Investigating Car Driver’s On-Street Parking Decisions

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Preface

Parking issues are creating concerns for urban planners all over the world. Being an urban planner and a transport scientist, I was always concerned with parking issues in my country; this urge pushed me to discover how other countries manage parking. During my Masters, I discovered that parking is a key element of transport; I wanted to explore it further with special focus on parking policy making. While exploring further, I came across tools that are being used to study parking in a city. It was really interesting to identify that several parking models have been developed by the researchers and scientists to identify parking related issues and provide efficient solutions to emerging parking problems.

Due to significant increase in car ownership rates during last decades, the need to house the vehicles has also increased. Commercial areas and city centers are the locations where cars are parked for short term, this causes a lot of search traffic and thus, causing nuisance for overall traffic flow. In order to solve this problem, car drivers parking choices need to be investigated.

In this piece of research, the car drivers' parking choices have been investigated with respect to on-street parking in central business districts. Cruising for parking is mainly caused due to short term on-street parking. Therefore, on-street parking choices of car drivers need to be emphasized. In the past, several models have been developed but the process of car drivers' parking decision making is not detailed. Understanding car drivers' decision making process can help to solve the underlying issue related to policy design in order to reduce cruising. Therefore, a behavioral model is required to explore preferable road conditions that trigger parking search traffic and identify road conditions that affect car drivers' parking decisions.

This research aims to direct the policy makers while planning to devise solutions for parking problems in downtown areas. This study is useful for the managers of shopping centers and decision makers to investigate the impact of certain policy measure on the behavior of car drivers' but it does not provide any directions for the implementation of certain policy measure in specific area.

At the end, I would like to acknowledge supervisors, colleagues and my family, who have helped me to complete this research

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Samenvatting

Parkeren is een interessant onderwerp binnen het domein van transport. In het verleden werden er slechts een beperkt aantal studies uitgevoerd rond parkeren, maar recent neemt de aandacht voor dit onderwerp toe. Dit komt omwille van een stijgend voertuigbezit. Een groot aantal auto's moet aan het einde van een verplaatsing ergens geparkeerd worden, wat moeilijk is. Parkeerbeheer is een interessant domein geworden om te verkennen. Onderzoek naar korte verplaatsingen naar de binnenstad (voor winkelen, vrijetijd enz.) is noodzakelijk omdat het verkeer resulterend uit de zoektocht naar goedkope parkeerplaatsen overlast veroorzaakt in stadscentra. Het verhoogt de reistijd, het brandstofverbruik en de frustratie bij bestuurders.

Het toenemende aantal auto’s in de binnenstad creëert een onrustwekkende situatie met betrekking tot verkeerscongestie. Onderzoek wijst uit dat 30% van het verkeer bestaat uit bestuurders die op zoek zijn naar een parkeerplaats en de gemiddelde zoektijd is ongeveer 8 minuten (Shoup, 2005).

In vakliteratuur wordt er gesuggereerd dat lokale overheden het parkeren op straat moeten beheren door het toewijzen van parkeerplaatsen en het bepalen van parkeertarieven naargelang het tijdstip van de dag. Om erachter te komen welke andere factoren gebruikt kunnen worden om het parkeren op straat efficiënt te beheren dient er een onderzoek gevoerd te worden naar de parkeerkeuzes van automobilisten bij het parkeren op straat.

Gemotiveerd door de beperkingen van vorige parkeerkeuzemodellen, is een van de belangrijkste bijdragen van dit onderzoek het modelleren en simuleren van de parkeerkeuzes van automobilisten, rekening houdend met de wegomstandigheden. Dit is nodig om het effect te onderzoeken van wijzigingen in parkeeromstandigheden op de parkeerkeuzes van automobilisten, d.w.z. waar men parkeert (ofwel op de straat, ofwel buiten de rijbaan ofwel blijven zoeken naar een parkeerplaats) wanneer bepaalde wegomstandigheden wijzigen. De studie naar het parkeerkeuzegedrag van automobilisten onderzoekt de impact van wijzigingen in het parkeerbeleid op de verkeersstroom. Een andere belangrijke bijdrage van dit onderzoek is de evaluatie van welke parkeer-en verkeersomstandigheden automobilisten aansporen om te zoeken naar een parkeerplaats. Onder wegomstandigheden verstaan we onder andere de beschikbare ruimte, de toegelaten snelheidslimiet of het grondgebruik in de nabije omgeving. Tijdens de eerste fase van mijn doctoraatsonderzoek werd vastgesteld dat er nog geen onderzoek gedaan werd naar de combinatie van parkeer-en verkeersomstandigheden die zoekverkeer veroorzaken.

In dit onderzoek wordt ook het ontwerp gepresenteerd van een conceptueel kader om het parkeerkeuzeproces van automobilisten te simuleren. Dit kader beschrijft dat wanneer automobilisten een straat binnenrijden en op zoek gaan naar een parkeerplaats, ze een keuze moeten maken. Indien ze een geschikte

parkeerplaats vinden, dan parkeren ze op straat; indien ze geen optimale parkeerplaats vinden, dan rijden ze naar de dichtstbijzijnde parkeergarage; en indien ze geen geschikte plaats vinden in de huidige straat en ze niet willen parkeren in een parkeergarage, dan blijven ze zoeken en rijden ze naar een volgende straat op zoek naar parkeergelegenheid. Dit kader werd ontworpen om op een realistische manier het gedrag automobilisten die zoeken naar een parkeerplaats te analyseren.

Er werd een uitgebreide online vragenlijst opgesteld voor het verzamelen van gegevens om de parkeerkeuzes van automobilisten met betrekking tot de verkeersomstandigheden te evalueren. Er werd een stated choice experiment ontworpen om de wegomstandigheden (gangbare parkeersituatie) voor te stellen aan automobilisten. Het was erg moeilijk om een dergelijke omvattende keuzetaak te ontwerpen die een bepaalde parkeersituatie op de weg beschrijft. Om een dergelijke omvattende keuzetaak te ontwerpen was er een hele reeks attributen vereist. Een standaard stated choice experiment kan niet overweg met een groot aantal attributen. Daarom werd de hiërarchische informatie integratiebenadering (HII) toegepast (andere benaderingen werden vermeden om de complexiteit zo laag mogelijk te houden). Er was een eenvoudige benadering vereist voor het behandelen van een groot aantal attributen. De vakliteratuur geeft aan dat hiërarchische informatie integratie (HII) nuttige resultaten heeft opgeleverd in combinatie met stated choice experimenten (Louviere, 1984) (Bos et al, 2003) (Richter en Keuchel, 2012). Daarom werd in dit onderzoek geopteerd voor de geïntegreerde hiërarchische informatie integratiebenadering (HII-I). In deze benadering worden attributen en attribuutniveaus gegroepeerd in verschillende categorieën, gekend als 'decision constructs'. Deze decision constructs geven beschrijvende samenvattingslabels voor sets van gerelateerde attributen die alternatieven in de studie definiëren. Verschillende experimentele ontwerpen werden ontwikkeld voor elke constructrie zodanig dat elk ontwerp een gedetailleerde beschrijving bevatte van een decision construct, terwijl de andere decision constructs aan het ontwerp toegevoegd werden als een 'algemeen attribuut'. Hierdoor wordt elke keuzetaak minder gedetailleerd, bestaande uit elf attributen in totaal; waarvan zeven algemene parkeergerelateerde attributen, drie gedetailleerde construct attributen, en een algemeen attribuut (hogere beschrijving van de decision construct behandeld als extra attribuut, ter vervanging van drie gedetailleerde attributen).

De ontworpen keuzetaken werden gepresenteerd in een online vragenlijst. De respondenten werd gevraagd te veronderstellen dat ze van hun huis rijden naar een (generieke) bestemming die gelegen was in het centrum van een stad. Tijdens deze verplaatsing rijden ze een bepaald wegsegment binnen (met specifieke parkeer- en wegomstandigheden) om te zoeken naar een geschikte parkeerplaats.

De volledige vragenlijst bestond uit drie delen en werd gemaakt met behulp van een online systeem dat ontwikkeld werd door de Technische Universiteit Eindhoven. Er werden twee selectievragen gesteld aan het begin van de vragenlijst, om respondenten te selecteren die een of meerdere wagens bezitten en enige ervaring hebben met het parkeren op de straat in stedelijke gebieden.

Het eerste deel van de vragenlijst was gerelateerd aan de ervaringen van automobilisten met parkeren op straat. Dit gedeelte bevatte vragen over zaken die gerelativeerd zijn aan het parkeren op straat en waarmee de respondenten geconfronteerd werden: zoektijd, reden voor het parkeren, parkeerfrequentie, wandeltijd tussen de parkeerplaats en de eindbestemming, parkeerinformatiebronnen, voorkeur voor parkeren op de straat of buiten de rijbaan en welk type weg (commercieel, residentieel) men als het moeilijkst ervaart bij parkeren. Het tweede deel bestond uit de hypothetische keuzecondities. Aan het begin van elk deel werd een gedetailleerde toelichting gegeven om de respondenten voor te bereiden op de volgende vragen. De context van de parkeerbeslissing werd vermeld in de toelichting van deel 2. Na het ontwerpen van de keuzetaak en het opstellen van de vragenlijst, bestond de volgende taak uit het identificeren van een evenwichtige steekproef en het verspreiden van de vragenlijst naar de respondenten. Hiervoor werd het online bedrijf 'PanelClix' ingehuurd om het vereiste aantal antwoorden te krijgen. Belgische panelleden/respondenten werden uitgenodigd om de online vragenlijst in te vullen. In totaal hebben 548 respondenten de vragenlijst ingevuld. De steekproefkenmerken tonen aan dat de groep respondenten heel representatief is voor de populatie.

