, the percentage of correctly predicted choices is low but acceptable. The model with the predicted consideration sets predicts approximately 9.1 percent of the observations correctly. The percentage shows an improvement compared to the approach of an equal distribution of choices across all alternatives which leads to a correct prediction of 4.2 percent (100 percent divided by 24 alternatives). Figure 6.10 presents the number of correctly predicted choices for each choice alternative. The percentages are calculated by dividing the number of correctly predicted choices by the total number of predicted choices for each alternative. For example, the third choice alternative (Veghel-center, car, parking facility 3) is predicted 120 times (17.1 percent) of all 700 trips. From these 120 predictions 20.8 percent is correctly predicted. Figure 6.8 shows the highest percentage correctly predicted for choice alternatives 3 (Veghel-center, car, parking facility 3) and 12 (Veghel, car, parking facility 12).

The third measure compares the observed and predicted distributions of shoppers across the available combined travel alternatives. The observed and predicted choices are summarized in Figure 6.11. It is clear that the estimated model predicts the combined travel choices of shoppers at the aggregate level quite well. The observed and predicted choice distributions are compared using the correlation coefficient (r). The r is equal to 0.92 indicating a strong relation between observations and predictions (where a relation with an r of 0.80 is generally considered as a strong relation; De Vocht, 2004).

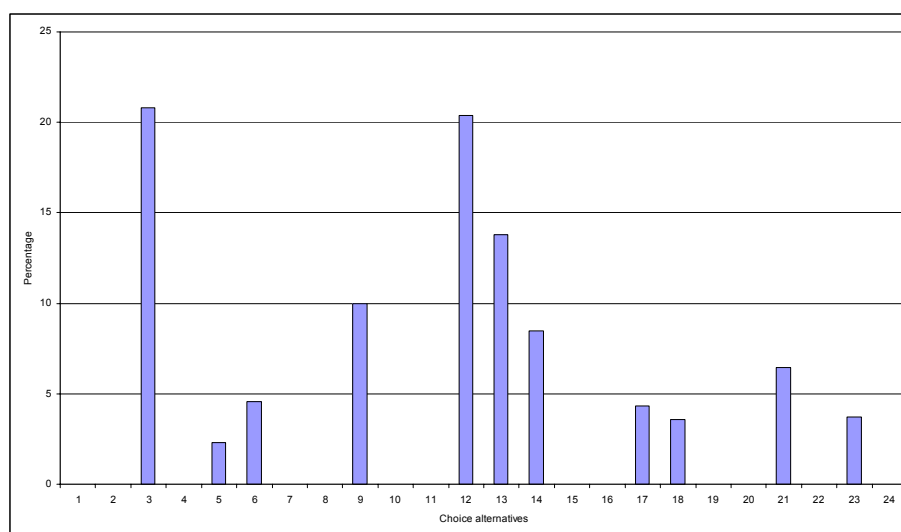


Figure 6.10: *Percentage of correctly predicted choices per combined travel choice alternative*

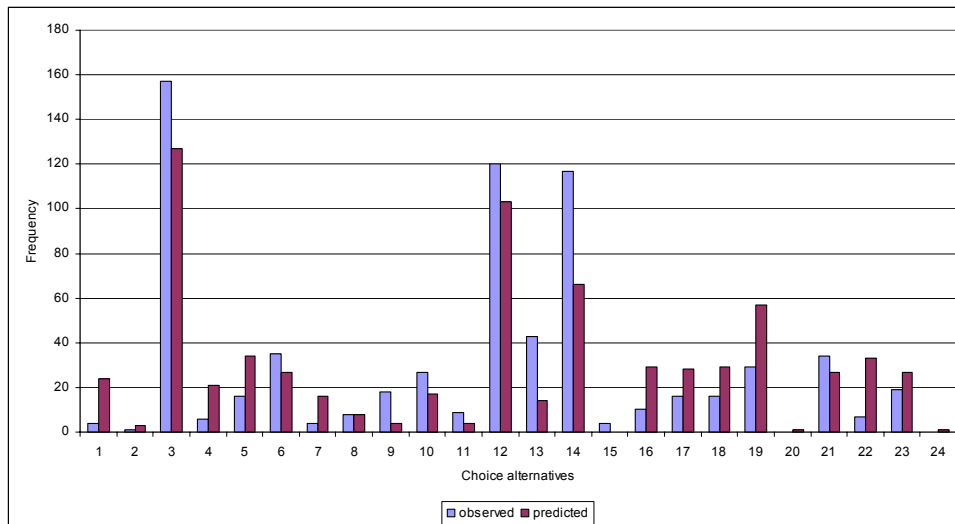


Figure 6.11: *Observed and predicted combined travel choice*

Overall, the model predicts the choice of the shopping centers satisfactory with a small over-prediction for the two smaller shopping centers. The choice of the bicycle is not well predicted. This holds especially for Veghel center (choice alternative 14) while for shopping center De Boekt more bicycle users are predicted than observed (alternative 19).

Standard for discrete choice models, the scale factor is equal to 1.0 (see μ in equation 3.1). The use of different alternative scale factors was evaluated (Figure 6.12). For different scale factors the overall log-likelihood was calculated. It appears that a scale factor of approximately 1.25 increases the model performance significantly. The log-likelihood is equal to -1997.44. This makes that the value of the Log-likelihood Ratio Statistics is equal to 10.70 while the critical value of chi-square for 1 degree-of-freedom is equal to 3.84. Despite this increase in model performance, the model is still not able to approach the observed probabilities.

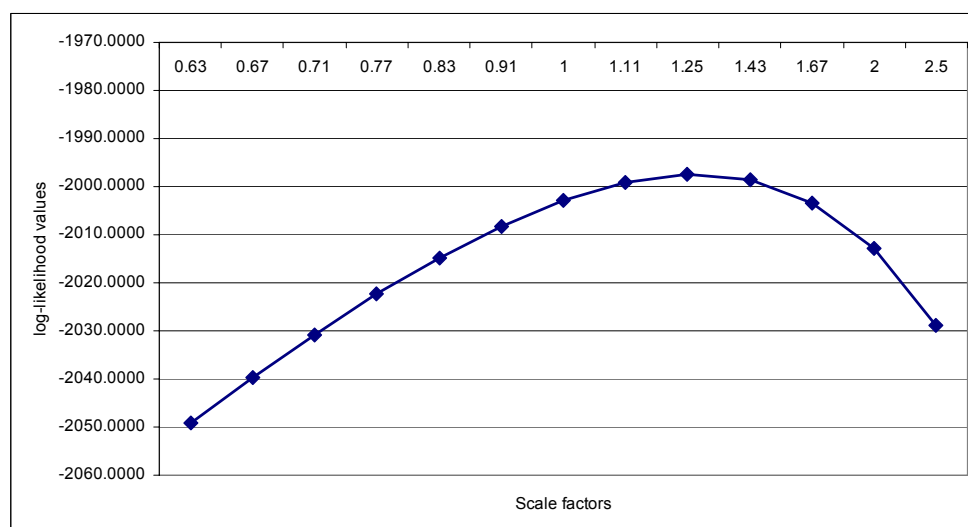


Figure 6.12: *Log-likelihood value with different scale factors*

6.5 Conclusion

This chapter presented the results of the external validation tests of the estimated parking consideration set model and the combined travel choice model for weekly shopping trips. The situation of Veghel is described using the characteristics that are included in both models. Most of the suggestions of Sacks *et al.* (2002) for carrying out an external validation were taken into consideration. The data collection was set up specifically for validation purpose and provided the observed behavior required by the choice models. Only the quantification of uncertainties is not worked out in detail. Regarding the performance of the models, it appears that the consideration set model is reasonably able to predict the composition of consideration set that is observed in Veghel. On average, the model predicts in approximately 67 percent the presence or non-presence correctly. The highest percentage of correctly predicted consideration is approximately 86 percent.

The combined travel choice model shows at the aggregate level acceptable results. A determination coefficient of 0.84 shows a strong relation between observations and predictions. However, at the disaggregate level the model performs poor. The model estimations of the probabilities outperform estimations with the null models. Predicted probabilities, however, are significantly different from observed probabilities. Only 9 percent of the predictions at the individual level were correct. The highest percentage correctly predicted choice is approximately 21 percent. These findings suggest that it may be useful to consider an extension of the current models with constants for specific situations (see also Sacks *et al.*, 2002). Another way to improve the predictions is using a scale factor that adapts the influence of parameters to a specific situation (e.g., Louviere *et al.*, 2000).

CHAPTER 7

Simulations with *Pamela*

7.1 Introduction

In the previous chapters of this thesis, the structure of the parking analysis model *Pamela* has been described in detail. The main purpose of *Pamela* is to provide insights into the effects of alternative parking instruments on residents' shopping behavior. *Pamela* consists of several separate models and additional information that need to be integrated when *Pamela* is going to be applied to assess the impact of planning scenarios. Such integration of the models to an 'easy accessible' working planning tool is the main purpose of this chapter. To illustrate the working of *Pamela*, a simple example is set up using the multi-agent platform NetLogo, version 4.1 (Wilensky, 1999). The purpose of this illustration is to show how parking instruments affect the various choices of residents that are included in *Pamela* with respect to individuals' parking consideration sets, travel modes, shopping destination and parking or stall choice, and if necessary, adaptive parking choice.

The remainder of this chapter is organized as follows. First, attention is paid to agent-based modeling and multi-agent systems. In addition, the simulation platform NetLogo is briefly introduced. Next, the design and the working of the simulation are described. This section is followed by a discussion of the application of *Pamela* for the evaluation of different transport policies: leveling out parking costs, reduced bicycle stall costs, and relocated parking facilities. The chapter ends with conclusions.

7.2 Simulation platform

The simulation presented in this chapter is based on the principles of a modeling approach called ‘agent-based modeling’. According to Gilbert (2008), agent-based modeling can be defined as ‘a computational method that enables a researcher to create, analyze, and experiment with models composed of agents that interact within an environment’. A multi-agent system (MAS) can be defined as ‘a loosely coupled network of problem solvers that interact to solve problems that are beyond the individual capabilities of each problem solver’ (Durfee & Lesser, 1989). These problem solvers, often called agents, are autonomous and can be heterogeneous in nature. The main characteristics of MASs are that each agent has incomplete information or capabilities for solving the problem and, thus, has a limited global control; data are decentralized; and computation is asynchronous (e.g., Sycara, 1998). In the context of this thesis, agents are residents who demonstrate particular parking behavior. In the current application agents do not interact. Based on their personal characteristics and requirements agents react on changes in the environment they act in. The actions of the agents, in turn, change the system state in time (in this case the parking occupancy rates). In that sense, agent-based simulation in this context is similar to micro-simulation (see for example Miller, 2003).

Several platforms are available to build a multi-agents system such as Swarm (<http://www.swarm.org>), Repast (<http://repast.sourceforge.net>), and Mason (<http://cs.gmu.edu/~eclab/projects/mason>). The latter two include a variety of features to build an agent-based program (Gilbert, 2008). The systems are open source software and available for noncommercial use. The main disadvantage of both systems is their complexity, which means that it can take some months before one can take full advantage of the wide range of available features. More suited are modeling environments that provide complete systems in which a model can be created and executed, and the results visualized, without leaving the system. NetLogo (<http://ccl.northwestern.edu/netlogo/>) is an example of such a system.

NetLogo is an open source programmable multi-agent modeling platform. The platform is not designed for specific problems, but allows defining almost any problem of interest through programming (e.g., Zhu, 2008). NetLogo also provides a graphical representation called ‘world’, which is especially useful for visualizing spatial activities. World is a grid-based graph composed of cells, called patches, with definable size where an agent, called turtle, stand and moves. The simulation of agent movements is controlled by commands, which adjust the status of patches and the activities of turtles. NetLogo is designed to be object-oriented, implying that patches and turtles may contain properties implemented as variables, and behaviors that are programmed procedures. It simulates the real world situation by representing changes in the status of multiple agents ‘simultaneously’ (of course, processed sequentially in computation) as if they occur in parallel. Interactions between agents can also be modeled.

To see the effect of planning instruments users of the NetLogo application can change different settings using sliders and switches. Sliders have a range of numeric values that can be adjusted between a predefined minimum and maximum according to a predefined step size. Sliders can be used for changing characteristics of the patches but also for setting the initial values such as the number of turtles involved in the

simulation and the number of periods of the simulation. Switches have two values: on and off. Switches are often used to include or exclude patches, groups of turtles or actions. The effects of implemented planning instruments can be easily presented using plots and monitors. Plots show outcomes over time, while monitors show the status at certain moments in time. For example, Figure 7.1 shows a plot containing the number of visitors for three different shopping centers (Center 0, Center 1, and Center 2) during 10 time slices (or steps).



Figure 7.1: Example of a plot in NetLogo

7.3 Setting up the simulation

The simulation is divided into three successive steps. In the first step a physical environment underlying the simulation is created. In this physical environment, the simulation of residents' shopping behavior takes place. The next step consists of the definition of the residents who will be part of the simulation. After having set all the agents, the various actions have to be specified in the last step.

Step 1: Define the physical environment

The first step of the simulation consists of the definition of the physical environment (called patches, a square) in which the simulation has to run or with other words 'in which the agents (or turtles) act'. In this step, the number and locations of various physical objects such as roads, shopping centers, parking facilities, and bicycle stalls are set. In NetLogo, each group of objects forms a so-called 'agent group' that can have various characteristics. The characteristics of the agent groups are the same as used in the choice models. For example, parking facilities can be described in terms of number of parking spaces, parking tariff, number of exits, type of parking, etc.

In the example that is worked out, the following hypothetical environment is defined: a simple road network with three shopping centers that are surrounded by a different number of parking facilities (Figure 7.2, labels p^*) and bicycle stalls (label s^*).

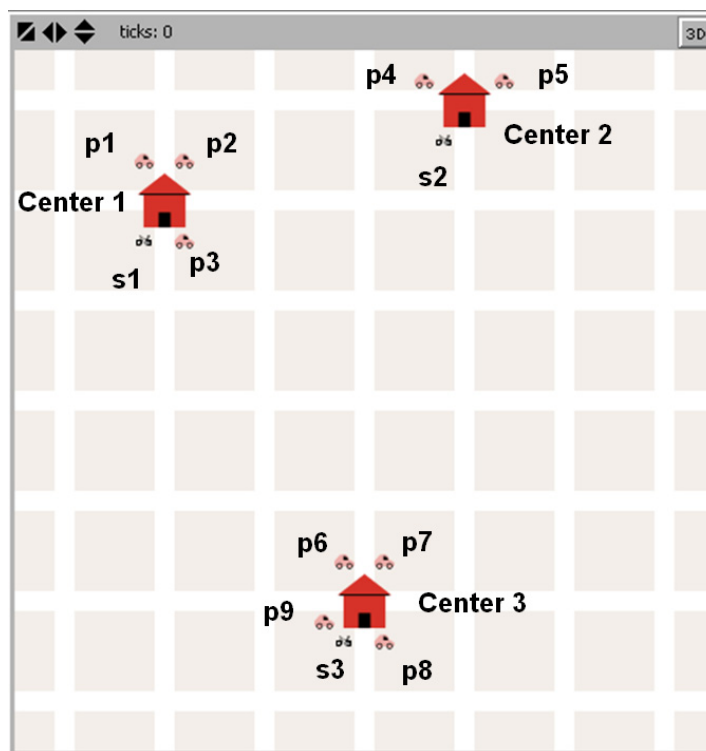


Figure 7.2: *Physical environment of the simulation*

The agent groups used in this simulation are defined as follows. The roads and building block follow a regular pattern of cells. Roads have a width of 1 cell while building blocks have a width and a length of 4 cells. In line with the contents of the combined travel model, shopping centers (🏠) are defined by the characteristics supply of shops and distribution of shops. Parking facilities (🚗) are defined using the characteristics that are included in *Pamela*: size, chance of finding free space, parking costs, maximum parking duration, average egress time, driving space, type of facility, type of security, location in relation to residents' home location, location in relation to other parking facilities, and distance to nearest supermarket/department store. In the same way, bicycle stalls (🚲) are described using the characteristics level of security, storage charge, and walking distance to nearest supermarket or department store. Tables 7.1, 7.2, and 7.3 present the characteristics of the shopping centers, parking facilities, and bicycle stalls included in this simulation. The values are chosen such that a variety in shopping centers, parking facilities, and bicycle stalls is present. As shown, three shopping centers are defined. In addition, 9 parking facilities are defined. Parking facilities 1, 2, and 3 are located around shopping center 1, while parking facilities 4 and 5 are located close to shopping center 2. The parking facilities 6 through 9 are close to shopping center 3. The numbers of the bicycle stalls correspond with the number of the shopping centers.