Na het verzamelen van de data diende deze nog opgeschoond te worden. De verzamelde data werd grondig gecontroleerd op inconsistenties bij het invullen van de vragenlijst (d.w.z. door de duur die nodig was om de vragenlijst in te vullen). Na het zorgvuldig opschonen van de data, werden de gegevens gecodeerd (dummy gecodeerd) en geanalyseerd met behulp van NLOGIT versie 5 (Econometric Software Inc., 2012). De data werd eerst geanalyseerd met behulp van een standaard multinomiaal logitmodel en vervolgens met behulp van een gemengd multinomiaal logitmodel. De data paste goed in het standaard multinomiaal logitmodel (MNL) alsook in het gemengde multinomiale logitmodel (MMNL). Bij het standaard multinomiale logitmodel (MNL) zijn slechts enkele attributen significant op het conventionele niveau (95 procent), zoals 'parkeertarief', 'verwachte parkeerduur', 'snelheidslimiet', 'omliggende activiteiten', 'parkeertarief buiten de rijbaan' en 'maximale parkeerduur'. De belangrijke parameters komen overeen met de verwachtingen. Dit resultaat kan erop wijzen dat automobilisten geen rekening houden met 'veiligheid' of 'betaalopties' wanneer ze zoeken naar een parkeerplaats op de straat. Het gemengde multinomiale logitmodel bleek het best overeen te komen met de data, omdat een groot aantal van de gemiddelde en standaardafwijkingen van attributen significant zijn. Voorbeelden hiervan zijn: 'het parkeertarief buiten de rijbaan', 'parkeerkost op de straat', 'mate van parkeergemak', 'omringende activiteiten', 'verwachte parkeerduur', 'snelheidslimiet', 'afstand tussen parkeerplaats en bestemming' en 'aantal bezochte straten'. Dit betekent dat de respondenten een willekeurige smaak/voorkeurvariatie vertonen met betrekking tot deze attribuutniveaus (omdat het MNL model veronderstelt dat alle individuen hetzelfde zijn, terwijl het MMNL model van mening is dat elk individu anders is; daarom zijn de resultaten van de modellen verschillend). De modelresultaten tonen aan dat wanneer de snelheidslimiet 20km/u bedraagt, de verwachte parkeerduur korter is dan 60 minuten, en het parkeertarief buiten de rijbaan hoog is (2,50 euro/uur) er een hogere kans bestaat dat een automobilist de auto parkeert op de straat. Bovendien zijn gratis parkeren, het voorzien van parkeerplaatsen dichter bij de bestemming, wegen met lagere snelheidslimieten (bij voorkeur in woonwijken), en het ontbreken van veiligheidsvoorzieningen de belangrijkste omstandigheden die bestuurders aanzet tot het zoeken naar parkeerplaatsen. Vergelijkbare omstandigheden die zoekverkeer veroorzaken kunnen geïdentificeerd worden met de modelresultaten.

Na het analyseren van de data, worden de schattingen van het gemengde multinomiale logitmodel gebruikt om de waarschijnlijkheid van de parkeerkeuzes van automobilisten te voorspellen. De modelvoorspellingen zijn gebaseerd op de principes van de Monte-Carlo simulatie. Deze simulaties worden gegenereerd met behulp van een Excel rekenblad. De resultaten van de simulatie bieden een scala aan mogelijke uitkomsten aan de beslisser en de mate van waarschijnlijkheid met betrekking tot parkeerkeuzes van automobilisten. De simulatie kan de werking van het model illustreren bij het onderzoek naar de effecten van parkeermaatregelen. De simulatie evalueert de effecten van (a) de omliggende activiteiten (b) de snelheidslimiet (c) parkeerduur en (d) de invoering van betaald parkeren of een verhoging van de kosten voor parkeren op de straat van 1,00 euro tot 2,00 euro. De simulatie geeft duidelijk de wijzigingen weer voor de waarschijnlijkheid van de parkeerkeuzes van automobilisten d.w.z. parkeren op de straat, parkeren naast de rijbaan en blijven zoeken als gevolg van de verandering in de parkeerkosten. Er kunnen tegelijkertijd ook conclusies getrokken worden voor andere belangrijke attributen zoals 'afstand tussen parkeerplaats en bestemming' en 'aantal bezochte straten'. Het model voorspelt dat activiteiten die langs een straat gelegen zijn ook een sterke impact hebben op de parkeerkeuzes van automobilisten. Het model geeft aan dat er veel langzaam rondgereden zal worden wanneer er recreatieve of commerciële activiteiten plaatsvinden in een straat, zoals bijvoorbeeld een straat met een sportstadion, speeltuin, winkelcentrum, enz. Residentiële straten beschikken meestal over een aantal parkeerplaatsen, wat realistisch is. Dit model is ook in staat om het aantal auto's te voorspellen dat zal rondrijden op zoek naar een parkeerplaats, aan de hand van bepaalde wegomstandigheden. Indien we een wegomstandigheid veranderen, kan de wijziging in parkeerkeuze bij automobilisten voorspeld worden. Hierdoor kunnen we de meest geschikte wegomstandigheid voor het parkeren op de straat identificeren.

Via dit onderzoek kunnen er bepaalde andere gerelateerde beleidsimplicaties afgeleid worden. Ermee rekening houdend dat de attributen uit de bestaande literatuur, zoals wandelafstand, tarief, zoektijd, voertuigtype, toegangstijd, enz. slechts een beperkte kennis bieden met betrekking tot de parkeerkeuzes van automobilisten, is er een gedetailleerd begrip nodig van weggerelateerde attributen om de impact van het beleid te verhogen. Dit komt aan bod in het huidige onderzoek. De genomen aanpak benadrukt het relatieve belang van de parkeer- en weggerelateerde attributen en demonstreert hoe het zoekverkeer verminderd kan worden door een aanpassing van deze weggerelateerde parkeerfactoren (zoals een snelheidsverlaging en een gewijzigd parkeertarief).

Kortom, beleidsmakers kunnen gebruik maken van de resultaten van deze studie om te achterhalen welke parkeer-en wegomstandigheden bijdragen aan zoekverkeer. Daarom kunnen bepaalde wegsituaties die leiden tot zoekverkeer vermeden worden door het opstellen van een passend beleid. Dit modeltype kan eveneens nuttig zijn voor beleidsvormers om bepaalde parkeermanagementstrategieën te bevorderen die complementair zijn voor de bebouwde kom en stedenbouw. Bovendien kan dit onderzoek gebruikt worden als onderdeel van multi-agent simulatiesystemen om een gedetailleerder beeld te geven van de parkeerkeuzes van automobilisten bij het voorspellen van de impact van wijzigingen van parkeermaatregelen op de verkeerstoestand van een stad.

Summary

Car parking is an interesting domain in transportation. In the past, a limited number of studies investigated parking issues but the attention paid to car parking research is increasing with time. This is because car ownership rates are increasing. Large number of cars need to be parked somewhere at the end of the journey, which is difficult to manage. Parking management has become an interesting domain to explore. Investigating short term (shopping, leisure etc.) car trips to city center is necessary because the traffic searching for cheap on-street parking spaces creates nuisance in city centers. It increases travel time, fuel consumption and drivers' frustration.

The increasing number of cars cruising on downtown streets are creating alarming situation with respect to traffic congestion. Studies suggest that the share of traffic cruising for parking is 30% and the average cruising time is about 8 minutes (Shoup, 2005). Although there is a debate regarding myths of parking (Syden & Scavo, 2006) but the importance of on-street parking cannot be ignored. The literature suggests that local governments should manage on-street parking by controlling price and allocation of parking spaces during different times of the day. In order to find out which other factors can be controlled to manage on-street parking efficiently a research related to car drivers' on-street parking choices needs to be executed.

Motivated by the limitations of previous parking choice models, one of the major contributions of this research is to model and simulate car drivers parking decisions keeping in view the road conditions. This is necessary to investigate the effect of changes in parking conditions on car drivers' parking choices i.e. where do people park (either on-street, off-street or continue search) if certain conditions of road are changed. The study of car drivers' parking choice behavior investigates effects of changes in parking policy on traffic flow. Another major contribution of this research is to evaluate which parking and road conditions urge car drivers to search for parking. Road condition depict the circumstances prevailing on the road such as space availability, allowed speed limit or surrounding land uses. During the initial phase of my PhD research project, it was observed that no research has been carried out to identify combination of parking and road conditions that induce search traffic.

The design of a conceptual framework to simulate the parking choice process of car drivers' is also presented in this research. This framework depicts when car drivers enter a street and start looking for parking, they have to make a choice. If they find a suitable parking place they park on-street; if they do not find an optimal parking space, they drive to the nearest parking garage; and if they do not find a suitable place in the current street and they do not want to park in a garage, they keep on searching and drive to a next street looking for parking. This framework is setup to analyze the realistic behavior of car drivers' parking search. To collect data for evaluating car drivers' parking decisions with respect to road conditions a comprehensive online questionnaire was prepared. A stated choice experiment was designed to present the road conditions (prevailing parking

situation) to a car driver. It was very difficult to design such a choice task that can detail a particular parking situation on a road. For designing such a comprehensive choice task a large set of attributes was required. A standard stated choice experiment cannot handle a large number of attributes. Therefore, the hierarchical information integration (HII) approach was applied (other approaches were avoided to keep the level of complexity as minimal as possible). A simplistic yet controlled method for dealing with large number of attributes and hypothetical situations was required. There is evidence in the literature that hierarchical information integration (HII) has provided useful results when combined with stated choice experiments (Louviere, 1984) (Bos et al, 2003) (Richter and Keuchel, 2012). For this research, the integrated hierarchical information integration (HII-I) approach has been used. According to this approach, attributes and attribute levels are grouped together in different categories known as 'decisions constructs'. These decision constructs depict descriptive summary labels for coherent sets of attributes that define alternatives in the study. Different experimental designs were developed for each construct such that each design included a detailed description of one decision construct while the other decision constructs are added to the design as a 'global attribute'. This process makes each choice task less detailed, consisting of eleven attributes in total; seven general parking related attributes, three attributes of detailed construct, and one global attribute (high-order description of decision construct treated as additional attribute, replacing three detailed attributes).

The designed choice tasks were presented in an online questionnaire. The respondents were asked to assume that they are driving from their home to a (generic) destination located in the center of a city. While driving they enter a certain road segment (with specific parking and road conditions) to search for a suitable parking space.

The full questionnaire consisted of three parts and was constructed using an online system developed by the Eindhoven University of Technology. Two screening questions were conducted at the beginning of the questionnaire, to select respondents who own one or more cars and have some experience with on-street parking in urban areas. The first section of the questionnaire was related to car drivers' experiences with on-street parking. This section included questions regarding on-street parking issues faced by the respondents, search time, parking purpose, parking frequency, walking time between parking place and final destination, parking information sources, preference for on-street and off-street parking, and which type of road (commercial, residential) they find most difficult to park at. The second section consisted of the hypothetical choice conditions. At the beginning of each section a detailed explanation was provided to prepare the respondents regarding the forthcoming questions. The context of parking decision was mentioned in the explanation of section 2. After designing the choice task and the questionnaire, the next task was to identify a well-balanced sample and disseminate the questionnaire to the respondents. For this purpose, the online company 'PanelClix' was hired to get required number of responses. Belgian members of the panel were invited to fill out the online questionnaire. In total, 548 respondents completed the questionnaire. The sample characteristics show that the group of respondents is well representative of the referenced population (car drivers' who visit inner city areas by car and have parking experiences).