Table 7.1: *Description of the shopping centers included in the simulation*

Characteristics	Shopping centers		
	Center 1	Center 2	Center 3
Supply of shops	Limited	Average	Average
Distribution of shops	Concentrated	Concentrated	Dense

Table 7.2: Description of the parking facilities included in the simulation



Characteristics	Parking facilities								
	p1	p2	p3	p4	p5	p6	p7	p8	p9
Size of parking facility	450	250	250	450	250	450	450	250	50
Chance of free space	75	50	75	75	75	75	50	50	25
Parking costs	1.00	1.00	2.00	Free	1.00	Free	1.00	2.00	2.00
Max parking duration	Unlim	Unlim	1 hr	Unlim	Unlim	3 hr	1 hr	Unlim	Unlim
Average egress time	0	2	2	2	2	2	4	0	0
Driving space	Limit	Limit	Aver	Limit	Limit	Spaci	Aver	Aver	Limit
Type of parking facility	Lot	Lot	Gara	Lot	Lot	Lot	Lot	Gara	Gara
Type of security	None	None	Video	None	Video	None	Video	Video	Secur
Location home	-	-	-	-	-	-	-	-	-
Location other parking	Close	Neutr	Neutr	Neutr	Neutr	Far	Neutr	Neutr	Close
Walking distance	50	150	50	150	50	150	250	50	50

*depends on the home location of the resident

Table 7.3: Description of the bicycle stalls included in the simulation

Characteristics	Bicycle stalls		
	Stall 1	Stall 2	Stall 3
Level of security	Secured	Secured	Secured
Storage charge	DFL 0.50	DFL 1.00	Free
Walking distance to stores	125 meters	75 meters	75 meters

Step 2: Define the residents

In this step the residents who want to go out for shopping, are defined. The following characteristics are connected to shoppers (dark -  - for weekly shopper and light -  - for non-weekly shoppers): home location (Figure 7.3, green cell), distance between home location and shopping centers, type of shopper, shopping duration, and location of the various parking facilities vis-à-vis the shoppers' home location. To set the characteristics of the shoppers the following actions are carried out. First, the distance (D) between home location *i* (coordinates: x_i and y_i), and the available shopping center *j* (coordinates: x_j and y_j), is determined for each resident using the rectangular road network and the following formula.

$$D_{ij} = |x_i - x_j| + |y_i - y_j| \tag{7.1}$$

Second, each resident is semi-randomly assigned to the group of weekly (black) or non-weekly (yellow) shoppers. The semi-random process is organized as follows. First, a random number between 0 and 1 is generated. Next, if the number is smaller than or equal to 0.60 the resident is assigned to the weekly shoppers. The breaking point is based on the distribution of weekly and non-weekly shoppers according to the *Albatross* system (Arentze & Timmermans, 2000). Third, for each resident the duration of traveling, shopping and in addition of parking is randomly selected from the distributions (one for weekly and one for non-weekly shopping) observed in Veldhoven (Figure 7.4).

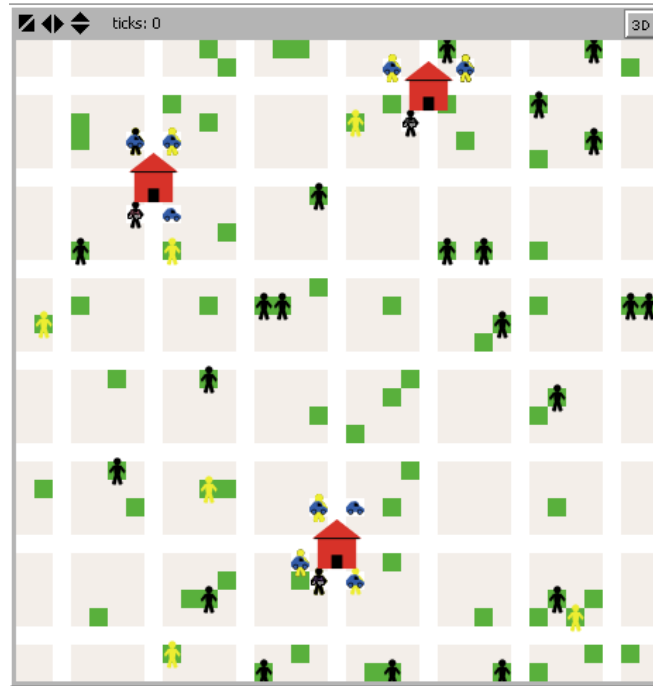


Figure 7.3: Example of created shoppers at home locations

Fourth, the characteristic ‘location of the various parking facilities vis-à-vis the shoppers’ home location’ is determined automatically according to the following rules. For each shopping center, an imaginary cross is drawn (+) with its midpoint in the middle of the shopping center. If the residents’ home and facility are both located in the same quadrant, the value of the characteristic is set to ‘favorable’. If the residents’ home location is in the opposite quadrant, the value is set to ‘unfavorable’. In the remaining cases the value is set to ‘neutral’.

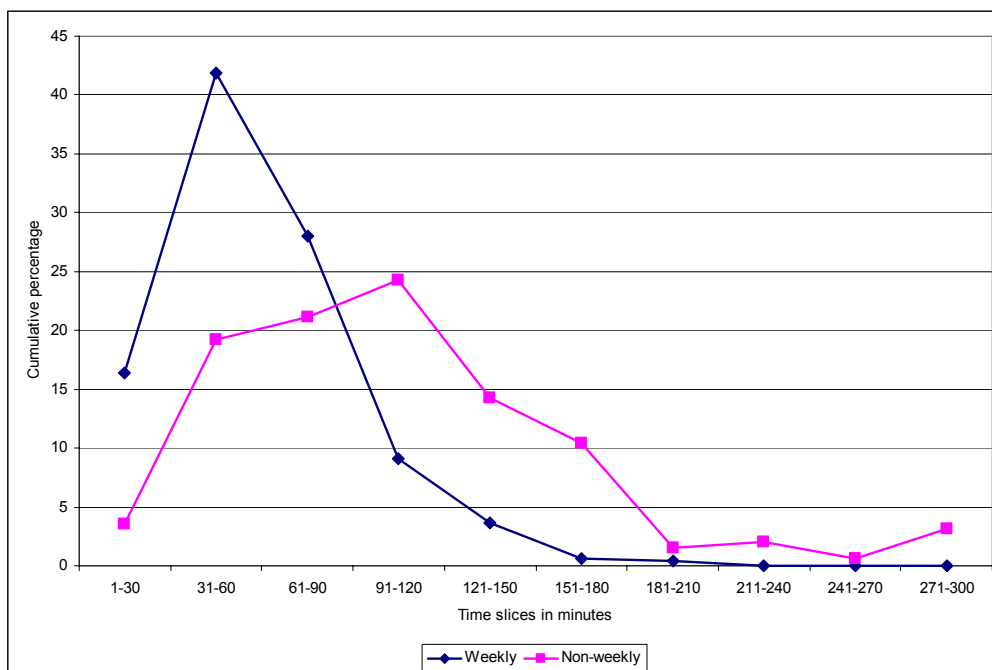


Figure 7.4: Observed distributions (weekly and non-weekly) of shopping duration

Step 3: Define actions

In the simulation, the residents carry out several actions that are described by the various choice models. The estimated parameters are implemented in the models that are part of the simulation. For all variables included in the choice models, the utility of the first two levels of a variable is equal to the corresponding estimated parameter; for the third level of each variable (the base level), the utility is equal to the sum of the utilities for the first and second level, multiplied by -1 (effect coding). Because of the use of effect coding an assumption has to be made regarding the standard deviation of the base level utilities. These standard deviations are assumed to be equal to the root of the sum of squared standard deviations for the corresponding first and second level parameters because it is assumed that the random parameters are uncorrelated.

In addition, two actions are added to this process. The first action concerns the move from home to the chosen shopping center and to the chosen parking facility or bicycle stall. After the shopping visit ends the shopper moves from the chosen shopping center back home. In the simulation, the two actions are made visible by the location of the persons. If a person occupies a green square, this person is at home. If a green square is not occupied, the person is still visiting the shopping center (see Figure 7.3).

7.4 Simulation process

Figure 7.5 presents a flowchart of the simulation process of *Pamela*. In fact, the simulation can be subdivided into 8 steps. In the first step, the simulation generates the residents who leave home for a shopping trip at time period t . The total number of residents generated per period depends on the period of the day and is based on empirical data (see section 7.5). For each generated shopper, the following characteristics are determined: trip purpose (weekly or non-weekly shopping), shopping duration, and home location (to determine the location vis-à-vis the various parking facilities) in step 2. In step 3 the composition of the parking choice set per shopping trip is determined. Step 4 consists of the choice of the combined travel alternative. When the combined travel choice is known, the resident moves to the chosen destination (step 5). In the case that the resident chooses a parking facility that is not fully occupied the simulation continues with step 7. If the resident has chosen for a parking facility that is fully occupied, the parking choice will be reconsidered by carrying out the adaptive parking model in step 6. Depending on the outcome of the adaptive parking choice model, the simulation continues with step 7 (adaptive choice alternatives ‘Wait’ and ‘Illegal parking’), step 4 (adaptive choice alternative ‘Search alternative parking’ and ‘Go shopping elsewhere’), or step 8 (adaptive choice alternative ‘Go home’). The simulation ends when the resident moves home after exceeding the total shopping duration.

7.5 Evaluating transport policies

Now the structure of simulation is defined, *Pamela* can be used to evaluate different hypothetical transport policies. The basic settings of the simulation have already been discussed in section 7.3. Some additional information is added to let the simulation work.

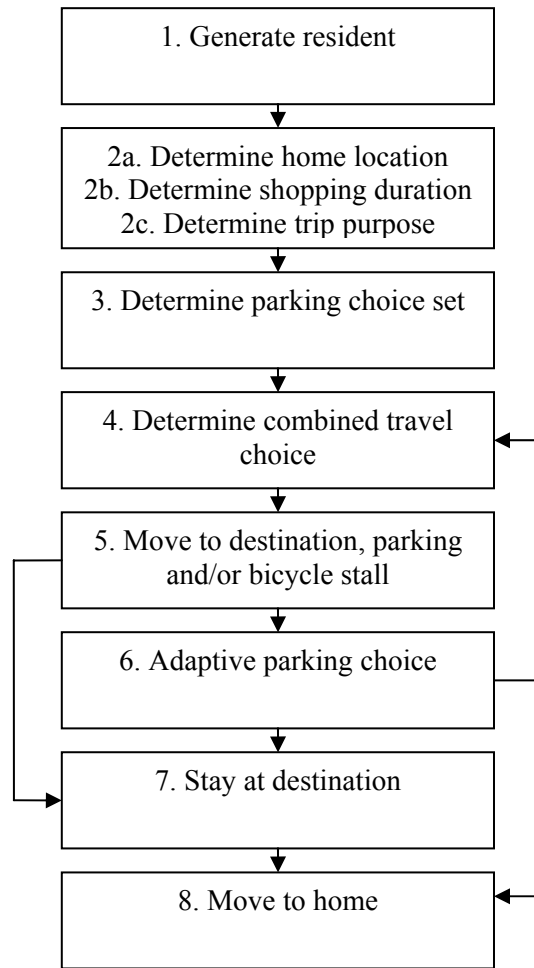


Figure 7.5: Flowchart of the multi-agent simulation

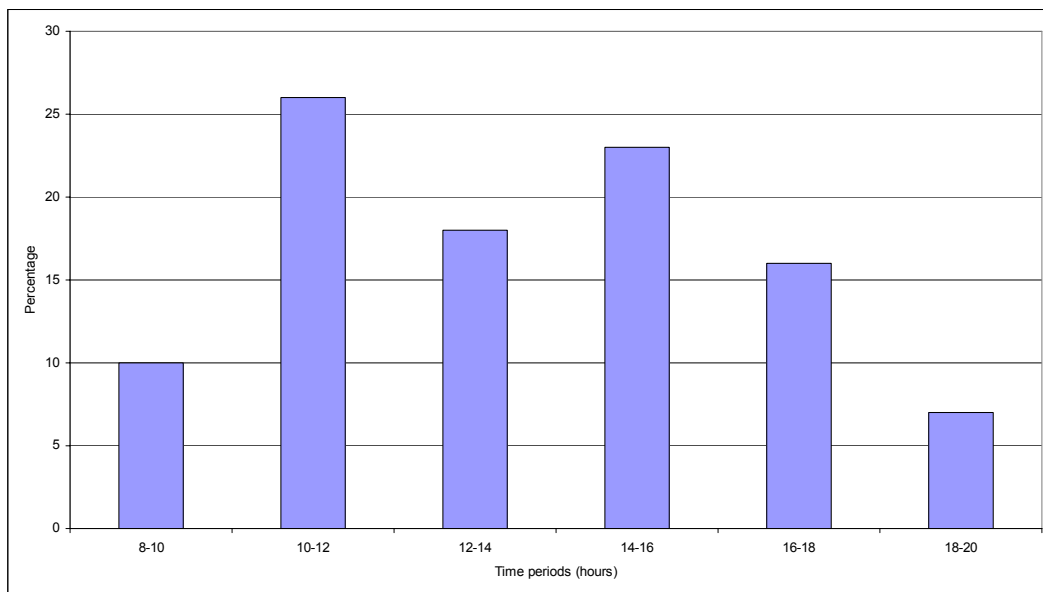


Figure 7.6: Distribution of departures for shopping (percentages)

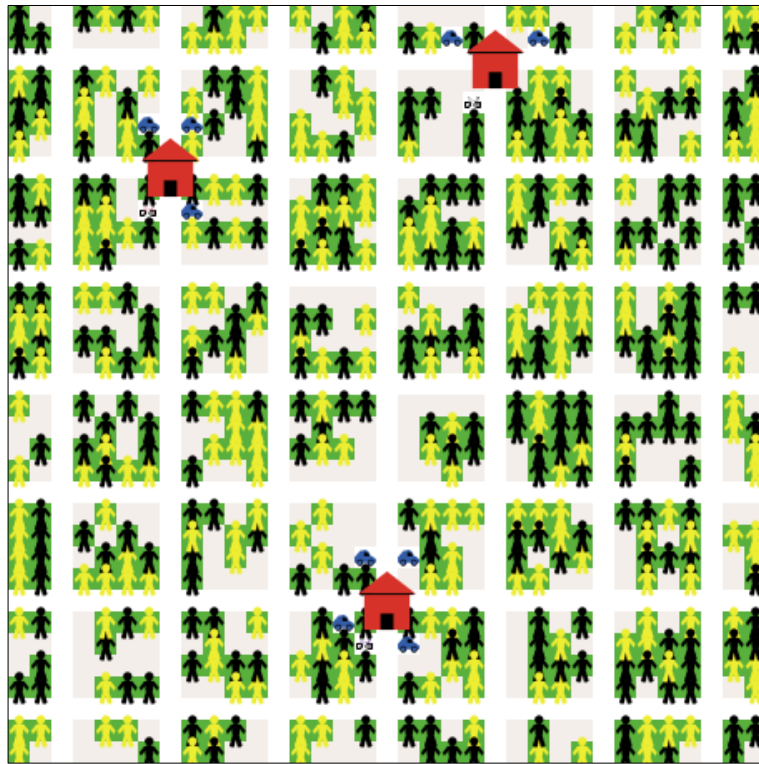


Figure 7.7: *Simulation of 500 residents during 720 time slices*

First, the period of the simulation runs is set between 8:00 and 20:00 hours (total of 720 minutes). The time steps in the simulation are set to 1 minute. Second, the generation over time of residents who go out for shopping is based on a distribution of trips that is retrieved from observed travel data of the Ministry of Transport, Public Works and Water Management (2008). The distribution over time of shopping trips is presented in Figure 7.6. The available travel data do not provide a distinction between weekly and non-weekly shopping. The shopping trips of 500 residents are included in each run of the simulation. To cancel out random effects, in total 10 simulation runs were carried out each starting with a different random seed. The figures presented in this chapter, include averages over these 10 runs.

To show the working of *Pamela* three different kinds of transport policies are evaluated. The first policy (label **TwoGuilders**) consists of a leveling out of the parking costs for all parking facilities at DFL 2.00. The policy includes an increase of the parking costs of two parking facilities from free to DFL 2.00, and four parking facilities from DFL 1.00 to DFL 2.00. With the second policy (label **FreeStorage**) the storage costs of all bicycle stalls are set to DFL 0.00 which is equal to free storage. The final policy (label **ParkingDistance**) focuses on the walking distance between parking and supermarkets/department stores. With different infrastructural measures (breakthroughs, movement of parking spaces, etc.), all walking distances are set to 150 meters. The suggested planning policies can be easily set in the simulation using sliders (see Figure 7.8). The researcher can move the slider from left to right vice versa, changing the characteristics of shopping centers, parking facilities, and bicycle stalls. All the other characteristics of the shoppers (home location, shopping purpose, and shopping duration) remain constant for all transport policies. The simulation

produces the following outcomes: shopping center choice, travel mode choice, parking choice, adaptive parking choice, storage use, and distance traveled. All outcomes of the different policies are compared with the base situation that was defined in Tables 7.1, 7.2 and 7.3 (label **Base**).

The outcomes are presented at two different levels of aggregation: for the whole daytime period and for each time slice of the daytime period. At the *first level*, the choices of the total number of residents are presented for each transport policy at the daytime period. The figures show the total use of the included facilities: shopping centers, parking facilities, and bicycle stalls. The *second level* focuses on the use of all facilities for each time slice of the daytime period (between 8:00 and 20:00 hours) that was considered in the simulation. The figures include not only the residents' choices but also their visit duration, resulting in an average (over 10 simulation runs) number of visitors present at a facility for each time slice. This way, the use of facilities can be visualized during the day.



Figure 7.8: *Slider to change the characteristics of parking facilities*

Shopping center choice

Based on the simulations, the effects of the included transport policies on the various choices of residents can be visualized and presented at different levels of aggregation as suggested above. The first choice that is considered concerns the residents' shopping center choice. It seems that the suggested transport policies affect the choice of shopping destinations only marginally (Figure 7.9). The figure shows for each transport policy the average number of visitors (over 10 simulation runs) of each shopping center. As expected, the equalization of parking costs (TwoGuilders) results in fewer visitors for shopping center 2 (decrease of approximately 7 percent) and more visitors for shopping center 1 (increase of 4 percent) and 3 (increase of 3

percent). These changes make sense because the parking situation of shopping center 2 changes mostly compared to the parking situations of the two other shopping centers. The introduction of free bicycle stall (FreeStorage) does not seriously affect the residents' shopping center choice. The relocation of parking facilities (ParkingDistance) also shows only a minor relocation of visits from shopping Centers 1 (minus 2 percent) to shopping center 3 (plus 2 percent). This change is according to our expectations because the attractiveness of the parking situations of shopping center 1 decreases most due to the increase of walking distance to the parking facilities while the utility of shopping center 3 in relation to the other centers becomes more positive.

For each transport policy, the presence of visitors in each shopping center can be visualized for each time slice of the daytime period (between 8:00 -time slice 1- and 20:00 -time slice 720- hours). The residents' shopping center choices in combination with the duration of the residents' shopping activity determine for each time slice the number of shoppers present in the shopping centers. The residents' home locations and shopping durations are kept constant over all transport policies. Figure 7.10 presents for each of the transport policies the average number of shopper per shopping center during the daytime period.

It appears that for each time slice the different transport policies have a relatively small effect on the presence of residents at each shopping center. In the case of the equalization of parking costs (TwoGuilders), the pattern for shopping center 1 is more or less stable compared with the base policy. For shopping center 2 and 3, the corresponding curves move down and up respectively. In the case of the free storage policy (FreeStorage) it appears that the presence of shoppers in the shopping centers during the daytime period is more or less equal to the presence of shoppers in the Base scenario. More or less the same holds for the case of the relocation of parking facilities (ParkingDistance).

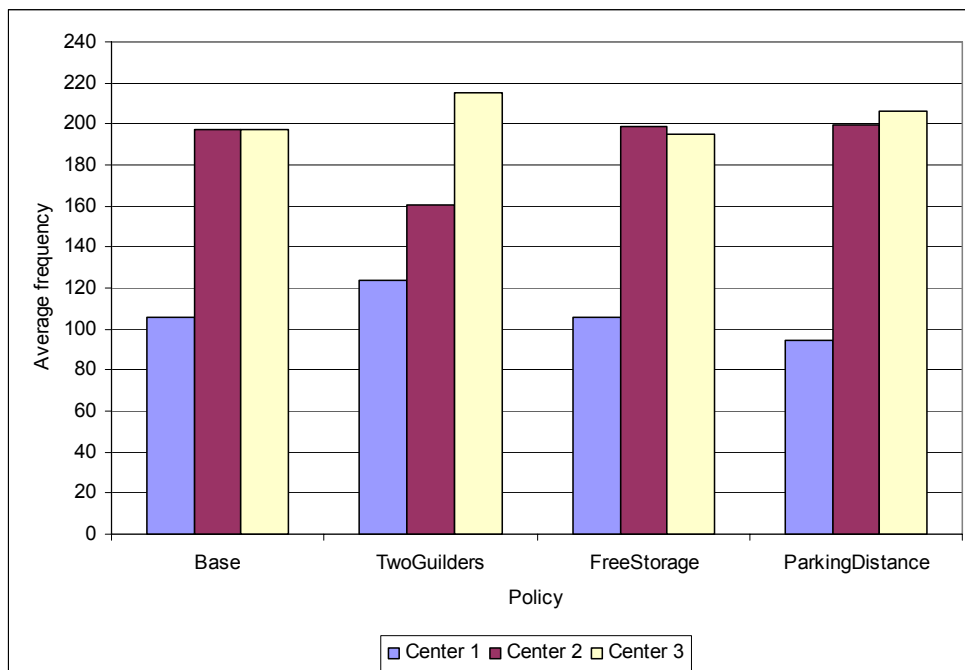


Figure 7.9: *Effect of transport policies on shopping center choice*

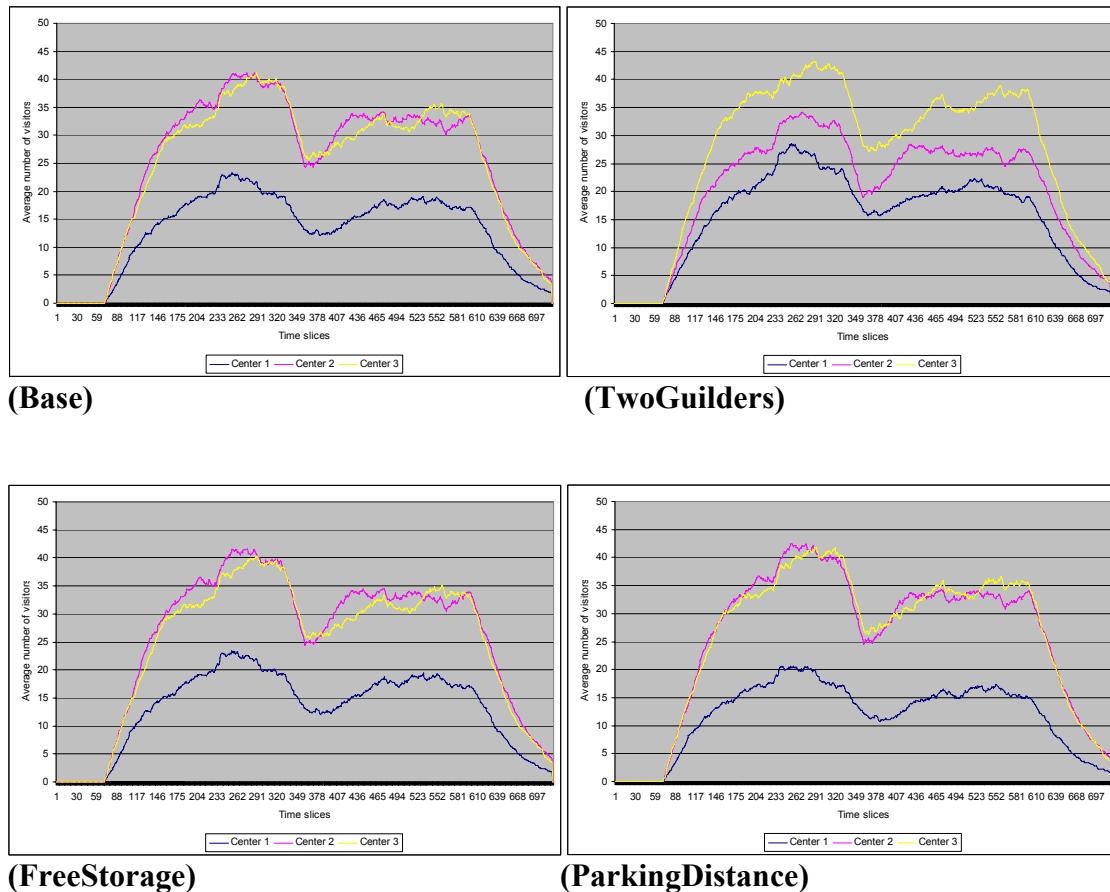


Figure 7.10: Effect of transport policies on shopping center choice during the day

Travel mode choice

The effects of the suggested transport policies on the shoppers' travel mode choice are presented in Figures 7.11 and 7.12. According to Figure 7.11, it appears that the effect of the investigated transport policies on the choice of travel mode is considerable (maximal change of almost 30 percent). As expected, the equalization of parking costs affects the travel mode choice from car (decrease of almost 30 percent of all residents) to bicycle (increase of approximately 27 percent) and bus (increase of 3 percent). The introduction of free storage results into a small exchange between car (decrease of 1 percent) and bicycle (increase of 1 percent) use. It seems that also the relocation of parking facilities affects the residents' mode choice marginally. The use of the car decreases with almost 4 percent while the use of the bicycle increases with the same percentage. The use of the bus stays more or less the same in both situations.

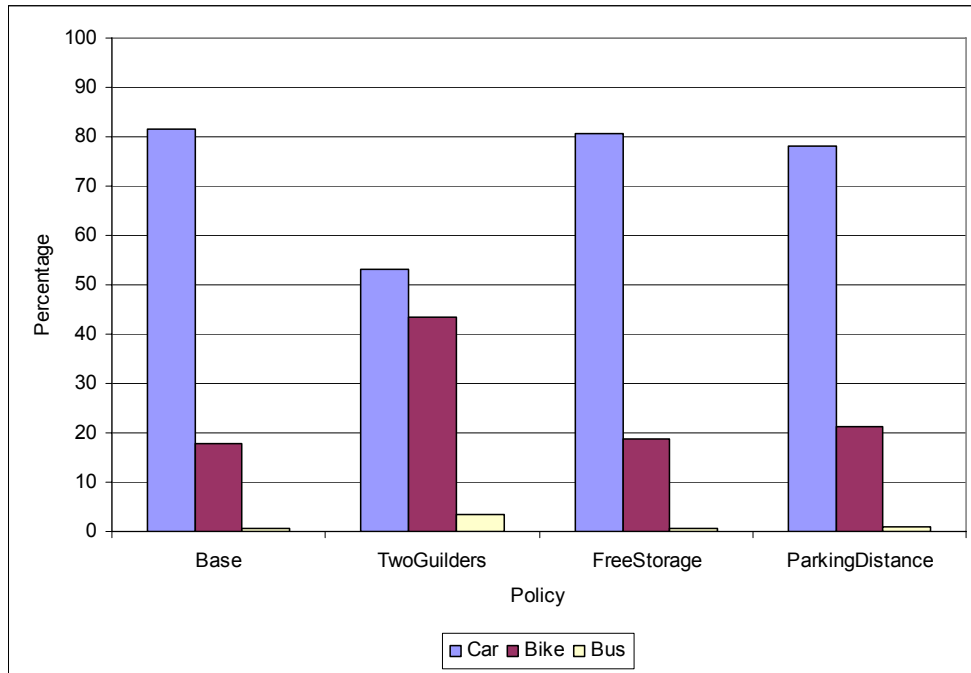


Figure 7.11: *Effect of transport policies on travel mode choice*

When looking into more detail to the results, it appears that over the scenarios the effect of the policy measures on the use of cars is not equal for each shopping center. Figure 7.12 presents for each transport policy the average number of cars (over 10 simulation runs) arriving at each shopping center per day. It appears that the equalization of parking costs (TwoGuilders) results in a decrease in cars arriving at all shopping centers. The largest decrease is noticed for shopping center 2 (on average minus 80 cars) followed by shopping centers 3 (minus 50 cars). Apparently, due to the explicit increase in parking costs at shopping center 2, people visiting this center tend switching to the bicycle.

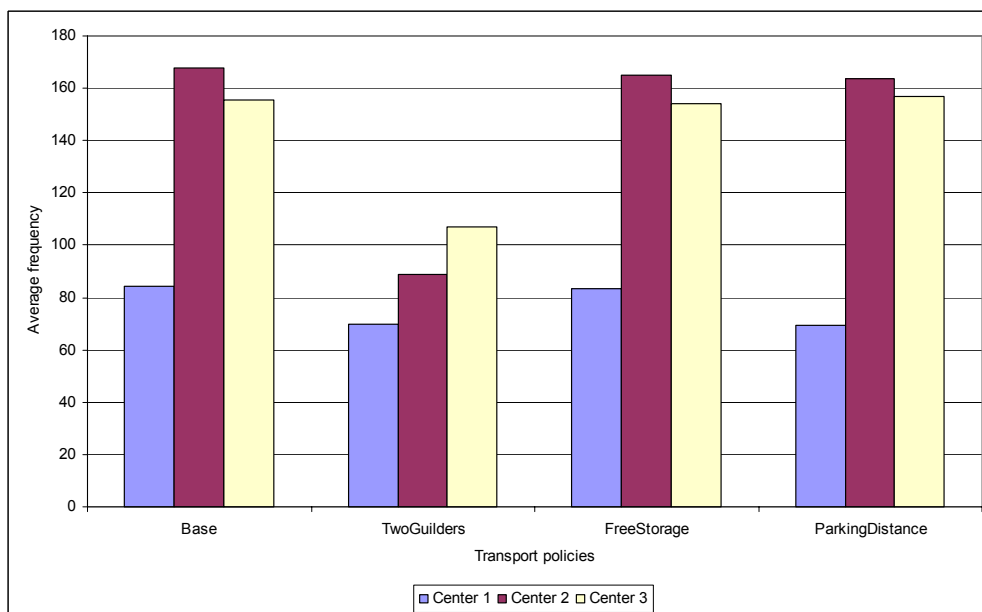


Figure 7.12: *Average number of cars arriving at the shopping centers*

The number of cars arriving at the shopping centers when free bicycle stall (FreeStorage) is introduced, changes only marginally. This result shows that a change of storage fee has almost no effect on car use. The relocation of parking facilities (ParkingDistance) results in a small decrease in the average number of cars arriving at shopping centers 1 (minus 15 cars) while the number of cars arriving at shopping centers 3 increases a bit (plus 1 car). These findings for car use across the policy scenarios are similar to the findings for shopping center use. This may be expected as in this simulation, the car is by far the most popular transportation mode for shopping.

Parking choice

Figure 7.13 presents the effects of the transport policies on residents' parking choices for the entire day. The figure includes only residents who used the car for their shopping trip. As expected the use of parking facilities that had no parking costs in the Base scenario, like P4 and P6, decreases substantially (respectively with approximately 90 and 100 cars) due to the equalization of parking costs (TwoGuilders). Alternative parking facilities like P5 (plus 10 cars) at Center 2, and P8 (plus 30 cars) and P9 (plus 20 cars) at Center 3 are used more often now.

Regarding the effect of the introduction of free bicycle stall (FreeStorage) it appears that the choice of parking is affected marginally which is consistent with previous findings.

The relocation of parking facilities at the distance of 150 meters to the nearest supermarket or department store (ParkingDistance) motivates car drivers to choose more often for the parking facilities P4 (plus approximately 20 cars) and P6 (plus 15 cars). For both facilities the walking distance does not change.

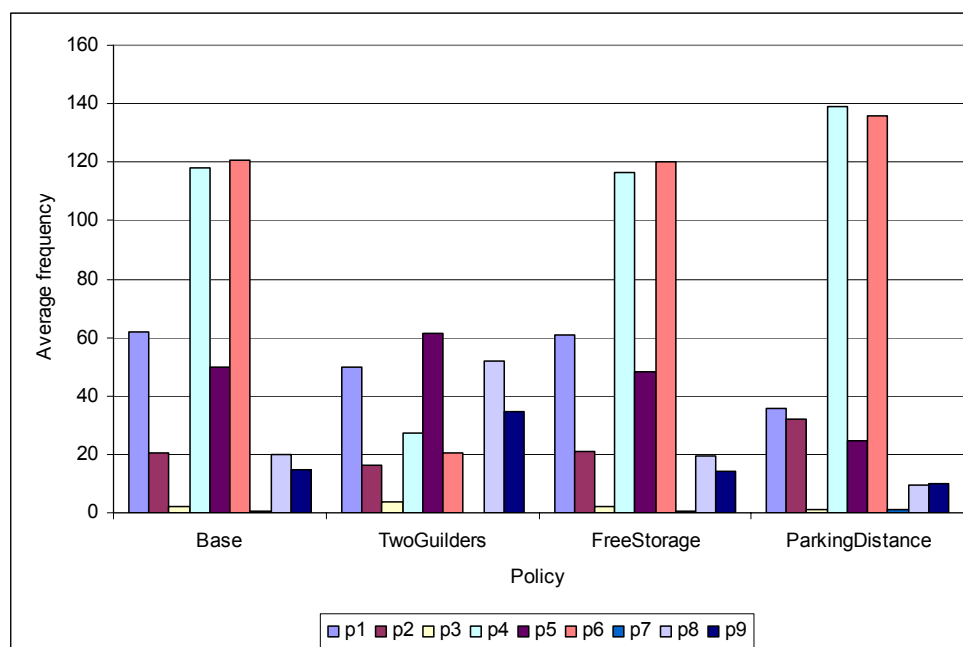


Figure 7.13: *Effect of transport policies on parking choice*

Note that the direct competitor of parking P4 (P5) becomes less attractive because of an increased walking distance. In contrast, parking P6 may suffer from the increased attractiveness of P7. This explains largely why P4 takes more advantage of equalizing walking distances than P6. The effect on the use of the other parking facilities, except for P1, is relatively small. The use of P1 decreases with approximately 25 cars due to the increase of walking distance from 50 meters to 150 meters. In contrast, the use of P2 increases because the distance to the nearest supermarket or department store of its direct competitors (P1 and P3) increases.