After data collection the next task was to perform data cleaning. The collected data was checked thoroughly for inconsistencies in questionnaire completion behavior (i.e. by length of time taken to fill out the survey). After carefully performing data cleaning, the data was coded (dummy coded) and analyzed using NLOGIT version 5 (Econometric Software Inc., 2012). The data was first analyzed using standard multinomial logit model and later on, the data was analyzed using mixed multinomial logit model. The data fitted well with standard multinomial logit model (MNL) and mixed multinomial logit model (MMNL). With standard multinomial logit model (MNL) only a few attributes are significant at the conventional level (95 percent) such as 'parking tariff', 'expected parking duration', 'speed limit', 'surrounding activities', 'off-street parking tariff' and 'maximum parking duration'. The significant parameters are in anticipated direction. This result might indicate that car drivers do not consider 'security' or 'payment options' while looking for a parking space on-street. Mixed multinomial logit model also appeared as a good fit for the data because more number of the means and standard deviations of attributes such as 'off-street parking tariff', 'on-street parking cost', 'level of parking convenience', 'surrounding activities', 'maximum parking duration', 'speed limit' , 'distance between parking location and destination' and 'number of streets visited' are significant. This means that there is random taste variation across the respondents regarding these attribute levels (since the MNL model assumes that all the individuals are same while MMNL considers that every individual is different therefore the results of model estimation are different). The model estimation results show that if speed limit is 20km/h, the expected parking duration is less than 60 minutes, and the off-street parking tariff is high (2.50 euro/hour) then there is a higher probability that a car driver parks the car on-street. Moreover, free parking, providing parking closer to destination, roads with reduced speed limits (preferably in residential areas), and without any security feature are the major conditions that induce parking search. Similar conditions that induce search traffic can be identified using the model results.

After analyzing the data, the estimates of mixed multinomial logit are used to predict the probability of car drivers' parking choices. The model predictions are based on the principles of the Monte-Carlo simulation, these simulations are generated using excel worksheet. The results of the simulation provide a range of possible outcomes to the decision-maker and the probabilities related to parking decisions of car drivers. This simulation setup is able to illustrate the working of the model when investigating the effects of parking measures. With the simulation, the effects of (a) surrounding activities (b) speed limit (c) parking duration (d) the introduction of paid parking or an increase of the on-street parking cost from 1.00 euro to 2.00 euro are evaluated. The simulation shows clearly the changes in probabilities of car drivers parking decisions i.e. park on-street, park off-street, and continue to search due to the change in parking cost. Similarly, other inferences can be drawn for other significant attributes such as 'distance between parking location and destination' and 'number of streets visited'. The model predicts that the activities located on a road also have a strong impact on the car drivers' parking decisions. The model identifies that cruising would be high in case of a roads having recreational and commercial activities such as sports stadium, playground, shopping malls, etc. Residential streets usually have several parking spaces available, which is realistic. This model is also capable to predict the number of cars that will be cruising for parking with respect to certain road conditions. If we change a road condition the change in car drivers parking decisions can be predicted and thus the most preferable road conditions for on-street parking can be identified.

Certain other policy related inferences (policy implications) can be drawn from this research. Keeping in view, the existing literature attributes such as walking distance, price, search time, vehicle type, access time, etc. only provide limited knowledge related to car drivers parking decisions, in order to raise the policy implications a detailed understanding of road related attributes is required, which are highlighted in the current research. The adopted approach has highlighted relative importance of the parking and road related attributes resulting in demonstration of how through adjustment of these road related parking factors (such as speed reduction and changing parking tariff), the number of cars cruising for parking can be reduced. In a nutshell, policy makers can use the results of this study to find out which parking and road conditions contribute to search traffic. Therefore, certain road situations can be avoided that induce search traffic by devising suitable policies. Also this type of models can be useful for decision makers to promote certain parking management strategies that complement built environment and urban planning strategies. Moreover, this research can further be used as a part of multi-agent simulation systems to express in more detail car drivers parking decisions for predicting effect of change in parking measures on traffic conditions of a city.

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1. Introduction

This chapter discusses the basis of this research. It includes the background, the problem statement, the research aim, and the structure of the thesis.

1.1. Overview

Cities round the world are facing rapid changes in social, economic, demographic and physical landscape trends. Cities facing economic crunch are trying to revitalize their downtown areas where as cities with strong economies are facing growth pressure in their downtown areas. In order to shape urban development in these cities, an integrated transport system is required. Transportation professionals are highly aware that such integrated transport systems can only be developed by efficiently planning land use and transportation. The need of such integration is necessary because transportation systems and land use patterns are strongly linked. Both of these components influence transportation planning process at regional, local and neighborhood level.

Literature suggests that parking policies should be considered seriously for implementing desired transportation and urban system changes (Marsden, 2006), (Ottomanelli, Dell'Orco, & Sassanelli, 2011), (Latinopoulou et al, 2012), (Ibeas, dell'Olio and Moura, 2018). The decisions about parking strongly influence traffic situation of a city. These decisions have also have a huge impact on pedestrian and transit accessibility to work, shopping, and other destinations. Decision-makers consider a number of factors that link transportation planning to other planning activities while developing transportation plans. Such plans help the decision-makers to reach their broader goals of creating and sustaining livable communities. All these new directives can be linked, tested and advanced using parking policies, because parking is a key determinant of modal choice, an important ingredient of economic development and land use plans, a contributing factor to air and water pollution, and a key element shaping building layout and design (Shaw, 1997).

Parking also plays a major role in terms of improving urban traffic flow as it is connected to different activities for example workplace parking, parking at a retail outlet or a school. Management of parking is a complex issue both in terms of supply and in managing the demand; therefore an efficient parking policy should take into account work, retail, leisure, education, residential parking, as well as changing demographics, mobility patterns, levels of car ownership and public transport provision.

Several parking related Transport Demand Management (TDM) measures are available to transportation planners in order to bring about change in travel behavior and address the urban traffic-related issues of congestion, emissions, proper allocation of land use, safety and urban economic development. These include

- Parking information (actual parking charges, free space availability);

- Parking related regulatory measures (parking control, pedestrianized zones, parking reduction, increased tariff, duration limitation, maximum allowed parking duration and opening hours of parking facilities).

All these TDM measures can be defined as a set of actions that influence travel behavior of people in such a way that people consider alternative mobility options and thus reduce congestion (Ison and Rye, 2008); (Meyer, 1999).

Parking management is a key element of overall Transport Demand Management. It constitutes policies and programs that make an efficient use of parking resources. If the strategies of parking management are applied properly a variety of economic, social and environmental benefits can be achieved (Litman, 2013). The aims of parking management vary depending on the provider for example some local authorities use parking management to address congestion or generate revenue where as private providers only focus on profit generation as a basic aim. Parking policies are considered as an important option in terms of demand management. These policies are easier to implement as these tend to achieve public acceptance more than other strategies such as road pricing. Also parking policies provide a reasonable link with the type of problem to be addressed. Each authority has its own objectives and priorities in terms of traffic management with parking as an integral part. Therefore, clarity of objectives is crucial while developing parking policies. Moreover, local and political situation in a given urban area direct the overall aims of a parking policy.

Approaches that can be used for managing parking; include parking restrictions i.e. controlling the availability of parking spaces. The basic aim of this approach is to limit car use thus providing clear access to public roads. The enforcement of parking restrictions should help to ensure that the needs of residents, shops and businesses are met. The other commonly used management approach relates to on-street parking regulations such as on-street parking pricing mechanism and legislation. On-street parking price can influence both the supply and demand for spaces. An inefficient on-street price mechanism can lead to large amount of search traffic. This search traffic has implications both for the motorist and the urban environment in terms of additional vehicle miles travelled on the transport network. Therefore, a careful review of parking policies at all levels of government is required to ensure that such policies should support rather than contradict other transportation and land use goals.

Parking choice of car drivers has a huge impact on parking management of an area. The choice of parking type and location is a decision problem tackled daily by many drivers. The question of how drivers actually carry out these parking decisions has not attracted a significant research effort. Until now, various modelling techniques have been used to represent parking decisions of car drivers which include mode choice or traffic assignment procedures (Axhausen and Polak, 1989). According to these studies, parking choices are considered as the outcome of a complex interaction between parking preferences of individual drivers, their prior experience or knowledge related to parking supply, prevailing traffic conditions and the instantaneous availability of parking opportunities (Axhausen and Polak, 1991). Thus, it can be predicted that cruising is a natural phenomenon because even the driver with most recent information cannot be certain of achieving his desired parking outcome, since this will depend on the instantaneous availability of parking opportunities at the time the driver wishes to park. Several facts such as the spatially diffused nature of parking supply and the competition among drivers regarding the use of most optimal parking spaces indicate that a given driver can never avoid the necessity to engage in parking search. Even with the advent of sophisticated car navigation systems the search traffic cannot be avoided (because finding an optimal spot, still needs insights into car drivers' preferences. If these are not considered, the car driver will not follow up the advice). There is a knowledge gap regarding such research studies that investigate car drivers' parking decisions with respect to prevailing parking and road conditions.

This thesis documents the development of a behavioral model designed to evaluate responses of car drivers due to change in parking measures. More specifically, with this model the effects of changes in parking and road conditions can be evaluated. This model describes the decision making processes of a car drivers when they enter a street looking for parking. It is focused on the behavior of car drivers when driving and looking for an on street parking with special emphasis on the evaluation of different parking measures. It aims at improving the theoretical knowledge, the definition and deployment of effective parking policies.

The overview provided in this chapter shows that there is still no general view concerning the success or benefits of suggested parking measures. Increase in car ownership and car use along with decrease of available space in cities in the near future requires detailed insights (Axhausen and Polak, 1991). Also the increasing 'competition' between cities and regions to attract economic activities asks for better insights related to the effects of parking policy. Therefore, it is necessary to look for tools that are able to provide insights regarding the effects of parking policy in general and parking measures in particular. These tools can be used to support decision makers when evaluating different planning alternatives for their city or region. Also car drivers and other stakeholders (shopkeepers, developers, etc.) could use the tools to get insights related to the effects of parking measures on their personal circumstances. This chapter is structured as follows; first section highlights the role of parking with respect to mobility management in urban areas. Section 2 discusses the importance of parking behavior in relation with urban parking policy. Section 3 presents distinction between on-street and off-street parking. Later sections include the problem statement, the research aim and the thesis outline.

1.2. Parking and Mobility

Parking is considered an important component of urban mobility as it has a strong impact on the travel behavior of individuals (EPCOMM, 2003). Parking and mobility go alongside in providing efficient functioning of urban transport. It supports transit-oriented development, walkable site designs and economic development. Significant increase in car ownership and automobile use over the past few years has highlighted parking as an integral part of governments' mobility management programs (CROW, 2002). Livability of communities can be revived by providing proper mobility management. Mobility plan is the most important instrument of mobility management. It provides comprehensive guidelines for maintaining mobility management in a specific region. It also promotes sustainable transport and manages the demand for car use by changing travelers' attitudes and behavior.

Mobility is defined as the ability of an individual to move in the community, using all the available options. These options consist of road infrastructure and all kinds of parking facilities including bicycle stalls. Formulating strategies to make the mobility of an individual hurdle free is known as 'Mobility management'. The mobility management strategies aim at enhancing information related to available choice alternatives for travelers and reducing the necessity of moving. Core measures of mobility management include some soft and hard measures. Soft measures of mobility management include information and communication (related to mobility plan), organizing services and coordinating activities, while hard measures include infrastructure (i.e. roads, tram lines etc.). The soft measures enhance the effectiveness of the hard measures. Major aims of mobility management are to apply all these measures to reduce motorized vehicle trips such as controlling visitor and commuter traffic.

The value of parking in maintaining character, form, function and flow of communities cannot be underestimated. In order to address these parking concerns such as traffic congestion and lack of convenient parking, municipalities need to form parking policies. Parking polices are the management strategies developed to encourage the development of livable communities. These policies need to be designed and managed very carefully because these affect the accessibility and walkability of city centers. One of the major challenges that the municipalities are facing nowadays is to create a balance between parking demand and supply. Providing additional parking without managing the existing supply will not only encourage car use but also increase parking demand.

The primary goal of parking management is to ensure efficient functioning of transportation and land use system (Willson, 2015). For instance, creating parking availability near businesses and restaurants helps customers to find easily a free parking space. If drivers face parking shortage, they waste time and fuel in searching for a parking spot thus creating frustration. Parking management helps not only to provide information regarding closest availability of parking (employing smart parking technologies or real time information systems) but also directs the drivers to most desirable spaces. This means providing efficient utilization to parking spaces. There are parking strategies that municipalities can employ to manage parking. For example, pricing allows to centralize off-street parking, freeing up parking spaces for short-term parking and encourage modal shift (i.e. drivers shift mode, travel at different times of the day or combine trip). The same is valid for prioritizing availability of parking spaces at most convenient places, shifting long-term parkers to lower demand spaces, and converting private parking to shared parking, discouraging private parking, making payment options as simple as possible. All these strategies can appear as potential solutions to reduce cruising for parking reducing traffic congestions, roadway costs, and pollution. Hence, achieving transportation demand management with all these mobility management strategies can lead to an efficient transport system that directly influence travel behavior and parking demand.

Thus, parking policy can be considered an efficient mobility management tool that can help manage the existing parking supply in a cost effective way, reduce demand and increase effectiveness of underutilized parking facilities. Parking polices encourage transit use and commercial activities in turn increasing opportunities for shared parking. With parking policies municipalities can take appropriate steps for addressing present and future challenges related to parking and mobility management. The next section provides more details related to importance of parking policy.

1.3. Urban parking policy and parking behavior

Urban parking policy has a key link with transportation, environment, and spatial planning. This importance is supported by the expected increase of cars in the future. It helps in creating balance between revenue generation of local authorities and discouraging visitors for damaging urban vitality (Marsden, 2006). Several parking studies suggest efficient use of the transport network, lower emissions, and efficient urban design that can only be achieved with well-designed parking policies. Such sort of parking policies can help to envisage required parking situation in the area with respect to mobility. It has become an important element of local and regional transportation policy.

Governments are trying to achieve mobility management goals in the context of parking by designing a favorable parking policy. Parking policy is a tool to optimize existing parking supply for achieving an effective and balanced urban transport system (Bradley, 1996). It has a substantial impact on travel behavior of individuals such as mode choice and route choice (Feeney, 1989). With parking policy, transportation planners aim to achieve goals such as regulating car use and traffic flow in congested areas and stimulating economic development in Central Business Districts (Marsden, 2006). To achieve these policy goals transportation planners have a variety of parking measures at their disposal. These include measures related to parking volume, parking charges, parking duration and parking information (Litman, 2006). This shows that parking polices are truly valuable and effective therefore, it is necessary that these policies should be carefully integrated in transport plan for achieving long term sustainable mobility (Latinopoulou et al, 2012).

Parking policy can be distinguished at three levels: national, regional, and local level. At national and regional level the policy is limited and not decentralized. At regional level, the issues such as impact of parking charges and parking policies on alternative modes are discussed. Regional plans suggest how parking policies and parking management strategies can be used to promote broader urban and transportation goals (Shaw, 1997). The most detailed parking policy can be found at the local level. At this level, parking policy focuses on available parking facilities and locations. Municipalities define their own goals which include optimal distribution of available parking facilities, costs and effects of parking facilities and measures on overall mobility. Policies made at local level often have regional impacts (Shaw, 1997).

Major goals of parking policy are to increase accessibility and reduce cruising in urban areas. These goals can be achieved using several parking regulations. These regulations act as policy instruments that directly influence parking supply, for example parking type (i.e. on-street and off-street parking), use and location of parking spaces by type (e.g. out-of-town park and ride facilities, downtown garages ...). Parking measures are used to manage on-street parking include parking restrictions, pricing, shared parking etc. Most of these measures are already implemented with success.

In addition, parking policies can conflict with other transportation policies that affect parking practice. These other policies include type of housing and land-use planning. These policies can also have an impact on parking practice. Connection between land-use planning and parking policies can enhance economic viability in urban areas by providing accessibility (Marsden, 2014). Parking is considered as first and foremost land use issue because the decision has to be made if space should be allocated for parking or not consequently, parking policy should be highly integrated to land use planning. Similarly, the type of housing also has a strong influence on the design of residential parking policy because provision of parking has to be decided based on the type of new construction. Therefore, it is not wrong to say that parking also plays a key role in shaping built environment. This can be explained as it parking affects the layout and design of new developments and modifications of old developments.

After land-use policy, car drivers' parking behavior is considered an important aspect linked to parking policy. This is because the process of car drivers parking behavior has important impacts on traffic congestion, air pollution and accidents. However, research in the field of car driver's behavior when choosing for certain parking has been limited and management policies have been often based on ad hoc criteria instead of theoretically robust models or available empirical evidence (Ibeas, dell'Olio and Moura, 2018). Parking policy has a direct influence on travel behavior of car drivers. It strongly influences traveler's travel time and travel distance (Bonsall and Young, 2010). If car drivers spend a lot of time in finding a spare parking space, their travel time will increase. Similarly, if parking lot is far away from a destination, the travel distance increases with a longer walking distance. Also parking tariff influences the activity time in the sense drivers tend to search longer for an optimal parking space. That is why parking has mainly been considered as an explanatory variable for the analysis of travel mode choice. Moreover, there is a demonstrable link between travel behavior and parking situation. It is a critical issue for policy-makers to manage the parking spaces along roads in a multi-modal transportation system. Consequently, the parking and road related attributes should be taken into account while investigating car drivers' parking choices.

Parking choice decisions are linked to traffic management as choice leads car drivers to search for a preferred parking place based on a combination of factors, comprising time-related, price-related, area-wide traffic network and parking policy related, physical parking (built environment) and individual characteristics. This creates a problem in urban areas in terms of the impact on the traffic network due to additional vehicle miles travelled by drivers searching for a parking space (Brooke, Ison, and Quddus, 2014).

Policy measures such as changes in parking tariffs, enforcement measures and information provision are effectively used for managing travel demand (McShane and Meyer, 1982). The success of these policy measures lies within public acceptance. Viable economic benefits can only be achieved by planning policies in accordance with parking choice behavior of car drivers. In order to use parking policy for addressing diverse goals of travel demand management a detailed understanding of effects of change in parking policy measures on car drivers travel behavior is required (Axhausen and Polak, 1991). The acceptance of policy is only possible if all the stakeholders are involved in the decision-making process. Therefore, parking choices of car drivers need to be investigated. Also parking choice behavior of car drivers should be taken into consideration for an optimal utilization of parking infrastructure for efficient demand management, improving quality of life and accessibility in urban environment. The next section highlights the relative importance of on-street and off-street parking.

1.4. On-street versus off-street parking

Parking can be distinguished in two key types. These include on-street parking and off-street parking. On-street parking refers to park anywhere on or along the curb of streets. In some streets it is allowed to park the vehicle on the street, but sometimes there are restrictions (such as parking allowed to residents only or restrictions of parking duration). Mostly these restrictions are presented by traffic signs. Residents need a parking permit to park their cars on-street. In order to make sure people follow these rules and restrictions, cities hire enforcement officers to monitor violations. On-street parking can be differentiated as paid or free on-street parking. On-street parking can be done in many ways such as parallel or angled. It is usually open to general public and is meant for short-term parking.

Off-street parking refers to park the vehicle in a parking garage or parking lot. It is entered via driveway and is often not visible from public streets. Off-street parking includes different types of parking facilities. These can be indoor and outdoor, public or private. In other ways, it can be used for short stay, long-stay and contract. It can be in a built structure (parking garage, under-ground, at ground level) or can be in the open surface parking (parking lot). A substantial proportion of off-street parking in urban areas is both privately-owned/controlled. According to (Rye and Koglin, 2014), (non-regulated) off-street parking provides the majority of the parking space that is available in medium to large-sized cities in Europe.

The influence and value of on-street parking is often underestimated in planning for livable communities ("The Importance of Parking in Planning for Livable Communities", 2018). Drivers during their visits to city center consistently select on-street parking spaces over off-street surface lots and garage parking. Also on-street spaces are highly used and have highest turnover as compared to parking garages as these 'parking structures are expensive to build ("The Importance of Parking in Planning for Livable Communities", 2018). However, the issues associated with on-street parking such as increasing vehicle miles travelled and levels of local air pollution probe an efficient parking management.

On-street parking management has an extensive impact on overall parking situation of a city (Marshall, 2014). Management of on-street parking is one of the oldest techniques of parking management to achieve broader transportation demand management. Different strategies are employed by different cities to deal with on-street parking problems. For example, some cities completely remove on-street parking or restrict it during peak hour of the day to reduce traffic congestion (Barter, 2012). This not only creates additional capacity on the streets without widening actual roadway and improves safety by reducing conflicts between moving vehicles and those driving into or out of parking spaces, while some cities provide on-street parking for using curb space for parking and adopt time restrictions for managing parking spaces efficiently. Thus, keeping space for short-term visitors while requiring long-term parkers (such as commuters) to seek parking elsewhere. Such on-street parking controls are considered important component of many parking management strategies.