The demand for parking spaces for each time slice of the daytime period at the parking facilities surrounding shopping center 1 (P1, P2, and P3), is presented in Figure 7.14. The Figure shows that in the case of equalization of parking costs (TwoGuilders), demand for parking at parking P1 and P2 decreases in favor of the demand at parking P3. The changes in use are limited. In the case of free storage (FreeStorage) only minor differences can be noticed. The relocation of the parking facilities (ParkingDistance) clearly shows a lower demand for Parking P1 and a higher use of Parking P2 (see before). The demand for parking P3 does not change.

Figure 7.15 presents the demand for parking spaces for each time slice of the daytime period at parking facilities surrounding shopping center 2 (P4 and P5). It appears that the equalization of the parking costs (TwoGuilders) affects the demand for parking during the daytime period substantially. The demand at P4 decreases while the demand at P5 increases a bit.

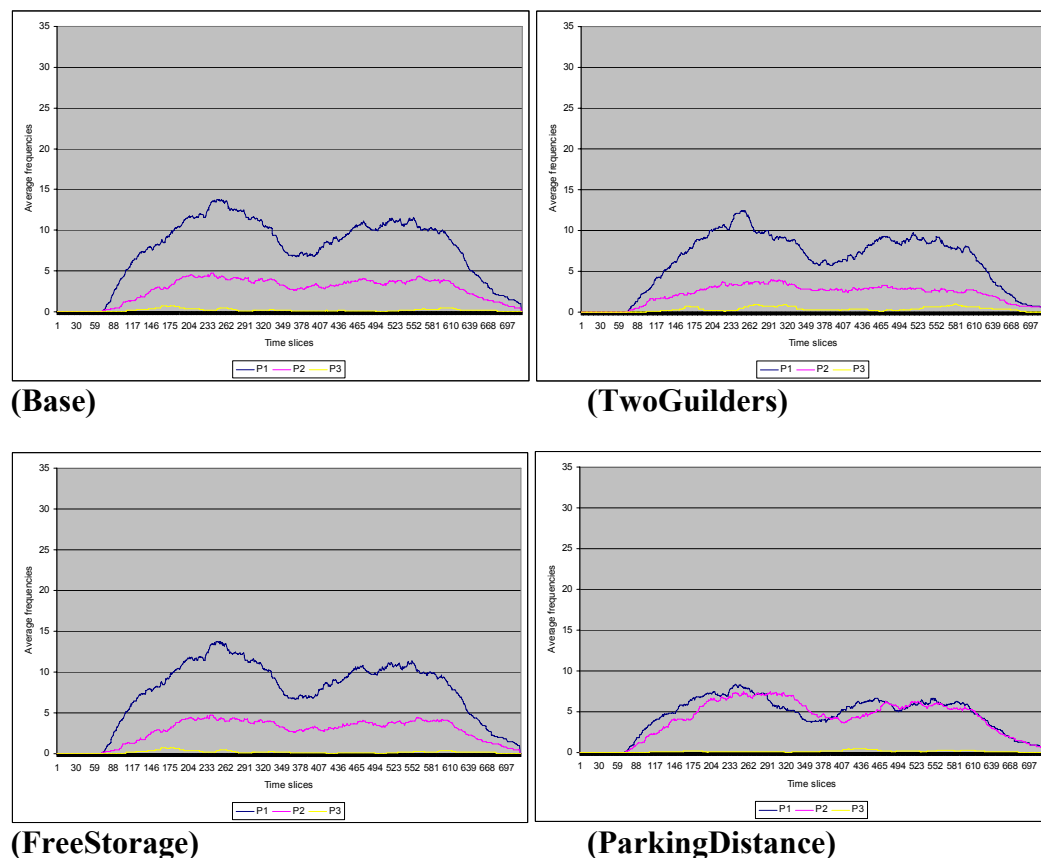


Figure 7.14: Effect of transport policies on parking choice at shopping center 1

The effect of the introduction of free storage (FreeStorage) on the demand of both parking facilities during the daytime period is virtually negligible. The relocation of parking facilities (ParkingDistance) results into a higher peak demand of parking at P4 and a lower demand at P5. This effect is as expected because P5 becomes less attractive due to the relocation.

The demand for parking spaces for each time slice of the daytime period at parking facilities surrounding shopping center 3 (P6, P7, P8, and P9) is presented in Figure 7.16. It appears that the equalization of parking costs (TwoGuilders) results into a substantially decrease of the demand of parking at P6 for the benefit of the other parking facilities surrounding center 3 especially P8 and P9. The introduction of free storage (FreeStorage) for bicycles shows no clear changes. The effect of the relocation of parking (ParkingDistance) facilities on the demand of parking is limited to an increase of the parking demand at parking P6 which now has a higher demand than in the Base situation.

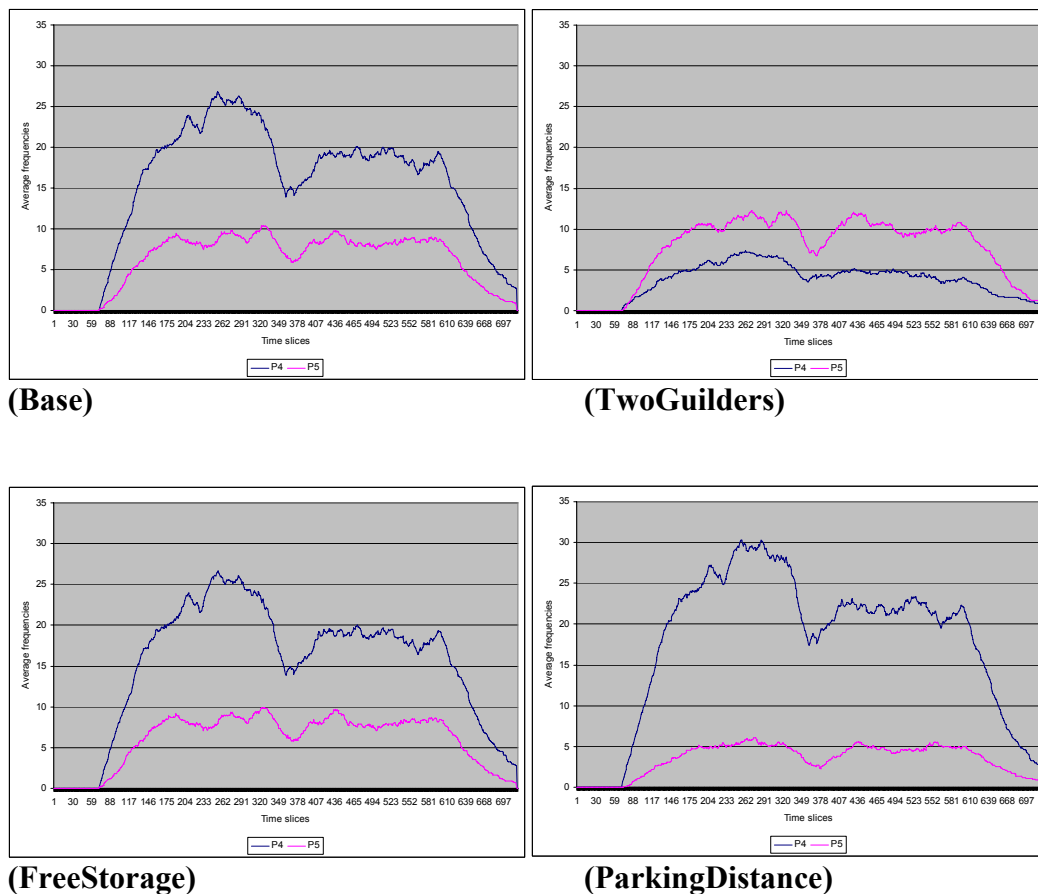


Figure 7.15: Effect of transport policies on parking choice at shopping center 2

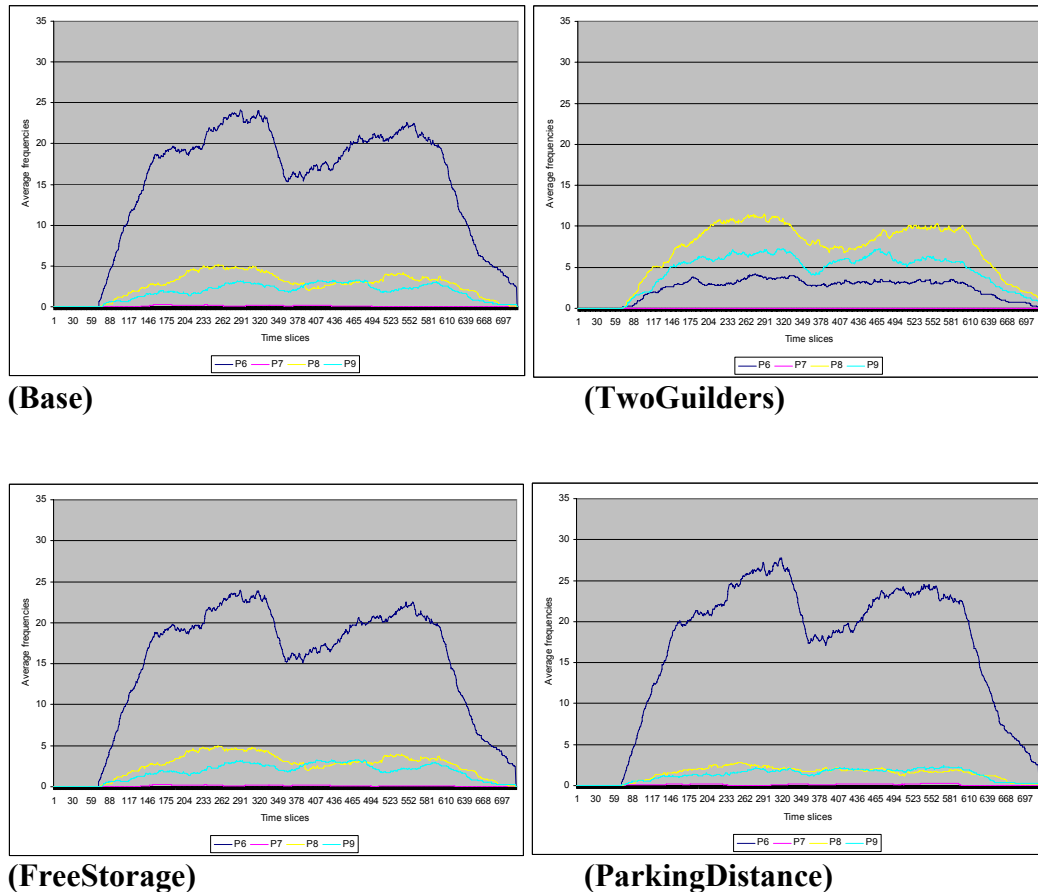


Figure 7.16: *Effect of transport policies on parking choice at shopping center 3*

Adaptive parking choice

The results regarding adaptive parking choices are only presented at the aggregate level (Figures 7.17 and 7.18). Car drivers who did not need to adapt their parking choice are represented in figure 7.17 by the category ‘No adaptation’. The simulations show that only in the case of the equalization of parking costs (TwoGuilders) a limited number of car drivers are confronted with fully occupied parking facilities. As shown before in Figure 7.13 car drivers are choosing more frequently for smaller parking facilities (P5, P8, and P9) that results in more adaptive parking choice behavior. The car drivers, who face a fully occupied parking facility react divers. Waiting for a free space and searching for an alternative parking facility are most popular reactions. In the case of the equalization of parking costs, almost 40 car drivers wait for a free space, while approximately 50 car drivers search for another parking alternative near the shopping center, and almost 20 car drivers move to another shopping destination. Only a few car drivers park their car illegal (2 car drivers) or return home (10 car drivers) when facing a fully occupied parking facility. The introduction of free storage (FreeStorage) does not change the distribution of the car drivers’ adaptive parking choices in comparison with the Base situation. It seems that the relocation of parking facilities triggers car drivers to choose for bigger parking facilities (especially P4 and P6) and decreases the number of car drivers who face a fully occupied parking facility.

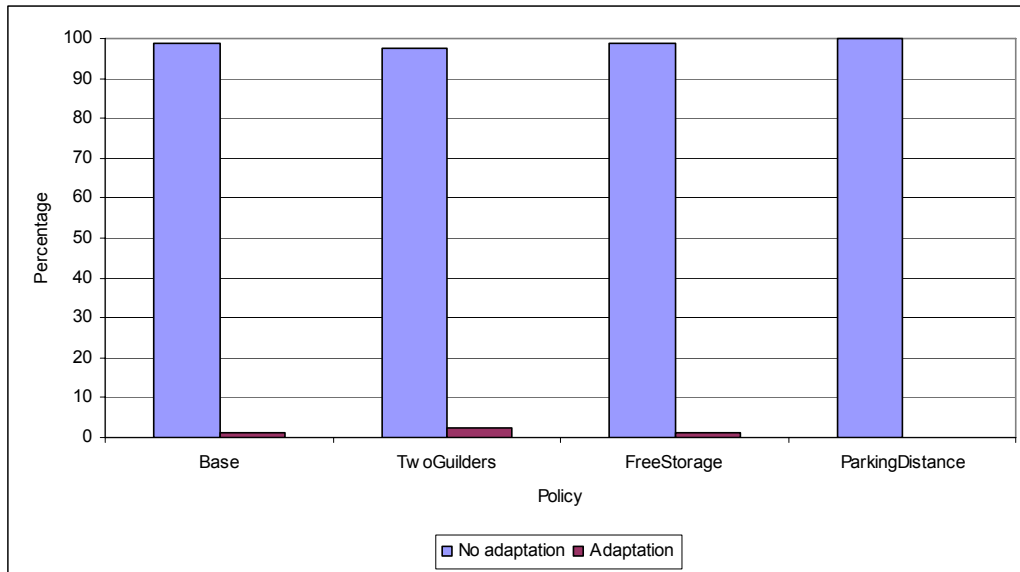


Figure 7.17: *Effect of transport policies on adaptive parking choice*

Bicycle stall choice

The different transport policies affect the number of bicyclists arriving at the three shopping centers. Figure 7.19 presents for each transport policy the average number (over 10 simulation runs) of cyclists arriving at each shopping center. The figure clearly shows the increase of bicyclists in the case of the equalization of parking costs (TwoGuilders). Despite the fact that all shopping centers benefit of the increase, the increase is highest for shopping center 3 (plus 59 cyclists) followed by shopping center 2 (plus 38 cyclists). The other two other planning scenarios (FreeStorage and ParkingDistance) only result in a small increase of bicyclists.