Weak on-street parking management can be quantified in terms of increased emissions, congestion and time delays both for drivers who are searching and other car drivers delayed by the slower vehicle speeds of searching drivers ("The Importance of Parking in Planning for Livable Communities", 2018). Injudicious solutions to on-street parking problems can lead to parking chaos. Similarly, on-street parking problems can aggravate if rise in parking demand is not addressed with improvements in parking management. Poor management of on-street parking harms safety, livability and accessibility in urban areas. Therefore, it is necessary to manage on-street parking. Figure 1.1 highlights the concerns associated with on-street parking.

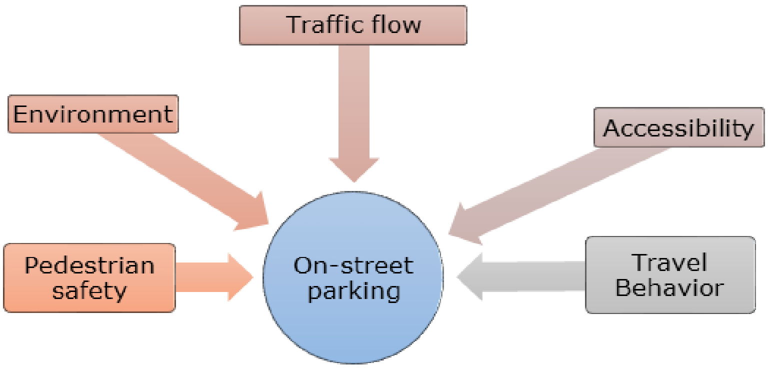

Figure 1.1. Concerns associated with on-street parking management (Marshall, 2014)

Several studies exist in the literature that investigated car drivers' parking choices. Existing parking literature indicates that the use of stated choice approach to study car drivers' on-street parking choice decisions is limited. Socio-demographic, time related and price related factors that influence car drivers' on-street parking search such as walking distance between parking and home, parking type, travel time, parking fee visibility of the car, motorized traffic in residential street, vehicle age, and security have been investigated using stated choice approach (Brooke, Ison, and Quddus, 2014); (Ibeas, dell' Olio, Bordagaray, and Ortúzar, 2014); (Pel and Chaniotakis, 2017). Studies that investigated off-street parking choices of car drivers include (Axhausen and Polak, 1991); (Miller, 1993); (van der Waerden and Oppewal, 1995); (Golias et al, 2002); (Hensher and King, 2001); (Bonsall and Palmer 2004); (Hess and Polak, 2004). There are also some studies that investigated both on-street and off-street parking choices such as (Kobus et al, 2012) and (Chaniotakis and Pel, 2015). All of these studies focused to investigate parking choices with respect to factors affecting parking choices such as time related factors (e.g. access time, search time, egress time, hours of operation, duration of parking, car availability), trip related factors (e.g. parking duration, travel duration, parking time restriction), personal characteristics (e.g. income, gender) and parking related characteristics (e.g. expected illegal parking fine, occupancy rate, type of parking, willingness to pay for parking). However, car drivers' reactions with respect to change in parking measures have not been investigated. As discussed in section 1.1. on-street parking can be managed by parking measures, in short parking measures are the tools to manage parking in urban areas. The effects of these parking measures need to be evaluated on car drivers parking choices.

Parking price is a crucial element which highly influences drivers' parking decisions (Shoup, 1999; Verhoef et al, 1995). Generally an increase in parking price decreases parking demand. However, determining an optimal parking price is a complicated. Under-priced parking price increases parking search time because available parking spots are hard to find (Marsden, 2006; Higgins, 1992; Shoup, 2006). Overpricing of parking, destroys the economic vitality of an area (Shiftan and Burd-Eden, 2001; Hensher and King, 2001; Taylor, 2002; Shiftan and Golani, 2005). Thus, the main goal in a parking pricing scheme is to determine an appropriate price to achieve a desired occupancy level.

Several studies have investigated the influence of change in parking prices on parking demand. These include (Fabusuyi & Hampshire, 2018); (Alemi, Rodier, & Drake, 2018); (Pu, Li, Ash, Zhu, & Wang, 2017); (Chatman & Manville, 2014). (Fabusuyi & Hampshire, 2018) developed SFpark, an innovative demand-responsive pricing program implemented by the City of San Francisco to improve the parking pricing mechanism and to reduce cruising. The program is used to investigate the influence of change in parking rates on parking demand using regression and optimization model. It employs a two-stage panel data to compute price elasticities of parking demand measures. The model evaluates the effectiveness of the altered pricing mechanism by comparing actual occupancy and parking rate. Through sensitivity analysis and SFpark pricing rules several policy scenarios are explored. The SFpark program helps in implementing a spatio-temporal price adjustment mechanism that modifies parking rates across both parking period and parking blocks based on presently observed occupancy levels. Similarly, (Pu et al, 2017) investigated the relationship between change in occupancy and change in parking rate using data obtained from downtown San Francisco between 2011 and 2014. The results showed that there is a significant negative correlation between occupancy change and parking rate change. Thus, sensitivity of on-street parking occupancy to price change has an obvious trend of spatial variation. Variables including time of day, block-level features, and socio-demographic characteristics were also found to be correlated with occupancy change. Findings of this study can be used to help parking authorities with tasks such as identifying which blocks are suitable for balancing parking demand and supply by adjusting price and designing optimal parking rate schemes to achieve desired on-street parking occupancy levels.

(Fabusuyi & Hampshire, 2018) investigated the effect of the San Francisco parking pricing program (known as SFpark) on curbside parking search time and distance in urban neighborhoods on non-commuter parking. This study differs from previous empirical evaluations of similar parking pricing programs in its use of direct field measurements of parking search time and distance, rather than simulated data or proxy variables, such as parking availability. The results suggest a significant reduction in average parking search time and distance due to SFpark. Average parking search time and distance declines by approximately 15% and 12%, respectively, from the control to the treatment areas.

(Chatman & Manville, 2014) also used SFpark to study the influence of change in parking prices on on-street parking availability. Results show that when prices rose, the block-level occupancy of parking fell, suggesting that SFpark worked as intended. Price increases also had no association with other factors such as parking availability, parking duration, vehicle turnover, and carpooling. According to (Chatman & Manville, 2014) a price system designed to improve average occupancy may not improve parking availability, and thus may not reduce cruising.

Studies that investigated the effects of parking measures on car drivers' parking decisions are also discussed in existing literature. These include (Litman, 2006), this study investigated the effect of parking policies on required space and traffic volumes. The results of this study show that a reduction in required number of spaces tends to reduce traffic problems and provides additional benefits.
Likewise, (Marsden, 2006) provided an overview of parking studies that investigated the effects of parking measures in different policy contexts (such as commuter, non-commuter, and residential parking) the result of this study indicate that non-commute drivers respond to parking restraint policies by decreasing the frequency of visit, changing destination and by altering the duration of visit.

(CROW, 2001) investigated the effects of the introduction of paid parking in major shopping areas of several cities. This study concluded that paid parking leads to an increase in parking pressure in areas of free parking. Introduction of paid parking decrease search traffic, make efficient use of parking spaces, and promote 'short stay' parking. (CROW, 2001) concluded that as a result of paid on-street parking drivers change destination rather than travel mode.

(Shiftan and Burd-Eden, 2001) investigated two policy measures i.e. an increase in parking charges, and a decrease in parking availability using stated choice approach. A stated choice experiment included an increase of hourly parking rates and a decrease in the number of available parking spaces. Car drivers were presented seven responses: continue to arrive by car without a change; shift to public transport; shift to taxi; shift to walk; cancel the trip; change destination; and change time of day. It appeared that workers are more likely to change their mode of travel or time of day than to change destination or cancel their activity. Non-workers are likely to make all types of changes and for all policies they are more sensitive than workers.

A through study of existing literature reveals that there is lack of insights related to on-street parking choices of car drivers. This knowledge gap is catered in current research. Next section discusses the problem in more detail.

1.5. Problem statement

On-street parking has the highest impact in a city center. It affects parking demand, land use, vehicle speed, road and pedestrian safety, the environment, accessibility and travel behaviors (Marshall, 2014; Vasconcelos and Farias, 2017).

The literature contains empirical evidence that 30% of cars traveling on downtown city streets end up in cruising for parking during a business day (Shoup, 2006). Cruising time increases with travel duration as well as with parking duration (van Ommeren, 2012). This is because on-street parking spaces are readily available and convenient to several destinations (Litman, 2006). Also cruising is considered as a natural behavior of drivers, it is actually their exploration for more affordable and convenient on-street parking (Lee, Agdas, and Baker, 2017).

Although there is little academic research on this subject, it cannot be neglected that on-street parking is considered a potential cause of congestion, traffic accidents and increase in travel time due to cruising for parking in city center (Shoup, 2006). Also a lack of understanding about how individuals respond to parking policy interventions and how drivers actually make parking decisions has not attracted a significant research effort.

Cruising creates a random queue of cars impeding traffic flow (Arnott and Inci, 2010). The traffic induced due to high level of cruising in urban areas is a critical issue for transport analysts and urban planners, as it impedes traffic movement along major routes (Marsden, 2014). On-street parking space search also differ from off-street parking space search in at least two ways. First, a lack of information given to drivers about vacant spaces in the street significantly influences parking search time (Hualiang et al, 2002), Second, illegal parking is also considered as a strategy, especially for short stays that creates obstruction in traffic flow and thus generates traffic issues (Spitaels and Maerivoet, 2008; Gantelet and Lefauconnier, 2006; Benenson et al, 2008; Bifulco, 1993).

Efficient parking management in urban areas can only be achieved by carefully designing the parking policy that not only coincides with overall transport policy goals but also positively affects behavior of car drivers. With parking policy, transport planners aim to regulate traffic flows in congested areas, thus enhancing accessibility and livability of these areas. Parking policies highly influence urban traffic flows and are able to cause modal shift (Tsamboulas, 2001). Most strategies to mitigate cruising are related to adjustment of on-street parking prices which enhance economic efficiency, demand management and provide an ideal 85% occupancy rate (Arnott and Inci, 2006; Shoup, 2006). It is obvious in large cities that receive more car trips, particularly for shopping and leisure activities. In order to reduce parking search, it is necessary to investigate the underlying factors related to car drivers' on-street parking decisions and analyze their effects.

In the past, researchers have developed several agent-based parking simulation systems for simulating parking search behavior of car drivers. The aim of these models was to identify the effects of change in policy measures on car drivers parking behavior. Some examples include PARKAGENT (Benenson et al, 2008), SUSTAPARK (Dieussaert et al, 2009), and the parking simulation model developed by the group of Waraich (Waraich et al, 2013). All these models are more or less capable of representing the parking search process of car drivers including the decision making process leading to the choice to park. However, the phenomenon of parking choices is based on limited behavioral principles (i.e. the process of car driver's parking choice decision is inadequate, as it should be based on their assessment of the available alternatives). To evaluate parking measures in detail, a more comprehensive model for predicting car drivers' on-street parking decisions is required.

The effects of many specific parking measures (related to road such as speed reduction, increase in parking tariff) in the context of on-street parking choices are not yet known. Parking measures are actually tools to cater parking management and achieve the overall goals of parking and transport policy. This kind of knowledge is very important for policy makers in order to implement the right policy options. For example, policy makers still do not know what the effects of changing parking costs are, especially in urban areas (Marsden, 2006 and 2014). Existing literature lacks information regarding parking and road attributes that trigger cruising. Specific role of parking and road attributes on car drivers' on-street parking decisions has never been investigated in the existing literature. Therefore, to identify the effects of street attributes on parking preferences of car drivers' and to clarify how search traffic can be avoided simply by using parking measures related to roads. More precisely, it is necessary to investigate the role of parking and road attributes on car drivers' parking decisions. Thus, the hypothesis for this research can be formulated as 'car drivers' choice of on-street parking space is determined by both parking and road conditions'. This research aims to identify parking/road conditions that affect car drivers' parking decisions. This knowledge is necessary for the development of parking policies so as to foster more sustainable mobility in urban areas.

1.6. Research aim

The main objective of this research is to provide insight into car drivers' on-street parking decisions in relation to parking and road attributes, while driving in central business district. This goal has been further sub-divided into the following specific objectives:

- Develop a framework for investigating car drivers' on-street parking choice behavior.
- Assess the influence of parking and road related attributes on car drivers' on-street parking decisions.
- Simulate car drivers' on-street parking decisions.

In order to clearly interpret the decisions of car drivers while driving on-street and searching for a suitable parking space, a comprehensive framework is required. Keeping in mind this conceptual framework, the on-street parking decision process of car drivers can be well defined. Later, a strategy to construct a relevant experimental design can be formulated and the car drivers' preferences can be collected. In the end car drivers parking preferences can be simulated to deduce final results (i.e. under certain parking/road conditions what parking related decision will be made by a car driver?).

There are four key stake holders that are most affected by parking conditions in an area. These include car drivers, retailers/developers, parking companies and the policy makers. The car drivers are most affected by parking conditions because these decisions increase their travel time therefore they need a convenient parking space with a reduced walking distance to final destination and minimal search time. The retailers consider on-street parking highly important for their businesses (Burns & Klein, 2016) while municipalities aim to reduce congestion and pollution keeping their centers accessible (Geurs & van Wee, 2004). Parking companies try to maximize revenue and increase the turnover of cars (the number of different cars using one space). Keeping in view these concerns, a few main policy implications can be deduced from this research. With knowledge about actual parking and road conditions, car drivers can get insights related to the effects of parking measures on their personal circumstances. Retailers can expect more insights of the effects of parking measures on their businesses and can make the accessibility of their businesses more attractive. While for policy makers this research is useful to evaluate parking policy such as investigating impact of the introduction of paid parking and adjusting speed limit on car drivers' parking decisions as well as identifying factors related to road that trigger cruising. This can provide policy makers with objective information to frame the city's parking policy. Moreover, this research suggests to incorporate the decision making process of car drivers in the policy framework to reduce cruising and achieve the actual travel demand management goals. The quantitative analysis of the dataset suggests that car drivers prefer certain parking conditions in a street/road while searching for parking, so policy makers can direct car drivers with specific measures like parking costs, available parking spaces, occupancy, and speed limit. Secondly, such comprehensive behavior models for parking form the basis of multi-agent simulation models that are currently being used for parking policy evaluation. This particular model is the first to investigate responses of car drivers to change in parking measures. More specifically, with this model the effects of changes in parking and road conditions can be evaluated (i.e. the effect of change in parking measure results as a change in setting of parking attributes). For instance, the increase of parking tariff (measure) results into a higher price (change) in the status of parking characteristics. Other examples include introduction of paid on-street parking, the adjustment of road speed limit and a change in land-use along a road.

Finally, the local authority might consider customizing the parking policy according to drivers' needs. Instead of offering spaces that not only remain underutilized but also create congestion during peak hour. The municipality may offer parking availability to particular target groups during different hours of the day. In this way, the problem related to cruising can be reduced and utilization of off-street parking spaces can be enhanced. Moreover, the outcome of this research is interesting for policy makers in other countries that deal with similar measures.

1.7. Thesis outline

This thesis consists of six chapters, three chapters are based on journal articles and conference papers each with a different focus. The following figure details the outline of the thesis.

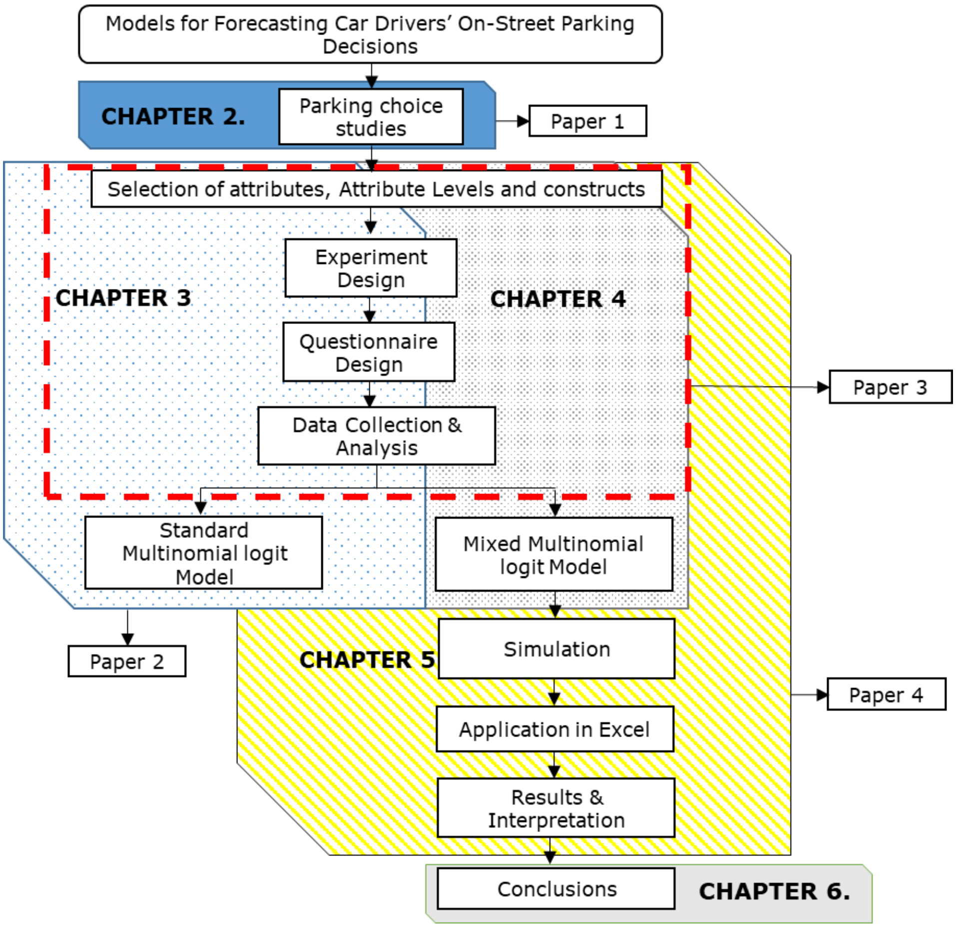

Figure 1.2. Outline of Doctoral thesis

The first chapter **'Introduction'** discusses the basis of this research. The background, problem statement, research aim and structure of thesis are stated in this chapter

The second chapter **'Parking choice'** discusses the importance of parking choice with respect to parking policy design. It provides a comprehensive overview of parking choice simulation models and factors affecting parking choice of car drivers mentioned in the literature, in order to identify which of the parking related attributes have been overlooked.

The third chapter '**Investigation of On-Street Parking Decisions**' is based on paper titled as 'Modelling car drivers' on-street Parking preferences using hierarchical Information Integration'. In this chapter, car drivers' parking decisions have been investigated using a stated choice experiment, in combination with the method of integrated hierarchical information integration. According to this approach, a large set of parking related attributes and attribute levels are grouped into two higher order decision constructs, which are presented as hypothetical street segments. The respondents were asked what parking decision they would make in the given street segment with the listed attributes. For a first exploration of the parking choices of car drivers, the collected data is used to estimate the parameters of a standard multinomial logit model. The standard multinomial logit model assumes that each individual is the same (i.e. every respondent makes decisions according to a similar pattern). The model does not consider users' heterogeneity.

The fourth chapter **'Detailed modeling of On-street parking Decisions'** is based on a paper titled as 'Forecasting Car Drivers' On-Street Parking Choice Decisions while driving in a Downtown Area'. In this chapter, a more detailed model is proposed to investigate cars drivers' on-street parking decisions considering road related attributes. The model is designed to evaluate parking decisions of car drivers while driving in the city center. Existing literature focuses on models explaining mainly off-street parking choices of car drivers, but none of the studies aid in investigating car drivers' parking decisions keeping in view the actual road conditions. The model is capable of describing car drivers' reactions, who face certain parking and road conditions in a street. In order to predict car drivers on-street parking preferences the stated choice data is analyzed using a mixed multinomial logit model. The basic aim is to identify preferable street situations that induce search traffic which can later be avoided using relevant parking measures. This implies considering on-street parking as a tool to achieve convenience and accessibility in the city center. This chapter is different from Chapter 3, because mixed logit model takes into account heterogeneity of users' considering that all respondents make decisions based on their own preferences/judgement assuming that all individuals are different. This explains respondents' parking decisions more comprehensively.

The fifth chapter **'Simulating On-street parking decisions'** is based on a paper titled 'Simulating Car Drivers' Parking Choice Behavior in the context of Parking Measure Evaluation'. This chapter describes an application of a behavioral model, capable of predicting on-street parking choices of car drivers in response to changes of parking and road conditions due to parking measures. The parking choices of car drivers are evaluated using a mixed multinomial logit model. With the results of the model estimation a simulation is setup to illustrate the working of the model when investigating the effects of parking measures. More specifically, with the simulation the effects of (a) surrounding activities (b) speed limit (c) parking duration (d) the introduction of paid parking or an increase of the on-street parking cost from 1.00 euro to 2.00 euro on car drivers' parking decisions are evaluated. The simulation clearly shows the changes in probabilities of on-street parking, off-street parking, and continue to search due to the changes in parking cost.