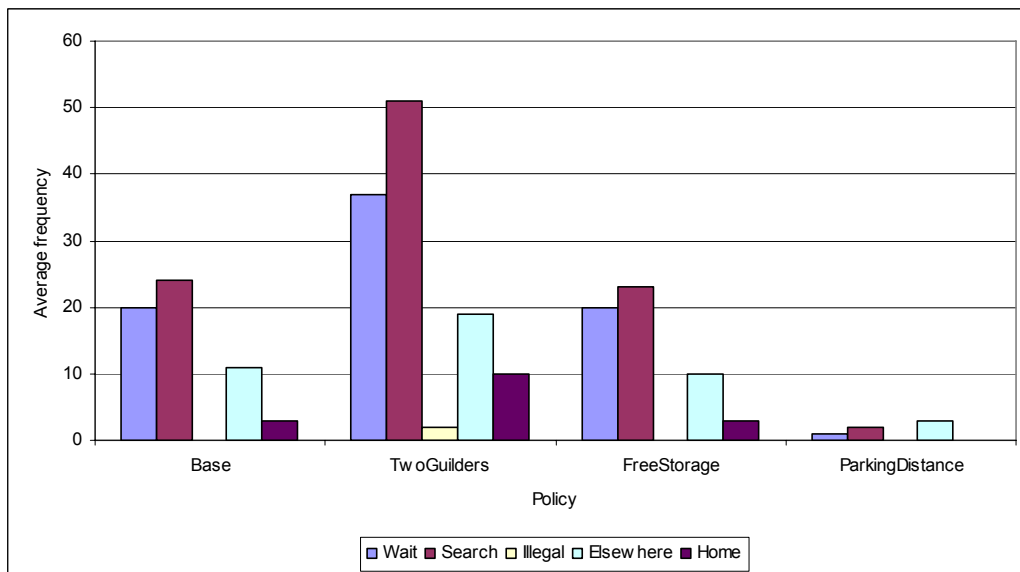


Figure 7.18: *Distribution of adaptive parking choices per transport policy*

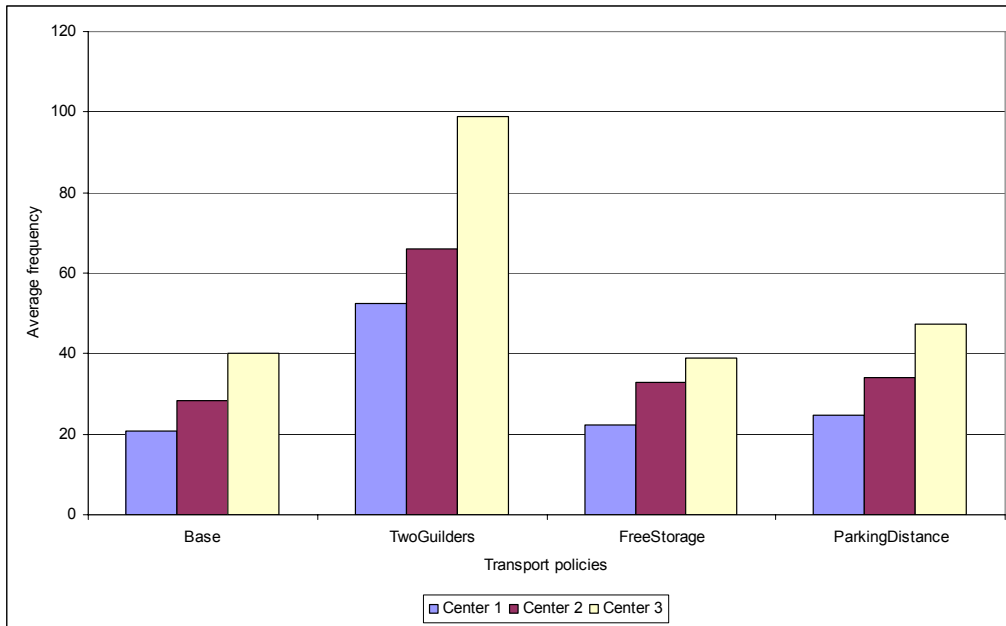


Figure 7.19: *Number of bicyclists arriving at the shopping centers per transport policy*

As can be expected, the increase of cyclists in the case of the equalization of parking costs does not affect the share of bicyclers using an official storage facility for bicycles (Figure 7.20). The same holds in the case of the relocation of parking facilities (ParkingDistance). In the case of the introduction of free storage (FreeStorage), however, using a storage facility becomes more attractive as can be seen in Figure 7.20. The amount of cyclists using the bicycle stall increases considerably from approximately 60 percent to more than 75 percent.

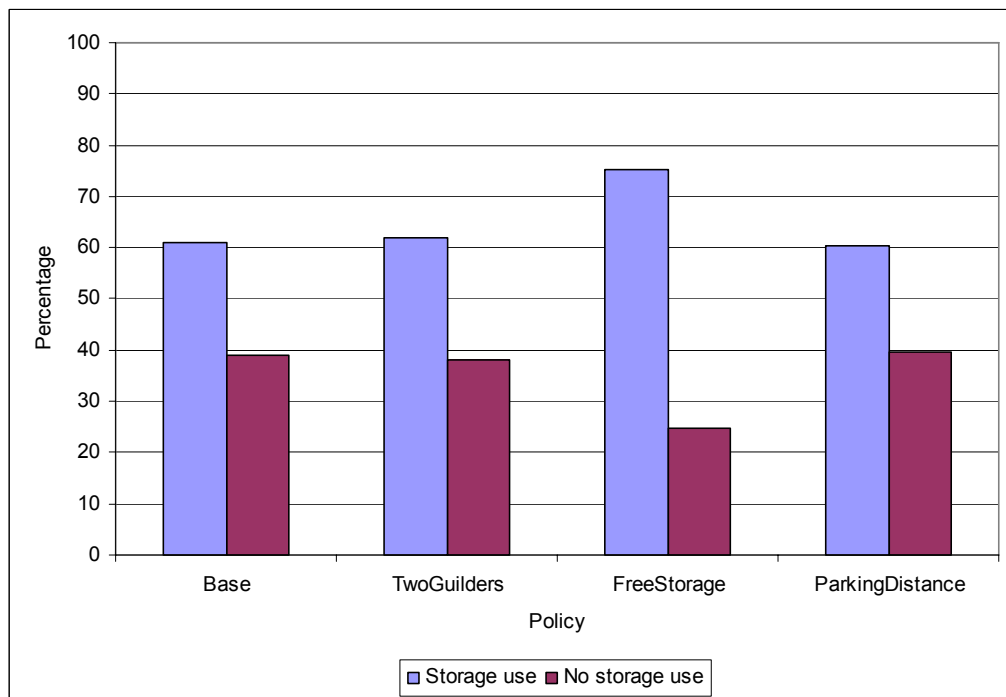


Figure 7.20: *Effect of transport policies on bicycle stall choice (as a percentage of the number of shoppers arriving by bicycle)*

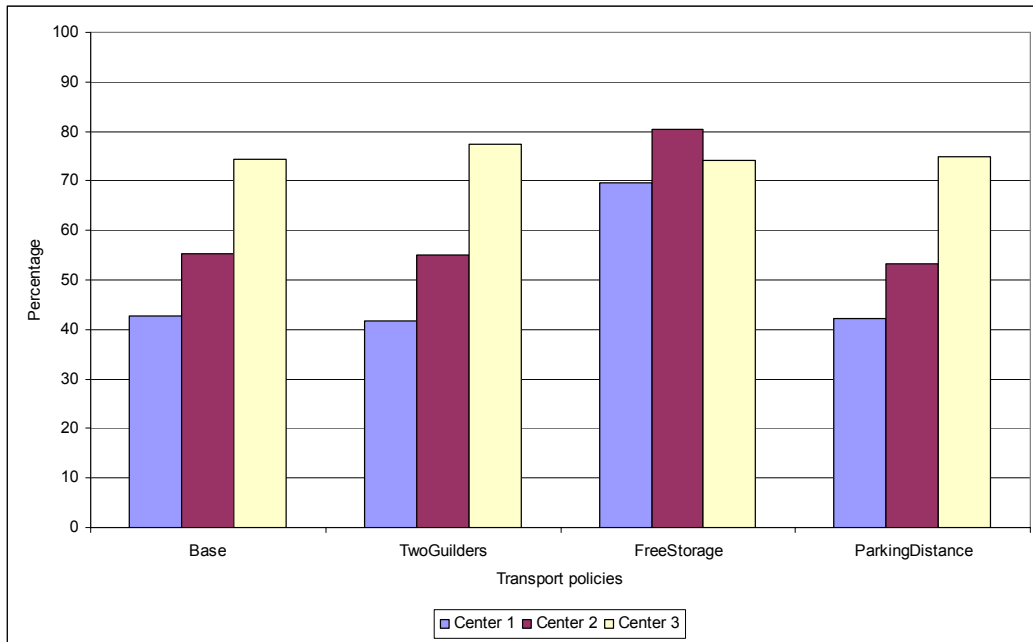
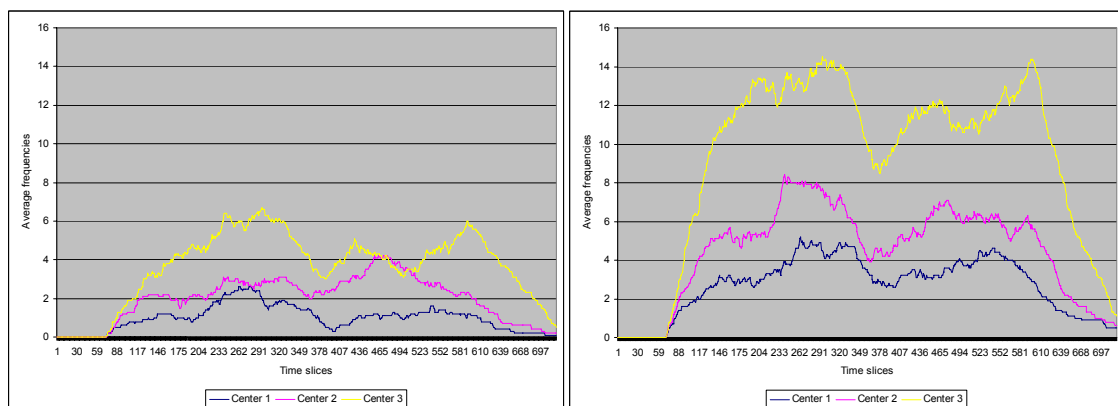
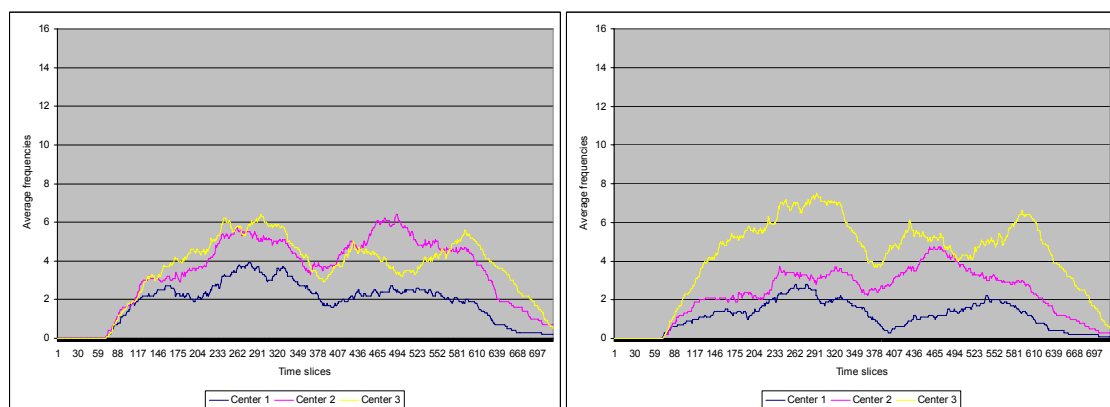


Figure 7.21: *Bicycle stall use (as a percentage of the number of shoppers arriving by bicycle) at the shopping centers for each transport policy*



(Base)

(TwoGuilders)



(FreeStorage)

(ParkingDistance)

Figure 7.22: *Effect of transport policies on bicycle stall choice during the day*

When looking to the individual shopping centers, it appears that according to our expectations only in the case of the introduction of free storage the relative use of storages changes (Figure 7.21). The decrease of storage costs of Storages 1 and 2 result in a higher use, while as expected the use of Storage 3 does not change. The occupancy of bicycle stalls during the daytime period is presented in Figure 7.22. It appears that in the case of equalization of parking costs (TwoGuilders) the use of bicycle stalls increases. This is in line with the previous finding regarding an increase in bicycle use (see Figures 7.11 and 7.19). The storage use is much higher than in the Base situation. Due to the changes in bicycle stall fees (FreeStorage) in shopping center 1 and 2 the use of the bicycle stores increases over the day. The effect of the relocation of parking facilities (ParkingDistance) is negligible.

Distance traveled

The final outcome of the simulation concerns the distance traveled by travel mode. Figure 7.23 presents the total distance travelled by 500 residents (averaged over 10 simulation runs). Equation 7.1 is used to calculate the travel distance between the resident’s home location (see green squares in Figure 7.3) and chosen destination (parking facility, bicycle stall, or bus stop). The figure shows that the total distance traveled by car in the case of the equalization of parking costs (TwoGuilders) decreases with more than 35 percent (from 9200 to approximately 5900 units). In addition, the distance traveled by bicycle increases with almost 150 percent (from approximately 1700 to 4200 units). In line with previous findings, the relevance of the bus is marginal. The changes in distance traveled in the case of the introduction of free storage (FreeStorage) are limited. The relocation of parking facilities results in an decrease of the total distance traveled by car of approximately 500 units and an increase of total distance traveled by bicycle of almost 500 units.

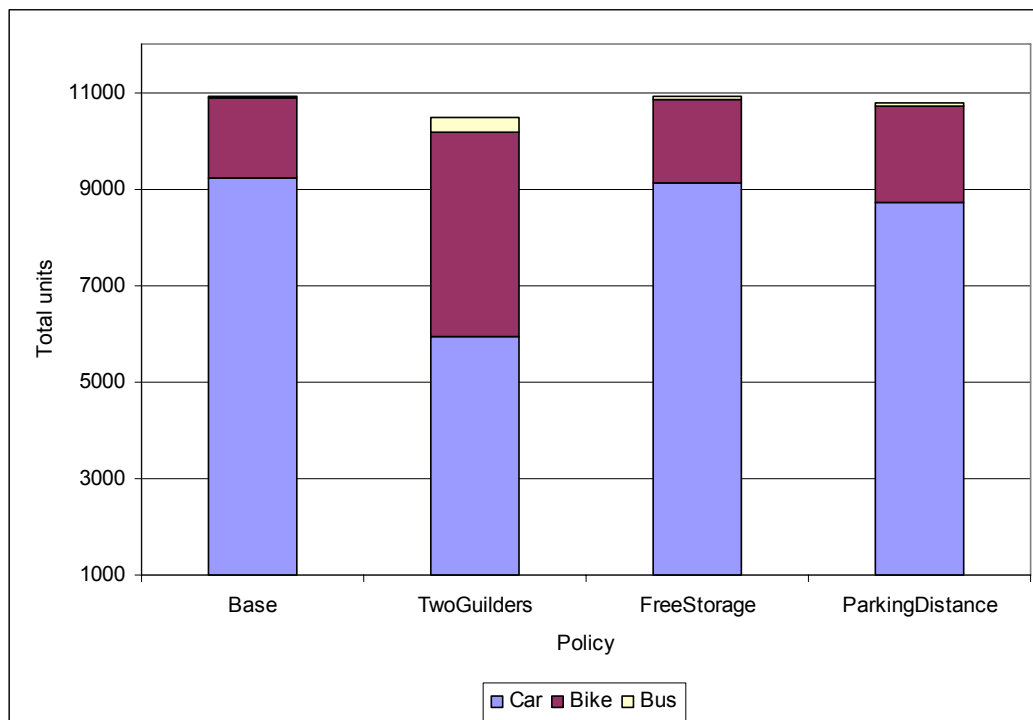


Figure 7.23: *Effect of transport policies on total distance traveled*

7.6 Conclusion

This chapter presented the integration of all models that are part of the parking analysis model *Pamela* into the multi-agent platform NetLogo. The three estimated models of *Pamela* presented in chapter 5 are implemented using this platform together with some additional information and mechanisms to generate residents, visit duration, and shopper type. A simple example with three shopping centers, 9 parking facilities, and 3 bicycle stalls, is set up to illustrate the working of *Pamela* for a daytime period of 12 hours between 8:00 and 20:00 hours. In addition, three different transport policies are evaluated using the multi-agent platform. The effects of the planning instruments are presented in various graphs and tables covering the choices of shopping center, travel mode, parking facility, and bicycle stall. The illustration shows the ease to implement and evaluate planning instruments using the analysis model of *Pamela* embedded in the multi-agent platform NetLogo. The various outcomes of the simulation give a clear view of the effects of the suggested planning instruments on the number of arrivals at shopping destinations, the number of users of the various travel modes, and the number of users of the different parking and storage facilities. The insights are generated at two different levels: aggregated for the entire day and for each time slice of the daytime period. The latter gives detailed information of the number of shoppers and use of parking and storage facilities per shopping center throughout the day. Also for each travel mode the total distance traveled is generated by the system.

Based on the assumptions of this hypothetical situation, it can be concluded that the equalization of parking costs results into the most evident changes in the travelers' destination, mode and parking choice decisions. These changes also result into changes in distance traveled through the system. The introduction of free storage only affects the use of bicycle stalls. The relocation of parking facilities mainly stimulates car drivers to choose alternative parking facilities.

Because of a lack of real world data, the current simulation is based on a hypothetical situation and assumptions regarding the generation of residents per period. The challenge will be to create a real world situation in NetLogo with a detailed street network, real location of residents' homes, shopping centers, parking facilities, and bicycle stalls, and realistic departure times and durations of the residents in the study area.

CHAPTER 8

Conclusions and discussion

8.1 Introduction

Since the nineties, parking policy has become an important element of urban and regional transportation policy. Local and regional governments have a variety of parking measures at their disposal to achieve transportation policy goals. Many measures have already been implemented with varying success. Clear insights into the benefits of suggested parking measures are still limited which makes it necessary to look for tools that are able to provide reliable insights into the effects of parking policy in general and parking measures in particular on travelers' decision making processes. The tools can be used to support transport planners and decision makers when evaluating different transport policy scenarios for their city or region.

In the past, a variety of parking models have been developed, ranging from models that describe car drivers' choice of parking facilities to models that describe different choices of travel behavior including destination, travel mode, and parking choice. The existing models cover various characteristics of destinations, transport system, and parking and bicycle stall facilities and have been applied for different trip purposes. Mostly, time and costs related characteristics have been included in these models. To get a more complete view of what is happening at different parking and storage facilities in the vicinity of shopping destinations during a certain time periods, it is necessary to add some new elements to the existing model approaches such as the composition of parking choice sets; the inclusion of the bicycle as means of travel and bicycle stalls as attractor; and car drivers' adaptive parking choice behavior. Because of increasing competition between parking facilities, it is also interesting to

investigate more service related characteristics such as chance of free parking space, available driving space, and type of security. Also attention has to be paid to the accessibility and integration of the models, improved model estimation techniques; and validation of estimated models.

This thesis provides the results of an extensive and detailed piece of parking research that can help practitioners in parking to improve their decision making process. The research covers several parts of the travelers' decision making process including the composition of the parking consideration set, the choice of shopping destination, travel mode, and parking/bicycle stall facility, and adaptive parking choice when a car driver faces a fully occupied parking. This chapter summarizes the adopted research approach and the findings of the research project (section 8.2), and gives different suggestions to extend research on the relation between the parking situation in the vicinity of shopping areas and travelers' decision making (section 8.3).

8.2 Summary and conclusions

To complement existing parking models and meet the suggested additional requirements of practitioners, a parking analysis model at the scale of cities and regions was developed. The model is named **Pamela** which stands for **Parking Analysis Model for predicting Effects in Local Areas**. **Pamela** covers different travel and parking decisions from the moment an individual has decided to leave home for weekly or non-weekly shopping until the moment the individual has completed her/his activity, leaves the chosen parking facility and goes home. Three different choice models form the heart of **Pamela**: (i) a parking choice set composition model to generate the car drivers parking choice set, (ii) a combined travel choice model combining the choice of shopping destination, travel mode and parking/bicycle stall, and (iii) an adaptive parking choice model that describes the car drivers' reactions when facing a fully occupied parking facility. The models include a variety of shopping destination, travel mode, and parking facility related characteristics. In addition, the adaptive parking choice model also includes characteristics that describe the situation at the parking facility at the moment a car drivers enters a fully occupied parking facility.

All included models are estimated using stated choice data collected in the town of Veldhoven and the city of Eindhoven, the Netherlands. For each part of **Pamela** a stated choice experiment was designed and presented to residents of Veldhoven and Eindhoven in a home sent questionnaire. The data of 1024 residents could be used for the analyses. The data were analyzed using mixed logit models that include both mean (consisting of mean and standard deviation) and context effects (only mean) where context effects represent the difference between weekly and non-weekly shopping. Most estimation results are satisfactory indicating that the estimated models give a good representation of the respondents' stated choice behavior. The percentage correctly predicted choices varies from almost 36 (combined travel choice model) to more than 70 (parking consideration set model) percent. In all cases the mixed multinomial logit model performs better than the traditional multinomial logit model. Most effects of the included model attributes are as expected. Regarding the *composition of parking choice sets* it appears that the characteristics parking costs and maximum parking duration influence the probability of a parking facility to be

included in the car drivers' choice set mostly. At some distance these characteristics are followed by the chance of a free space and walking distance between parking facility and nearest supermarket/department store. The effects found for the characteristics differ significantly for weekly and non-weekly shopping visits. Looking to the *combined travel choice behavior*, it appears that most influential characteristics are in order of influence: travel time of bicycle, parking costs, travel time bus, maximum parking duration, and supply of shops. Also in this case differences in influence were found between weekly and non-weekly shopping visits. Car drivers' *adaptive parking choice* is mostly influenced by the expected waiting time, the number of parking facilities visited before entering the fully occupied parking, and the chance of getting a parking fine. Differences between weekly and non-weekly shopping visits only exist for number of parking facilities visited before and number of cars waiting for a free space.

The validity of the estimated models was tested by applying the models in the town of Veghel, a comparable town to Veldhoven. Because of the available observations, only the parking choice set composition and the combined travel choice models for weekly shopping trips could be validated. Regarding the performance of the models, it appears that the consideration set model is well able to predict the composition of parking consideration sets that are observed in Veghel. On average, the model predicts in approximately 67 percent the presence or non-presence correctly. The performance of combined travel choice model is low, especially at the individual level. At the aggregate level the model is able to explain 84 percent of the distribution across the choice alternatives. However, at the individual level only 9 percent of the choices were correctly predicted which is somewhat better than the null model (4 percent correctly predicted). The model mainly predicts choice combinations that include the car as travel mode.

To illustrate the working of ***Pamela*** a micro-simulation was developed in the multi-agent system NetLogo. A hypothetical setting was created consisting of three shopping centers, nine parking facilities, and three bicycle stalls. The simulation includes the whole process from the generation of a traveler until the traveler's move from the shopping center to her/his home location. Besides the estimated model parameters the simulation is complemented with additional data retrieved from general insights (type of shopping) and the data collection (shopping duration). The simulation is used to evaluate the following three different transport policies: leveling out the parking costs for all parking facilities, setting all storage costs of bicycle stalls to 'no charge', and equalizing walking distance between parking facilities and final destination to 150 meters. The travel decisions of 500 residents were simulated for a base situation and the three transport policies. To level out random effects, the simulation was carried ten times resulting in the choice behavior of 5000 residents. The simulation shows the changes in destination, travel mode and parking/storage choice at an overall level (daytime period from 8:00 – 20:00 hours) and at the level of time slices (every minute of the daytime period). It also shows for each travel mode the changes in average and total distance traveled of all included residents during the daytime period.

8.3 Discussion and future research

This thesis presents various components of the parking analysis model *Pamela*. The model aims to handle several shortcomings of previous parking modeling approaches (see section 2.7). This aim resulted into two usable modeling approaches to define travelers' parking consideration set and combined travel choice both based on a stated choice data collection. The stated choice behavior is successfully explained using mixed multinomial logit models that are more sophisticated than the traditional multinomial logit model. Because of a variety of significant model parameters, a diverse set of parking measures can be evaluated and several effects can be assessed by transport planners (as shown in the simulation part of this thesis). New service related attributes are recognized as important in the context of consideration sets and destination, travel mode, and parking/storage choice like maximum parking duration, available driving space, location vis-à-vis home, and presence of security. In addition, the bicycle is successfully included as a travel mode in travelers' choice process in the context of shopping trips. The bicycle is represented by a significant travel mode specific constant and a significant parameter for travel time. Also the parameters of the bicycle stall characteristics 'level of security' and 'storage charge' show a significant influence of the characteristics of bicycle stalls on the travelers' combined travel choice. Modeling car drivers' adaptive parking choice behavior showed a variety of attributes that influences this type of behavior, especially the influence of the attributes on the choices of waiting for a free space and searching for an alternative parking facility. This model allows planners to provide detailed insights into the effects of high occupancy rates at parking facilities. Unfortunately, the model validation was not totally convincing and asks for extra attention when applying *Pamela*. The percentage of correctly predicted choices of the combined travel choice model is low but acceptable. The results of the simulation based on the models of *Pamela*, however, showed the ease and usefulness of using the models for the evaluation of various transport policies. Despite the fact that the data were collected in 1997, all results showed that the methodology as adopted in *Pamela* can be applied successfully. For an application of *Pamela* for current projects the models should preferably be estimated using more recent data.

To increase the power of *Pamela*, several parts could be added to the analysis model. The following issues could be included in future research and/or versions of *Pamela*. In the current study, the travelers' choice sets used for destination and travel mode choice are fixed. In the stated choice experiments three different shopping destinations and three travel modes (car, bicycle, and bus) are presented. Because of the availability of data, also in the external validation the destination and travel mode choice sets are fixed. Of course, it is interesting to get more insight into the real world composition of the choice sets. Travelers do not always consider all available shopping destinations when going out for shopping as noted by Arentze (1999) and travelers are not always able to use all types of travel mode (e.g., Hanson & Schwab, 1995). This makes it necessary to include the formation of destination and travel mode choice sets in the extension of *Pamela*.

In this research, the stated choice experiment of the combined travel choice behavior consisted of three shopping destinations, three travel modes, and a variety number of parking facilities. The number of parking facilities in the vicinity of the shopping destinations varied over the destinations: four parking facilities surrounding the first

destination, two surrounding the second destination and one surrounding the third destination. This fixed numbers makes it impossible to get a clear view of the influence of a varying number of parking facilities surrounding shopping destinations. The current research already showed that a different number (4, 2 or 1) of surrounding parking facilities has influence on the attractiveness of shopping destinations. This finding stimulates to go into more detail in this effect in the future.

Taking into consideration these new developments regarding parking information (e.g., real time parking information and parking location included in car navigation system) it is useful to extend the stated choice experiments as presented in this thesis with additional items such as information concerning the actual state of the parking facilities when making to the choice or when traveling to first chosen parking facility. Future experiments also could include travelers' uncertainty towards the characteristics of the choice alternative as suggested by Ottomanelli *et al.* (2011) who applied Possibility Theory in the context of parking choice to take into account imprecision and uncertainty underlying car drivers' choice process.

As shown in the conceptual framework of ***Pamela*** (see chapter 3) the model also could be extended with the choice of a specific parking space. Also this part is interesting to include in ***Pamela*** so that not only the parking demand at the parking facility level is known but also the demand per parking space or section of a parking facility can be presented (e.g., Van der Waerden *et al.*, 2003). Another extension of ***Pamela*** concerns the prediction of the travelers' parking duration as suggested by Van der Waerden *et al.* (2000), Schwanen (2004), and/or Caicedo (2012).

To carry out an external validation as suggested in this thesis several decisions and assumptions had to be made. The consequences of these decisions and assumptions are not investigated in detail. Regarding the achievement of the external validation, the following comments can be made to improve the validation in the near future.

- (i) The validation is only carried out once in the context of weekly shopping, the results give no information concerning weekly shopping trips in other contexts/cities and non-weekly shopping trips.
- (ii) The use of the predefined characteristic levels to describe the current situation in Veghel and the assignment of the level to the existing choice alternatives is arbitrary. The translation from the real world situation to the model parameters needs special attention in the future.
- (iii) Also the car drivers' adaptive parking choice has to be validated.

A final suggestion concerns the set up of a real world simulation that can help planners to get insight into the effects of different transport policies. The simulation included in this thesis already showed what kind of effects can be visualized. Especially from the viewpoint of parking management and a sustainable transport system the insights are valuable. In the real world simulation characteristics of residents and their shopping behavior have to be generated and all choice alternatives have to be specified in terms of the attributes included in the models.

Despite the fact that ***Pamela*** is set up for a shopping context, the adopted approach of analysis can also be used in other contexts such as leisure parks and office areas. Of course, the included models have to be reconsidered for these specific contexts which might result into other (definitions of) destination, travel mode, parking facility, and

bike stall characteristics. The principles underlying the modeling approach and the kinds of models used should however not be different.

Bibliography

Anderson, D., Borgers, A., Ettema, D. & Timmermans, H. (1992) Estimating Availability Effects in Travel Choice Modeling: A Stated Choice Approach, *Transportation Research Records* **1357**, 51-65.

Anderson, C.M., Das, C. & Tyrrell, T.J. (2006) Parking Preferences among Tourists in Newport, Rhode Island, *Transportation Research A* **40**, 334-353.

Arentze, T.A. (1999) *A Spatial Decision Support System for the Planning of Retail and Service Facilities*, Ph.D. Thesis, Eindhoven University of Technology, Eindhoven, the Netherlands

Arentze, T.A. & Timmermans H.J.P. (2000) *ALBATROSS: A Learning-Based Transportation Oriented Simulation System*, EIRASS, Eindhoven University of Technology, Eindhoven, the Netherlands.

Arentze, T.A., Hofman, F. & Timmermans, H.J.P. (2004) Predicting Multi-Facet Activity-Travel Adjustment Strategies in Response to Possible Congestion Pricing Scenarios using an Internet-Based Stated Adaptation Experiment, *Transport Policy* **11**, 31-41.

Arnott, R. & Inci, E. (2006) An Integrated Model of Downtown Parking and Traffic Congestion, *Journal of Urban Economics* **60**, 418-442.

Arnott, R. & Rowse, J. (2009) Downtown Parking in Auto City, *Regional Science and Urban Economics* **39**, 1-14.

AS (2004) *Parking Facilities, Part 1: Off-Street Car Parking*, Homebush, Australia.

- Axhausen, K.W. & Polak, J.W. (1991) Choice of Parking: Stated Preference Approach, *Transportation* **18**, 59-81.
- Balijepalli, N.C., Sheperd, S.P. & May, A.D. (2008) Modeling the Choice of Car Parks in Urban Areas and Managing the Demand for Parking, *Compendium of Papers CD-ROM of the 87th Annual Meeting of the Transportation Research Board*, Washington DC, USA.
- Bates, J. & Bradley, M. (1986) The CLAMP Parking Analysis Model, *Traffic Engineering & Control* **27**, 410-411.
- Bates, J., Skinner, A. Scholefield, G. & Bradley, R. (1997) Study of Parking and Traffic Demand: 2 A Traffic Restraint Analysis Model (TRAM), *Traffic Engineering & Control* **38**, 135-141.
- Ben-Akiva, M.E. & Lerman, S.R. (1985) *Discrete Choice Analysis: Theory and Applications to Travel Demand*, MIT Press, Cambridge, USA.
- Beunen, R., Jaarsma, C.F. & Regnerus, H.D. (2006) Evaluating the Effects of Parking Policy Measures in Nature Areas, *Journal of Transport Geography* **14**, 376-383.
- Bhat, C.R., Eluru, N. & Copperman, R.B. (2008) Flexible Model Structure for Discrete Choice Analysis. In: D. Hensher & K.J. Button (eds.) *Handbook of Transport Modeling, Second Edition*, Elsevier Ltd, Oxford, UK, 75-104.
- Bonsall, P. & Palmer, I. (2004) Modeling Drivers' Car Parking Behavior Using Data from a Travel Choice Simulator, *Transportation Research C* **12**, 321-347.
- Borgers, A., Kemperman, A., Toll, L. & Timmermans, H. (2010) Measuring Preferences for Parking Facilities in Old Residential Areas. In: *Proceedings of the 7th International Symposium on City Planning and Environmental Management in Asian Countries*, Fukuoka, Japan, 1-14.
- Borgers, A.W.J. & Vosters, C. (2011) Assessing Preferences for Mega Shopping Centers: A Conjoint Measurement Approach, *Journal of Retailing and Consumer Services* **18**, 322-332.
- Bovy, P.H.L. & Stern, E. (1990) *Route Choice: Wayfinding in Transport Networks*, Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Bradley, M., Kroes, E. & Hinloopen, E. (1993) A Joint Model of Mode/Parking Type Choice with Supply-Constrained Application, *Proceedings of the 21st Annual Summer PTRC Meeting on European Transport, Highways and Planning*, 61-73, Manchester, England.
- Broadbuss, A. (2009) No such Thing as a Free Spot: Pricing as a Demand Management Strategy for Parking. *Compendium of Papers CD-ROM of the 88th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Brown-West, O.A. (1996) An Optimization Model for Parking in the Campus Environment, *Proceedings of the 75th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Caicedo, F. (2012) Charging Parking by the Minute: What to expect from this Parking Pricing Policy?, *Transport Policy* **19**, 63-68

Chiou, L. & Walker, J.L. (2007) Masking Identification of Discrete Choice Models under Simulation Methods, *Journal of Econometrics* **141**, 683-703.

CROW (1994) *Guidelines for a Coordinated Parking Policy: Formulating and Implementing Policy*. Center for Research and Contract Standardization in Civil and Traffic Engineering, Ede, the Netherlands.

CROW (2001) *Effects of Parking Measures* (in Dutch), Center for Research and Contract Standardization in Civil and Traffic Engineering, Ede, The Netherlands.

CROW (2002) *From Parking Management to Mobility Management, Integrated Parking* (in Dutch), Center for Research and Contract Standardization in Civil and Traffic Engineering, Ede, the Netherlands.