The sixth and final chapter **'Conclusions'** summarizes the overall results of the research with future research directions and practical implications.

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2. Parking Choice

This chapter discusses the importance of parking choice with respect to parking policy design. It provides a comprehensive overview of parking choice simulation models and factors affecting parking choice of car drivers mentioned in the literature.

2.1. Abstract

Policy makers and urban planners want to address diverse travel demand management goals by designing a parking policy that fits in local perspectives. For a successful implementation, parking policy should incorporate all the perspectives of car drivers' parking choice. This chapter reviews several parking choice studies conducted to analyze the parking choice behavior of car drivers. In this review, a brief overview of the scope and structure of existing parking models and the characteristics used to develop parking models for supporting parking policy are highlighted. This chapter highlights the outcomes of multiple parking choice studies existing in the literature in order to draw relevant conclusions for practice and quantify significant factors influencing parking choice behavior. It can be concluded that factors such as parking cost, parking duration and walking distance to destination are mostly considered by drivers while choosing a parking space. Moreover, it can be noticed that a significant proportion of parking literature has focused on off-street parking choice behavior with little attention paid to on-street parking choice. The overall goal of this chapter is to provide a comprehensive overview regarding the factors affecting parking choice. This sort of review is useful for policy makers and researchers to identify the future research direction. This chapter is organized in four sections. Section 2 gives an overview of the significance of car drivers parking choice behavior with respect to parking policy design/evaluation. The categories of parking choice models existing in the literature are briefly discussed in section 3. Thereafter, the factors related to parking choice of car drivers with respect to off-street parking and on-street parking are outlined in section 4. Finally, the conclusions are presented and discussed in section 5.

2.2. Individual choice process

Car drivers' parking choice behavior is one of the main concerns of policy makers. Drivers evaluate certain factors cognitively while deciding to park at a certain parking space. These factors need to be studied precisely in order to make efficient parking policies. Behavior modelling techniques have been used to investigate car drivers' parking choice behavior in literature. Research debates that the parking behavior of drivers may depict the economic productivity of cities (Axhausen and Polak, 1991). Parking choice decisions are directly linked to parking policy as choice leads drivers to search for a preferred parking place (Brooke, Ison, and Quddus, 2014). Parking choice is an important aspect of travel behavior. It enables implementation of measures to address the issues created by individuals searching for preferred parking places.

Parking choices of car drivers can be described in terms of individual choice process in the context of activity-travel decisions. Classical theories of individual choice behavior (Luce, 1959) assume that individuals make a set of choices simultaneously. Trip related choices can be destination choice, activity duration, mode choice and, if the car is used, where to park the car. These classical theories are relatively important for the development of the parking simulation models. According to (Louviere et al, 2000), travelers or individuals' ultimate choice is based on a sequence of decisions. Six stages in this process can be distinguished as shown in (Figure 2.1).

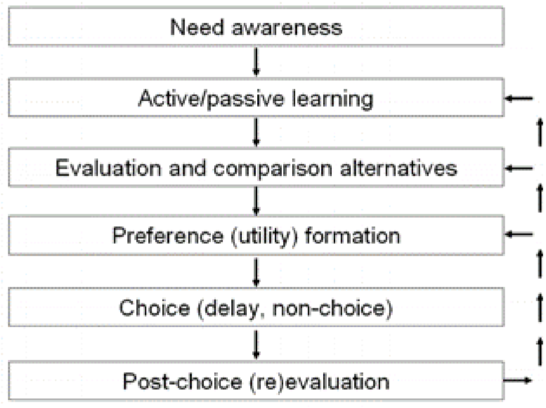

Figure 2.1. Individual choice process (Louviere et al, 2000)

The first stage of need awareness depicts the point when the traveler first becomes aware of needs or problems to be solved. In the second stage, the traveler gets to know available choice options offered that can fulfil the needs or solve the problems. During the third stage, the traveler makes a comparison among the available alternatives that match his/her objectives and respective attributes of alternatives related to the choice. After being adequately aware of the benefits and trade-offs associated with the attributes the travelers develop a value (preference) of the product. This preference then leads to the selection of final choice alternative. The last stage of this process, post-choice evaluation can be described as adaptive choice behavior. In case of parking this can be explained when the traveler adapts his/her final parking choice rather than using the chosen alternative. The generation of the set of available alternatives (choice set) and the determination of the actual choice (behavior) are the most important aspects of an individual's choice process. These two aspects are fundamental for the development of a choice model because the choice set formation has an influence on parameter estimates and the possible dependency of the choice set on the prediction of market shares. Keeping in view this individual choice process parking choice of car drivers can be easily investigated using choice models. By identifying actual choices of car drivers a goal oriented policies can be formulated and required parking situation can be achieved. The next section discusses parking models in more detail.

2.3. Overview of parking models

Modelling the process of parking has been considered attention-grabbing as a diverse amount of literature can be found related to parking models. These parking models have been categorized in several ways. (Young and Taylor, 1991) categorized models in four distinguished levels from microscopic to macroscopic depending on the scale of examination area these include: parking lot level, sub-center level, sub-regional level and urban level. (Young, 2008) categorized models based on their purpose of use such as parking design models, parking search models, parking choice models, parking allocation models and parking interaction models. Parking design models are used to design (calculate capacities and dimensions) and understand performance of the parking system. Parking search models investigate the search process travelers undertake while searching for a parking place, whereas parking choice models measure the reactions of travelers with respect to parking supply. Parking allocation models are introduced to assign parkers to available parking supply. Parking interaction models examine the response of people to new policies.

Several modelling approaches are mentioned in the literature for investigating parking choices. A major subdivision of parking models is done by (Martens and Benenson, 2008). According to them, parking models can be broadly categorized as '**spatially implicit models**' and '**spatially explicit models'**.
Spatially implicit models of parking are based on car drivers' stated preferences related to the parking facilities. These models consists of choice sets having alternatives consisting of attributes, some of these attributes include a spatial component such as the distance towards the destination, but these models do not simulate the actual traffic flow and its effects.

The second category, spatial explicit models simulate car drivers' behavior on a network. These models focus on the parking search and choice process of the drivers in order to make a parking decision. These models consider parking behavior of drivers as a sequence of drivers' responses to the actual traffic situation and, in principle, are capable of capturing the self-organizing nature of cruising dynamics. Most of these modelling approaches related to parking choice lack in defining the behavioral influence on ultimate choice. As these approaches assume that the driver has a perfect knowledge of the system. In order to apply these models to assess real-world policy scenario's, both types of models need substantial extension in terms of the modelled area and the types of behavioral rules.

Thompson and Richardson (1998) were the first to define parking search process within a behavioral modelling framework. They provided a conceptual representation of the parking search process. This process consists of various stages, based on a series of decisions, linked in a temporal fashion (shown in Figure 2.2). Motorists examine individual car parks sequentially as they move within an urban center. After an alternative is inspected, motorists can either select it or continue to search by travelling to another car park. The process is initiated when the first search (or trip) begins. Once searching has begun the process of inspecting and evaluating car parks commences. The decision of whether or not to accept the current car park determines if the current search is terminated or continues. After parking, the process continues when the next search is undertaken. Applications of the model showed that long term experience does not necessarily lead to better choices.

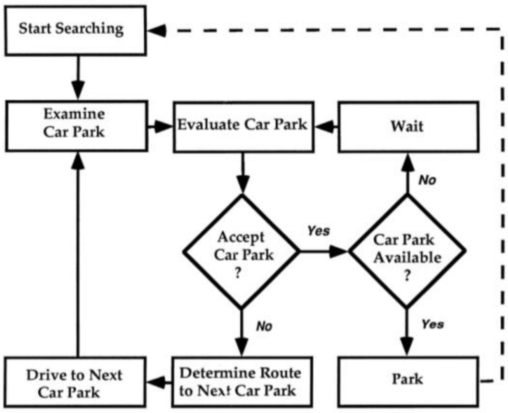

Figure 2.2. Parking search process (Thompson and Richardson, 1998)

Similarly, (Kaplan and Bekhor, 2011) proposed a behavioral modelling framework that includes the combined choice of parking type, parking facility and driving route during the search for a parking place. This framework (shown in Figure 2.3) is proposed to analyze the relationship between individual characteristics and cruising-for-parking behavior at the disaggregate level. This disaggregated model captures cruising-for-parking behavior to explore the impact of parking policies in congested urban areas. In addition, the model can be used to enhance the representation of cruising-for-parking traffic in micro-simulation models such as PARKIT (e.g., Bonsall and Palmer, 2004) and PARKAGENT (e.g., Martens and Benenson, 2008).

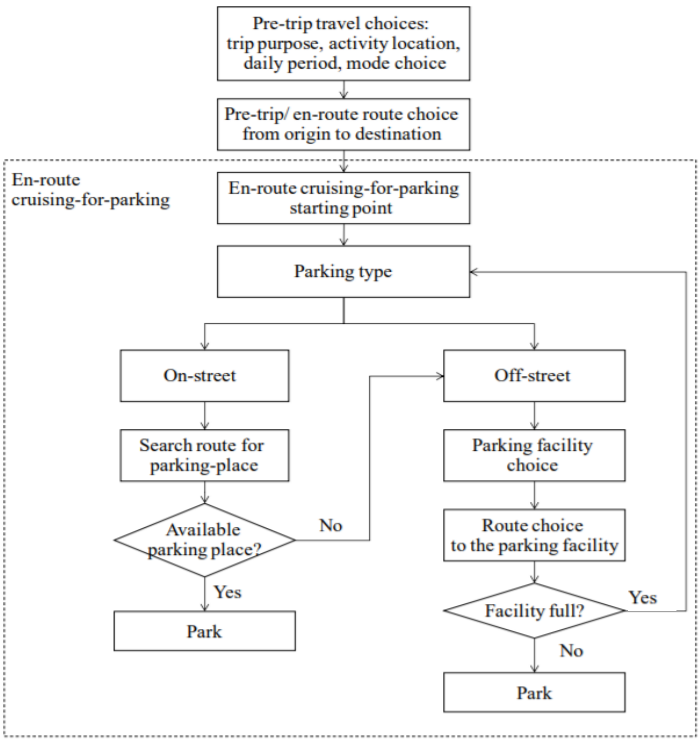

Figure 2.3. Cruising for parking decision framework (Kaplan and Behkor, 2011).

This framework represents en-route cruising for parking, given that a trip is conducted without a change in the pre-travel choices of activity location and daily period, and that a parking choice is made, during the trip. This model serves as a planning tool investigating the influence of parking policies and PGI systems on cruising-for-parking behavior in particular.