CROW (2003a) Parking Policy is more than Parking: Integral Parking Policy in Practice (in Dutch), In: *From Parking Management to Mobility Management, Part 6*. Center for Research and Contract Standardization in Civil and Traffic Engineering, Ede, the Netherlands

CROW (2003b) Parking Regulation: Application and Effects (in Dutch), In: *From Parking Management to Mobility Management, Part 5*. Center for Research and Contract Standardization in Civil and Traffic Engineering, Ede, the Netherlands

CROW (2004) The Development of Parking Policy in The Netherlands. In: *From Parking Management to Mobility Management, Part 8*. Center for Research and Contract Standardization in Civil and Traffic Engineering, Ede, the Netherlands

Danwen, B., Wei, D. & Shishui, G. (2010) Impact of Parking Rates on Resident Travel Behavior, *Journal of Transportation Systems Engineering and Information Technology* **10**, 80-85.

D'Arcier, B.F., Andan, O. & Raux, C. (1998) Stated Adaptation Surveys and Choice Process: Some Methodological Issues, *Transportation* **25**, 169-185.

Durfee E.H. & Lesser, V. (1989) Negotiating Task Decomposition and Allocation Using Partial Global Planning. In L. Gasser and M. Huhns (eds.) *Distributed Artificial Intelligence*, Volume 2, Morgan Kaufmann, San Francisco, CA, USA, 229-243.

Feeney, B.P. (1989). A Review of the Impact of Parking Policy Measures on Travel Demand, *Transportation Planning and Technology* **13**, 229-244.

Gilbert, N (2008) *Agent-Based Models*, Quantitative Applications in the Social Science 153, Sage Publications, London, UK.

Gillen, D.W. (1978) Parking Policy, Parking Location Decisions, and the Distribution of Congestion, *Transportation* **7**, 69-85.

Greene, W.H. (2007) *NLOGIT Version 4.0: Reference Guide*, Econometric Software Inc., Plainview USA and Castle Hill Australia.

Griffioen-Young, H.J., Janssen, H.J.W., Van Amelsfoort, D.J.C. & Langefeld, J.J. (2004) The Psychology of Parking, *Proceedings ECOMM 2004 Conference*, Lyon, France.

Guan, H., Xiaoduan Sun, P.E., Liu, X. & Liu, L. (2005) Modeling Parking Behavior for Better Control and Pricing: A Case Study from One of the Busiest Retail Shopping Areas in Beijing, China, *Compendium of Papers CD-ROM of the 84th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Hanson, S. & Schwab, M. (1995) Describing Disaggregate Flows, Individual and Household Activity Patterns. In: S. Hanson (ed.) *The Geography of Urban Transportation*, The Guildford Press, New York, USA, 166-187

Harmatuck, D.J. (2007) Revealed Parking Choices and the Value of Time, *Compendium of Papers CD-ROM of the 86th Annual Meeting of the Transportation Research Board*, Washington DC.

Hensher, D.A. & Johnson, L.W. (1981) *Applied Discrete Choice Modeling*, Croom Helm Ltd, London, UK.

Hensher, D.A. & King, J. (2001) Parking Demand and Responsiveness to Supply, Pricing and Location in the Sydney Central Business District, *Transportation Research Part A* **35**, 177-196.

Hensher, D.A., Rose, J.M. & Greene, W.H. (2005) *Applied Choice Analysis: A Primer*, Cambridge University Press, Cambridge, UK.

Hess, S. & Polak, J.W. (2009) Mixed Logit Estimation of Parking Type Choice. In: B.W. Sloboda (ed.) *Transport Statistics*, J. Ross Publishing Inc., Fort Lauderdale, USA, 77-102.

Hu, S. & Saleh, W. (2005) Impacts of Congestion Charging on Shopping Trips in Edinburgh, *Transport Policy* **12**, 443-450.

Hunt, J.D. & Teply, S. (1993) A Nested Logit Model of Parking Location Choice, *Transportation Research B* **27**, 253-265.

Ji, Y., Deng, W., Wang, W. & Liu, G. (2007) Two-phased Parking Choice Model for Pre-trip Parking Guidance system, *Compendium of Papers CD-ROM of the 86th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Kelly, J.A. & Clinch, J.P. (2006) Influence of Varied Parking Tariffs on Parking Occupancy Levels by Trip Purpose, *Transport Policy* **13**, 487-495.

- Kemperman, A.D.A.M. (2000) *Temporal Aspects of Theme Park Choice Behavior*, Ph.D. Thesis, Eindhoven University of Technology, Eindhoven, the Netherlands.
- Kroes, E. (1988) *Literature Review of Stated Preference Validation Research* (In Dutch), Hague Consulting Group, The Hague, the Netherlands.
- Lambe, T.A. (1996) Driver Choice of Parking in the City, *Socio-Economic Planning Science* **30**, 207-219.
- Lam, W.H.K., Li, Z.C., Huang, H.J. & Wong, S.C. (2006) Modeling Time-Dependent Travel Choice Problems in Road Networks with Multiple User Classes and Multiple Parking Facilities, *Transportation Research B* **40**, 368-395.
- Lamens, P., Jongen, E. & Van der Heide, W. (2008) Allowing Double Parking; Profit of better Use of Parking Facilities (in Dutch), *Verkeerskunde* **59**, 44-48.
- Lancaster, K.J. (1971) *Consumer Demand, a New Approach*, Columbia University Press, New York, USA.
- Litman T. (2006) *Parking Management: Strategies, Evaluation and Planning*, Victoria Transport Policy Institute (www.vtpi.org/park_man.pdf).
- Liu, C. & Lu, H. (2005) Study on a Parking Planning Method based on GIS: A Case Analysis, *Proceedings of the Eastern Asia Society of Transportation Studies* **5**, 900-906.
- Loudon, W.R., Coleman, E. & Suhrbier, J.H. (1989) Air Quality Offsets for Parking, *Proceedings of the 68th Annual Meeting of the Transportation Research Board*, Washington DC, USA.
- Louviere, J.J. (1988) Conjoint Analysis Modeling of Stated Preference: A Review of Theory, Methods, Recent Developments and External Validity, *Journal of Transport Economics and Policy* **XXII**, 93-119.
- Louviere, J.J., Hensher, D.A. & Swait, J.D. (2000) *Stated Choice Methods; Analysis and Application*, Cambridge University Press, Melbourne, Australia.
- Luce, R.D. (1959) *Individual Choice Behavior: A Theoretical Analysis*, John Wiley & Sons, New York, USA.
- Lusk, J.L. & Schroeder, T.C. (2004) Are Choice Experiments Incentive Compatible? A Test with Quality Differentiated Beef Steaks, *American Journal of Agricultural Economics* **86**, 467-482.
- Maetani, K., Kodama, M.R., Willson, R. & Francis, W. (1996) *Using Demand-Based Parking Strategies to Meet Community Goals*. The Mobile Source Air Pollution Reduction Review Committee, California, USA.

- Mahmassani, H.S. & Jou R.C. (2000) Transferring insights into Commuter Behavior Dynamics from Laboratory Experiments to Field Surveys, *Transportation Research Part A* **34**, 243-260.
- Manski, C. (1977) The Structure of Random Utility Models, *Theory and Decision* **8**, 229-254.
- Marsden, G. (2006) The Evidence Base for Parking Policy – A Review, *Transport Policy* **13**, 447-457.
- Martens, K., Benenson, I. & Birfir, S. (2008) Evaluating Urban Parking Policies using an Agent-Based Model of Driver Parking Behavior, *Transportation Research Record* **2046**, 37-44.
- Matsumoto, S. & Rojas, J. (1998) Discrete Logit Modeling Based on Stated Preference Data of the Analytical Hierarchy Process for Parking Choice. In: J.D. Ortúzar, D. Hensher, & J. Jare-Dias, *Travel Behavior Research: Updating the State of Play*, Pergamon Press, Oxford, UK, 181-195.
- Matthijssen, L. & Vissers, P. (2008) The City of Dordrecht Creates More Parking Spaces (in Dutch), *Verkeerskunde* **59**, 28-33.
- May, T., Jones, D. & Rigby, J. (1989) Parking Policy Assessment: The Contribution of a Parking Location Model in York, *Traffic Engineering & Control* **30**, 251-256.
- McFadden, D. (1974) Conditional Logit Analysis of Qualitative Choice Behavior. In: Zarembka, P. (ed.) *Frontiers in Econometrics*, Academic Press, New York, USA, 105-142.
- Mehta, N., Rajiv, S. & Srinivasan, K. (2003) Price Uncertainty and Consumer Search: A Structural Model of Consideration Sets Formation, *Marketing Science* **22**, 58-84.
- Meurs, H., Meijer, E. & Pommer, J. (1997a). Measuring the Quality of Parking (in Dutch), *Verkeerskunde* **48** (6), 30-34.
- Meurs, H., Meijer, E. & Pommer, J. (1997b). No Parking, No Business (in Dutch), *Verkeerskunde* **48** (8), 30-34.
- Miller, E.J. (1993). Central Area Mode Choice and Parking Demand, *Transportation Research Record* **1413**, 60-69.
- Miller, E.J. (2003) Micro-simulation. In: K.G. Goulias, *Transportation Systems Planning, Methods and Applications*, CRC Press, Boca Raton, USA, 12.1-12.22.
- Mingardo, G., Mouter, N. & Talens, H. (2009) No Parking, Still Business, Expenditures and Travel Mode tested in the Context of Neighborhood Supermarkets (in Dutch), *Verkeerskunde* **60**, 36-40

Ministry of Transport, Public Works & Water Management (2008) *MobiliteitsOnderzoek Nederland 2008* (National Travel Survey 2008). Staatsuitgeverij, Den Haag, the Netherlands.

MuConsult (1997) *Parkeeronderzoek Zuid-Limburg, Synthese*, Amersfoort, the Netherlands.

O'Flaherty, C.A. (1986) *Highways Volume 1: Traffic Planning and Engineering* (third edition), Edward Arnold, London, UK.

Orme, B.K., Alpert, M.I. & Christensen, E. (1997) Assessing the Validity of Conjoint Analysis - Continued, Sawtooth Software Research Paper Series, <http://www.sawtoothsoftware.com/education/techpap.shtml>.

Ortúzar, J. de D. & L.G. Willumsen (2001), *Modelling Transport, Third Edition*, John Wiley & Sons, West Sussex, England.

Ottomanelli, M., Dell'Orco, M. & Sassanelli, D. (2011) Modeling Parking Choice Behavior using Possibility Theory, *Transportation Planning and Technology* **34**, 647-667.

Pagliara, F. & Timmermans, H.J.P., (2009) Choice Set Generation in Spatial Context, a Review, *Transportation Letters: The International Journal of Transportation Research* **1**, 181-196.

Polak, J., Axhausen, K. & Errington, T. (1990) The Application of CLAMP to the Analysis of Parking Policy in Birmingham City Centre, *Proceedings of the PTRC Summer Annual Meeting*, Brighton, UK.

Richardson, A. (1982) Search Models and Choice Set Generation, *Transportation Research A* **16**, 403-419.

Rijkswaterstaat (2009) *Mobiliteitsonderzoek Nederland 2008, Tabellenboek*, Ministry of Transport, Public Works and Water Management, The Hague, the Netherlands.

Rye, T., Hunton, K., Ison, S. & Kocak, N. (2008) The Role of Market Research and Consultation in Developing Parking Policy, *Transportation Policy* **15**, 387-394.

Sacks, J., Roupail, N.M., Park, B. & Thakuriah, P. (2002) Statistically-Based Validation of Computer Simulation Models in Traffic Operations and Management, *Journal of Transportation and Statistics* **5**, 1-15.

Sattayhatewa, P. & Smith, R.L. (2003) Development of Parking Choice Models for Special Events, *Transportation Research Record* **1858**, 31-38.

Schwanen, T. (2004) The Determinants of Shopping Duration on Weekdays in The Netherlands, *Journal of Transport Geography* **12**, 35-48.

Sharp, S. (2005) Bus Priority: Economic Impacts on Town Centers, *Proceedings of the 3rd UK Transport Practitioners Meeting*, London, UK.

Spiess, H. (1996) A Logit Parking Choice Model with Explicit Capacities, www.spiess.ch/emme2/parkcap/parkcap.html.

Sycara, K.P. (1998) Multi Agent Systems, *AI Magazine* **19**, 79-92.

Taylor, M.A.P., Bonsall, P.W. & Young, W. (2000) *Understanding Traffic Systems: Data, Analysis and Presentation*, Avebury Technical, Aldershot, UK.

Thill, J.C. (1992) Choice Set Formation for Destination Choice Modelling, *Progress in Human Geography* **16**, 361-382.

Thompson, R.G. & Richardson, A.J. (1998) A Parking Search Model, *Transportation Research A* **32**, 159-170.

Thurstone, L. (1927) A Law of Comparative Judgment, *Psychological Review* **34**, 273-286.

Timmermans, H.J.P. (1982) Consumer Choice of Shopping Center: An Information Integration Approach, *Regional Studies* **16**, 171-182.

Timmermans, H., Borgers, A. & Van der Waerden, P. (1992) Choice Experiments versus Revealed Choice Models: A Before-After Study of Consumer Spatial Shopping Behavior, *Professional Geographer* **44**, 406-416.

Torgerson, W.S. (1958) *Theory and Methods of Scaling*, John Wiley & Sons, New York, USA.

Train, K.E. (2003) *Discrete Choice Methods with Simulation*, Cambridge University Press, Cambridge, UK.

Tsamboulas, D.A. (2001) Parking Fare Thresholds: a Policy Tool, *Transportation Policy* **8**, 115-124.

Van de Coevering, P., Snellen, D. & Talens, H. (2008) Where do we park 10,5 Million Cars 2030? Fighting for the last parking space (in Dutch), *Verkeerskunde* **59** (9), 22-27.

Van der Goot, D. (1982) A Model to describe the Choice of Parking Places, *Transportation Research A* **16**, 109-115.

Van der Waerden, P., Bernards, E. & Oppewal, H. (1995) Parking Situation and Travel Mode Choice of Shopping Center Visitors (in Dutch). In: H.J. Meurs & E.J. Verroen, *Decentralisatie van Beleid: Implicaties voor Kennis en Onderzoek*. Proceedings of Colloquium Vervoersplanologisch Speurwerk, Rotterdam, the Netherlands, 1093-1108.

Van der Waerden, P. & Borgers, A. (1995) Modeling Parking Lot Choice in the Context of Shopping Trips, In: R. Wyatt & H. Hossain (eds), *Proceedings of the 4th International Conference on Computers in Urban Planning and Urban Management, Volume One*, Melbourne, Australia, 119-130.

Van der Waerden, P., Borgers, A. & Timmermans, H. (2000a) Determinants of Parking Duration in the Context of Shopping Center Trips. In: *Wie betaalt bepaalt! Proceedings Colloquium Vervoersplanologisch Speurwerk 3*, Amsterdam, the Netherlands, 1513-1526.

Van der Waerden, P., Borgers, A. & Timmermans, H. (2000b) Modeling Consideration Sets in the Context of Parking related to Shopping Activities. In *Proceeding of 9th International Association for Travel Behaviour Research Conference*, Volume 10 Application Workshop 2 – SP Applications, Gold Coast, Australia.

Van der Waerden, P., Borgers, A. & Timmermans, H. (2009) Consumer Response to the Introduction of Paid Parking in a Regional Shopping Center, *Transportation Research Record* **2118**, 16-23.

Van der Waerden, P., Borgers, A. & Timmermans, H. (2003) Travelers Micro-Behavior at Parking Lots: A Model of Parking Choice Behavior, *Proceedings of the 82nd Annual Meeting of the Transportation Research Board (CD)*, Washington DC, USA.

Van der Waerden, P., Borgers, A. & Timmermans, H. (2006) Travel and Parking Choice Behavior in the Context of Weekly and Non-Weekly Shopping Trips, *Proceedings of the 13th International Conference on Recent Advances on Retailing and Services Science*, Budapest, Hungary.

Van der Waerden, P. & Oppewal, H. (1995) Modeling the Combined Choice of Parking Lot and Shopping Destination. In: D.A. Hensher and J. King (eds.) *Proceedings of the 7th World Conference on Transportation Research Volume 1*, Sydney, Australia, 129-137.

Van der Waerden, P., Oppewal, H. & Timmermans, H. (1993) Adaptive Choice Behavior of Motorists in Congested Shopping Center Parking Lots, *Transportation* **23**, 395-408.

Van der Waerden, P., Timmermans, H. & Bakx, C. (2010c) The Influence of Physical Characteristics of Parking Facilities on the Parking Choice Behavior of Visitors of a Regional Shopping Center, *Proceedings of the 17th International Conference on Recent Advances on Retailing and Services Science*, Istanbul, Turkey.

Van der Waerden, P., Timmermans, H. & Barzeele, P. (2011) Car Drivers' Preference Regarding Location and Contents of Parking Guidance Systems: A Stated Choice Approach, *Transportation Research Records* **2245**, 63-69.

Van der Waerden, P. Timmermans, H., Coppens, L. & Schaefer, W. (2010d) Car Drivers' Preferences Regarding Parking in Industrial Parks: A Stated Choice Approach, *Proceedings of 12th World Conference on Transport Research*, Lisbon, Portugal.

- Van der Waerden, P., Timmermans, H. & This, J. (2010a) Parking Information in Car Navigation Systems: A Stated Choice Analysis of Car Drivers' Preferences, *Compendium of Papers DVD of the 89th Annual Meeting of the Transportation Research Board*, Washington DC, USA.
- Van der Waerden, P., Timmermans, H. & Van Neerven, R. (2010b) Modeling the Combined Choice of Entrance and Parking in Enclosed Business Areas, *Proceedings of 12th World Conference on Transport Research*, Lisbon, Portugal.
- Van Huffelen, T. & Van Voorst, E. (2008) The Impact of Traffic Measures on the Performance of Shopping Centers (in Dutch), *Verkeerskunde* **59**, 46-51.
- Van Luipen, B., Stienstra, S. & Bongarts, J. (2008) Parking Policy for the Medium Term: How to deal with an Increasing Parking Demand (in Dutch), Proceedings of the Colloquium Vervoersplanologisch Speurwerk, Santpoort, the Netherlands.
- Van Maarseveen, M.F.A.M. (1985) *Validation of a Parking Simulation Model* (in Dutch), Verkeers- en Vervoersgroep TNO, Delft, The Netherlands.
- Wilensky, U. (1999) NetLogo. <http://ccl.northwestern.edu/netlogo/>. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL, USA.
- WPM Consultants (2002) *Amsterdam Rivierenbuurt, Spatial and Economic Policy Plan* (in Dutch), The Hague, the Netherlands.
- Young, W. & Taylor, M. (1991) A Parking Model Hierarchy, *Transportation* **18**, 37-58.
- Young, W. (2008) Modeling Parking. In: D. Hensher & K.J. Button (eds.) *Handbook of Transport Modeling, Second Edition*, Elsevier Ltd, Oxford, UK, 475-487.
- Zheng, J. & Guo, J.Y. (2008) Destination Choice Model Incorporating Choice Set Formation, *Proceedings of the 87th Annual Meeting of the Transportation Research Board (DVD)*, Washington DC, USA.
- Zhu, W. (2008) *Bounded Rationality and Spatio-Temporal Pedestrian Shopping Behavior*, Ph.D. Thesis, Eindhoven University of Technology, Eindhoven, the Netherlands.

Appendix

A1 *Overview of parking studies (chapter 2)*

A2 *Parking attributes and levels used in stated choice experiments (chapter 4)*

Appendix A1: Overview of parking studies

<i>Study</i>	<i>Choice alternatives</i>	<i>Variables</i>	<i>Field of application</i>	<i>Type of data</i>	<i>Model type</i>	<i>Main findings</i>	<i>Cities</i>
Gillen, 1978	3 blocks	Parking fee Parking fee gradient Walking time Age Gender Income	All purposes	Revealed choice	Binary logit model	The change in parking choice due to changes in parking fee depends on the location of the parking	Toronto (Canada)
Van der Goot, 1982	22 groups of parking spaces	Walking distance Parking time restriction Parking charges Occupancy rate Type of parking	All purposes	Revealed choice	Logit chance model	Walking time greatly influence visitor's parking choice; Preference for off-street parking facilities	Haarlem (the Netherlands)
Axhausen & Polak, 1991	5 types of parking facilities	Access time Search time Egress time Parking fee Expected fine illegal parking	Work and shopping	Stated choice	Multinomial logit model	There is a need to separately identify the costs associated with different components of the parking activity.	Karlsruhe (Germany) and Birmingham (UK)
Bradley <i>et al.</i> , 1993	2 travel modes and 5 types of parking facilities	Type of parking Parking fee Search time Walk time	Business, commuting, and other	Revealed and stated choice	Nested logit model	Most significant variables were travel costs, parking search time and parking walk time	Several cities (the Netherlands)
Hunt & Teply, 1993	147 parking facilities	Walking distance Parking fee Location vis-à-vis home Residential land use Measure for delay Number of stalls Type and condition surface Type of winter provision Accessibility Cleanness	Commuting	Revealed choice	Nested logit model	Parking choice is influenced not only by money costs and proximity to final destination, but also by other factors.	Edmonton (Canada)

Miller, 1993	5 travel modes and Various parking locations	Gender, Car availability Travel time Costs for car Costs for transit Parking fee Walk time	Commuting	Revealed choice	Nested logit model	Commuters are very sensitive to changes in parking walk times and parking costs	Toronto (Canada)
Van der Waerden <i>et al.</i> , 1995	81 combinations of travel mode and parking facilities	Maximum parking duration Parking fee Walking distance Chance of free space	Shopping	Stated choice	Multinomial logit model	Most important variables are parking costs and walking distance, also cross-effects were significant	Boxtel (the Netherlands)
Van der Waerden & Borgers, 1995	8 parking lots	Distance from home Number of spaces Status of exits Presence of supermarket entrance Distance measure to shops	Shopping	Revealed choice	Multinomial logit model	All variables are significant; best performing distance measure is a sequence measure describing visitors' route in the center	Veldhoven (the Netherlands)
Van der Waerden & Oppewal, 1995	3 shopping destinations and 4 parking lots	Number of clothing stores Travel time home - parking Maximum parking duration Parking fee Distance parking - destination	Shopping	Stated choice	Multinomial logit model	Most important parking lot characteristics is parking costs	Boxtel (the Netherlands)
Lambe, 1996	5 parking lots and parking garages	Distance home – parking Distance parking – destination Parking fee	Work and shopping	Revealed choice	Multinomial logit and probit model	Traffic route to parking short and direct; parking directly connected to major destination points	Vancouver (Canada)
MuConsult, 1997	9 parking alternatives	Walking time Number of parking spaces Parking fee	Shopping	Stated choice	Nested logit model	Relation between walking distance and willingness to	Heerlen and Maastricht (the Netherlands)

		Maximum parking duration Type of parking Security Moment of payment Possibilities illegal parking Chance of getting a parking fine				pay for parking. Shoppers do not want to pay in advance and do not like a maximum parking duration.	
Matsumoto & Rojas, 1998	8 parking places and 11 shopping centers	Parking capacity Distance parking – destination Type of parking Waiting times Parking costs Presence of signs Presence of discounts	Shopping	Stated and preference	Logit model based on Analytic Hierarchy Process (AHP) data	Walking distance and waiting time are most important variables followed by parking costs and discounts.	Nagaoka (Japan)
Tsamboulas, 2001	2 parking facilities (including the one used for the trip)	Difference in walking distance Initial walking time Parking fee Trip purpose Age	All purposes	Revealed and stated choice	Multi-linear logit model	Most influential walking time and parking fare, Influence of personal characteristics	Athens (Greece)
Bonsall & Palmer, 2004	5 parking facilities	Parking fee Walking time Number of spaces Number of car parks passed Last car park used Income Gender	Business and shopping trips	Stated choice	Multinomial and nested logit model	Price of parking and implied walking times influence the parking choice; Influence of income level	London, Southampton, Leeds (UK)
Hess & Polak, 2009	5 types of parking facilities	Access time Search time Egress time Parking fee Expected fine illegal parking	Work and Shopping/Errands	Stated preference	Multinomial logit and mixed multinomial logit	Strong influence of taste variation in respondents' evaluation of parking options, advantage of MMNL model	Birmingham, Sutton Coldfield, Coventry (UK)
Guan <i>et al.</i> , 2005	9 parking facilities	Parking type Parking fee Walking distance	Shopping	Revealed choice	Multinomial logit model	Walking distance is the most important in the parking choice decision process.	Beijing (China)

						Parking behavior is different for weekdays and weekends.	
Harmatuck, 2007	60 parking lots	Parking fee Lot-to-workplace distance Income Parking capacity	Commuting	Stated choice	Multinomial and Mixed logit models	Choice is relatively inelastic with distance and elastic with price	Madison (USA)
Borgers <i>et al.</i> , 2010	16 parking situations	Distance between parking and home Visibility of the car Motorized traffic in residential street Security	Residential parking	Stated choice	Multinomial and Mixed logit models	Residents prefer the absence of motorized traffic and presence of security above walking distance and view on the car	Eindhoven
Van der Waerden <i>et al.</i> , 2010b	27 on- and off-street parking facilities	Number of parking spaces Presence of vegetation Distance area entrance – parking Distance parking – workplace	Commuting	Revealed choice	Nested logit model	Most influential are distance variables.	Eindhoven
Van der Waerden <i>et al.</i> , 2010c	4 parking lots	Presence of ATM Presence of trolleys Presence of bottle bank Location vis-à-vis home	Shopping	Revealed choice	Multinomial logit and mixed logit model	Most influential presence of trolleys and location vis-à-vis home	Eindhoven
Van der Waerden <i>et al.</i> , 2010d	8 parking alternatives	Parking fee Distance parking – workplace Presence of guarding Type of parking Chance of free space	Commuting	Stated preference	Multinomial logit model	All variables significant, influence of personal characteristics	Several cities (the Netherlands)

Appendix A2: Parking attributes and levels used in stated choice experiments

<i>Attributes</i>	<i>Levels</i>	<i>Source</i>
Parking fee per hour	1.00 DM; 2.00 DM; 3.00 DM 0.20 DM; 0.50 DM; 1.00 DM Free; DFL 2.00; DFL 6.00 Free; DFL 1.00; DFL 2.00 2 IR-pound, 4 IR-pound, 7 IR-pound	Axhausen & Polak, 1991 Axhausen & Polak, 1991 MuConsult, 1997 Van der Waerden <i>et al.</i> , 1995 Kelly & Clinch, 2006
Access time	18 minutes; 22 minutes; 24 minutes 18 minutes; 20 minutes; 24 minutes 10 minutes; 15 minutes; 20 minutes	Axhausen & Polak, 1991 Axhausen & Polak, 1991 Van der Waerden <i>et al.</i> , 1995
Egress time or walking distance	5 minutes; 10 minutes; 15 minutes 4 minutes; 8 minutes; 12 minutes 2 minutes; 5 minutes; 10 minutes 50 meters; 200 meter; 350 meter 1 minute, 3 minutes, 5 minutes 1 minute, 2 minutes, 3 minutes	Axhausen & Polak, 1991 Axhausen & Polak, 1991 MuConsult, 1997 Van der Waerden <i>et al.</i> , 1995 Hensher & King, 2001 Van der Waerden <i>et al.</i> , 2010c
Chance of parking ticket	1 of 10; 3 of 10; 5 of 10 20 percent; 70 percent	Axhausen & Polak, 1991 Van der Waerden <i>et al.</i> , 1995
Occupancy rates	Less than 80 percent; Between 80 and 90 percent; More than 90 percent Heavy use, Medium use	MuConsult, 1997 Kelly & Clinch, 2006
Maximum parking duration	Unlimited; 2 hours; 30 minutes Unlimited; 2 hours	MuConsult, 1997 Van der Waerden <i>et al.</i> , 1995
Chance of free parking space	Big, small 50 percent, 75 percent, 100 percent	Van der Waerden <i>et al.</i> , 1995 Van der Waerden <i>et al.</i> , 2010c
Type of parking	Garage, lot, on-street Company parking, public parking lot, public parking garage	MuConsult, 1997 Van der Waerden <i>et al.</i> , 2010c
Opening hours	24 hours, from 6.30 am, from 9.30 am	Hensher & King, 2001

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Summary

To improve existing parking models and to meet several additional requirements of practitioners, a parking analysis model at the scale of local areas is developed. The model called **Pamela** which stands for **P**arking **A**nalysis **M**odel for predicting **E**ffects in **L**ocal **A**reas. **Pamela** simulates at the local level different travel and parking decisions from the moment an individual has decided to leave home for weekly or non-weekly shopping until the moment the individual has completed her/his activity, leaves the chosen parking facility and goes home. Three different choice models form the heart of **Pamela**: (i) a parking choice set composition model to generate the car drivers parking choice set, (ii) a combined travel choice model combining the choice of shopping destination, travel mode and parking/bicycle stall, and (iii) an adaptive parking choice model that describes car drivers' reactions when facing a fully occupied parking facility. The models include a variety of characteristics related to shopping destination, travel mode, and parking and storage facility. In addition, the adaptive parking choice model also includes characteristics that describe the situation of the parking facility at the moment a car drivers enters a fully occupied parking facility.

All included models are estimated using stated choice data collected in the town of Veldhoven and the city of Eindhoven, the Netherlands. For each part of **Pamela** a stated choice experiment is set up and presented to residents of Veldhoven and Eindhoven in a home sent questionnaire. The data of 1024 residents are used for the analyses. The data are analyzed using mixed logit models that include both mean (consisting of means and standard deviations) and context (only means) effects where context effects represent the difference between weekly and non-weekly shopping. Most estimation results are satisfactory indicating that the estimated models give a good representation of the respondents' stated choice behavior. The percentage correctly predicted choices varies from almost 36 (in the case of the combined travel choice model) to more than 70 (in the case of the parking consideration set model)

percent. In all cases the mixed multinomial logit model performs better than the traditional multinomial logit model. Most effects of the included model attributes are as expected. Regarding the *composition of parking choice sets* it appears that the characteristics parking costs and maximum parking duration influences the probability of a parking facility to be included in the car drivers' choice set mostly. At some distance these characteristics are followed by the chance of a free space and walking distance between parking facility and nearest supermarket/department store. The effects found for the characteristics differ significantly for weekly and non-weekly shopping visits. Looking to the *combined travel choice behavior*, it appears that most influential characteristics are in order of influence: travel time of bicycle, parking costs, travel time bus, maximum parking duration, and supply of shops. Also in this case differences in influence are found between weekly and non-weekly shopping visits. Car drivers' *adaptive parking choice* is mostly influenced by the expected waiting time, the number of parking facilities visited before entering the fully occupied parking, and the chance of getting a parking fine. Differences between weekly and non-weekly shopping visits only exist for number of parking facilities visited before and number of cars waiting for a free space.

The validity of the estimated models is tested by applying the models to the town of Veghel, a comparable town to Veldhoven. Because of the available observations, only the parking choice set composition and the combined travel choice models for weekly shopping trips could be validated. Regarding the performance of the models, it appears that the consideration set model is well able to predict the composition of parking consideration sets that are observed in Veghel. On average the model predicts in approximately 67 percent the presence or non-presence correctly. The performance of combined travel choice model is low, especially at the individual level. At the aggregate level the model is able to explain 84 percent of the distribution across the choice alternatives. However, at the individual level only 9 percent of the choices were correctly predicted which is somewhat better than the null model (4 percent correctly predicted). The model mainly predicts choice combinations that include the car as travel mode.

To illustrate the working of **Pamela** a micro-simulation is worked out using the multi-agent system NetLogo. A hypothetical setting is created consisting of three shopping centers, nine parking facilities, and three bicycle stalls. The simulation includes the whole process from the generation of a traveler until the traveler's move from the shopping center to her/his home location. Besides the estimated model parameters the simulation is complemented with additional data retrieved from empirical data (type of shopping) and the data collection (shopping duration). The simulation is used to evaluate the following three different transport policies: leveling out the parking costs for all parking facilities, setting all storage costs of bicycle stalls to 'no charge', and equalizing walking distance between parking facilities and nearest supermarket or department store to 150 meters. The travel decisions of 500 residents are simulated for a base situation and the three transport policies. To level out random effects, the simulation is carried out ten times and all results are averaged over these ten simulation runs. The simulation shows the changes in destination, travel mode and parking/storage choice at an overall level (daytime period from 8:00 – 20:00 hours) and at the level of time slices (every minute during the day time period). It also shows for each travel mode the changes in average and total distance traveled of all included residents during the daytime period.

Curriculum vitae

After finishing his education of Transportation Engineer at the National Academy of Transportation in Tilburg, Peter van der Waerden started in 1986 his academic career at the Urban Planning Group of Eindhoven University of Technology. In 1988, Peter received his academic degree in Human Geography at the Utrecht State University in Utrecht. His final project dealt with parking choice behavior of shopping center visitors. This project was the beginning of many studies dealing with various aspects of parking such as car drivers' parking space choice behavior, the composition of parking guidance systems, and the provision of parking information in car navigation systems. Peter presented the results of the studies in some journals and at various international conferences. Peter's parking related research is complemented with a variety of studies concerning the use of public transport and bicycle infrastructure.

At the Eindhoven University of Technology, Peter has set up the courses Geographical Information Systems and Traffic Engineering. Peter is also involved in the courses Urban Plans and Basic Techniques of Urban Planning. Peter also set up and still contributes to the courses Traffic Engineering I (Basics) and II (Advanced) provided at Hasselt University in Belgium. At this university, Peter supervises several students with their Bachelor and Master projects. Peter provided guest lectures concerning (Transportation) Planning at the Joseph Fourier University in Grenoble (France) and the University of Minho in Braga (Portugal).