2.3.1. Discrete choice Models of Parking

Implicit choice models are also known as 'Discrete choice models' (DCM). Discrete choice models describe an individual's choice of one option from a finite set of options (Ortúzar and Willumsen, 2001). These models are used to understand and represent the behavioral process that lead to individuals decisions (Train, 2003). DCMs use Random Utility Maximization decision theory. According to this theory it is assumed that the decision makers try to maximize their utility (gain or profit) from the several alternatives offered (Train, 2003). It is one of the most widely used theories for the description of individuals' decisions (Cascetta, 2009).

Due to the complexity of decision makers' behavior, the mathematical description of decisions cannot represent complete set of attributes related to all individuals in a deterministic way. For this reason, probability is used to take into account stochasticity of decisions (Train, 2003). The actual thought behind this concept is that the individuals evaluate the available alternatives and make decisions based on their needs and environmental factors.

DCMs have been traditionally used to analyze parking problems and to study the interrelationship between parking conditions and parking policy. These models aim at specifying optimal use and utilization of parking space depending on the traffic flows, departure time, modal split, and so on. In the context of parking, the first proposed discrete choice models were used to simulate the effects of different parking pricing policies on mode choice. Later, more detailed interpretations have been suggested with more disaggregate modelling, with respect to both users class and supply system.

Extensive studies have been conducted to analyze parking choice behavior. These studies employed discrete choice approaches to model parking choice behavior. Parking related literature can be subdivided into three main groups based on research aims. The first group of studies investigated the effect of parking policies on parking decisions. These parking decisions were linked to choice with respect to parking type such as selection of on-street, off-street and illegal parking (van der Goot, 1982; Axhausen et al, 1988; Axhausen and Polak, 1991; Tekmono and Hokao,1997; Golias et al, 2002; Hess and Polak, 2004; Guan et al, 2005); choice among different off-street parking facilities (Lambe, 1996; van der Waerden et al, 2000; Harmatuck, 2007; van der Waerden et al, 2008); or combined choice of parking type and facility (Hunt and Teply, 1993).

The second group of studies analyzed the effect of parking policies on trip-making decisions connecting parking choices and other travel choices. The addressed joint decisions are: travel mode and parking type (Bradley et al, 1993); travel mode and parking location (Hensher and King, 2001; van der Waerden et al, 2006); travel mode, destination and time of day changes as a result of parking policy changes (Shiftan and Burd-Eden, 2001); and travel mode, destination and parking facility (van der Waerden et al, 2001).

The third group of studies investigated the effect of parking guidance and information (PGI) systems on reduction in search traffic and congestion. Consequently, the third group seeks to explore car drivers' decisions and behavioral changes in response to parking information available within the travel route. The investigated factors are: parking-search duration, parking-search direction and parking search difficulty (Axhausen et al, 1994; Axhausen and Polak, 1995; Thompson and Richardson, 1998; van der Waerden et al, 2002); en-route revision of pre-trip parking facility choice, highway-exit choice, adaptive choice behavior and waiting time at the entrance of the parking facility (van der Waerden et al, 2002; Bonsall and Palmer, 2004); choice of a parking stall inside parking facilities (van der Waerden et al, 2003; Caicedo et al, 2006); parking behavior before and after arrival to the destination (Benenson et al, 2008). All these studies investigated effects of different factors on parking choice decision. The purpose of trip, methods used and statistical analysis performed in order to investigate car drivers' parking choices in these studies are explained in next sections.

2.3.1.1. Factors affecting parking choice

Most of the reviewed literature acknowledges that 'walking time' and 'parking costs' as the main determinants of the cruising behavior in the context of both on-street and off-street parking (Miller, 1993; van der Waerden and Oppewal, 1995; MuConsult, 1997; Bonsall and Palmer, 2004; Hess and Polak, 2004; Brooke, Ison, and Quddus, 2014; Chaniotakis and Pel, 2015; Pel and Chaniotakis, 2017). It seems that in case of short term trips (e.g. shopping and recreation trips) to city center cruising has a spatial and time component. Cruising time increases with travel duration as well as with parking duration (van Ommeren, 2012). Figure 2.4 shows list of factors studied in the literature.

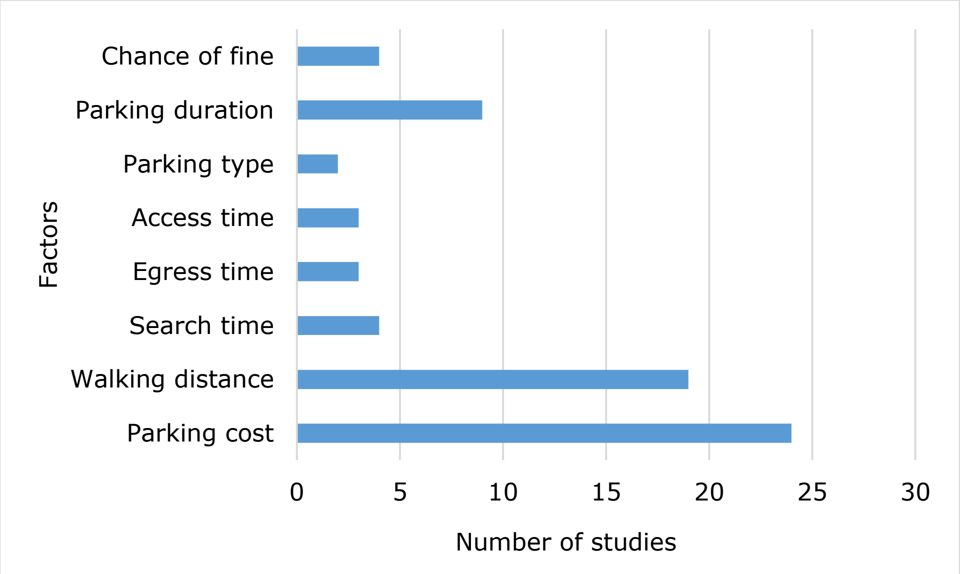

Figure 2.4. Factors affecting parking choice of car drivers

The factors listed above can be segregated with respect to off-street parking and on-street parking. Several characteristics that significantly affect off-street parking choice include access time, search time, egress time, expected parking fine, parking time restriction, occupancy rate, type of parking, willingness to pay for parking, hours of operation, a tariff schedule, number of spaces, number of car parks passed, last car park used, duration of parking, car availability, travel time, costs for car, costs for transit, income and gender (Axhausen and Polak, 1991; van der Goot, 1982; MuConsult, 1997; Hensher and King, 2001; Golias et al, 2001; Miller, 1993; Bonsall and Palmer, 2004).

A thorough study of existing parking literature indicates that the use of stated choice approach to study car drivers' on-street parking choice decisions is limited (Belloche, 2015). Various time related, price related and socio-demographic factors that influence car drivers' on-street parking search such as walking distance between parking and home, parking type, travel time, parking fee visibility of the car, motorized traffic, vehicle age and security have been investigated using stated choice approach (Brooke, Ison, and Quddus, 2014; Ibeas, dell' Olio, Bordagaray, and Ortúzar, 2014; Chaniotakis and Pel, 2015; Pel and Chaniotakis, 2017). Table 2.1. gives a detailed overview of potential factors affecting on-street parking choice mentioned in the literature.

Table 2.1. Factors influencing on-street parking choice behavior (Khaliq et al, 2017)

Study	Factors influencing parking choice
Tsamboulas, 2001	- Difference in walking distance - Initial walking time - Parking fee - Trip purpose
Coppola, 2002	- Illegal parking - Parking duration - Search time - Parking cost - Occupancy - Trip purpose
Kobus et al, 2012	- Price of parking - Parking duration
Brooke et al, 2014	- Search Time - Walk time - Trip purpose - Parking habit - Number of Parking Places Visited - Familiarity - Trip Time (Access Time) - Parking Duration - Heavy equipment - Parking Bay Type - Type of Carriageway - Parking Bay Type - Direction of Traffic Flow

	- Side(s) on which Parking Spaces are located - Carriageway Side(s) - Road Width - Direction of Traffic Flow
Chaniotakis and Pel, 2015	- Parking type - Walking distance to destination - Travel time - Parking fee

Other approaches that are used to represent on-street parking search behavior of car drivers, include behavioral modelling framework, traffic assignment or network based simulation models, agent-based parking simulation model (Eldin and Ismail,1981; Thompson and Richardson, 1998; Arnott and Rowse, 1999; Young and Weng, 2005; Leephakpreeda, 2007; Benenson et al, 2008; Gallo, et al, 2011; Waraich et al, 2012; Steenberghen, Dieussaert, Maerivoet, and Spitaels, 2012; Guo et al, 2013; Bifulco, 1993). Possibility theory has also been employed to to investigate car drivers' parking choice behavior with respect to different parking policies (Dell'Orco, Ottomanelli, and Sassanelli, 2011). However, Agent based models (ABMs) are more advanced and detailed than parking choice/search models.

2.3.1.2. Trip purpose

Literature shows that trip purpose significantly affects parking choice behavior of car drivers. Figure 2.5 shows that parking choice behavior has been investigated for almost all trip purposes such as employment, shopping and recreation. Most of the studies have investigated parking choice behavior of motorist for shopping activity. It can be noticed that trip purpose is a time related aspect, so parking choice for shopping trips is important to investigate as this activity does not have a fixed duration and a lot of parking problems are associated with this activity as compared to work. (Gillen, 1978), (van der Goot, 1982), (Teknomo and Hokao, 1997), (Tsamboulas, 2001), (Hensher and King, 2001), (Coppola, 2002), (Bonsall and Palmer, 2004), (Brooke et al, 2014) and (Chaniotakis and Pel, 2015), (van der Waerden et al, 2015) examined parking behavior for all trip purposes (including social visits, commuting and recreation). This summarizes that discrete choice models can efficiently be employed to investigate parking choice behavior of individuals for all trip purposes. (van der Waerden and Borgers, 1995) ,(van der Waerden et al, 1998), (Matsumoto and Rojas, 1998) and (van der Waerden and Timmermans, 2014) investigated parking choice for the context of shopping. Commuting is termed as distance travelled between home and workplace on a regular basis. According to (AASHTO, 2013) '16% of all person trips include commuting to work. (Hunt and Teply, 1993), (Miller, 1993), (Harmatuck, 2007) investigated parking choice behavior in the context of commuting. The studies from (Axhausen and Polak, 1991), (Bradley et al, 1993), (Lambe, 1996), (Clinch and Kelly, 2006), (Hess and Polak, 2009) investigated parking choice in the for work trips. Figure 2.5 explains the work and shopping trips as the most investigated trip purposes with respect to parking choice.

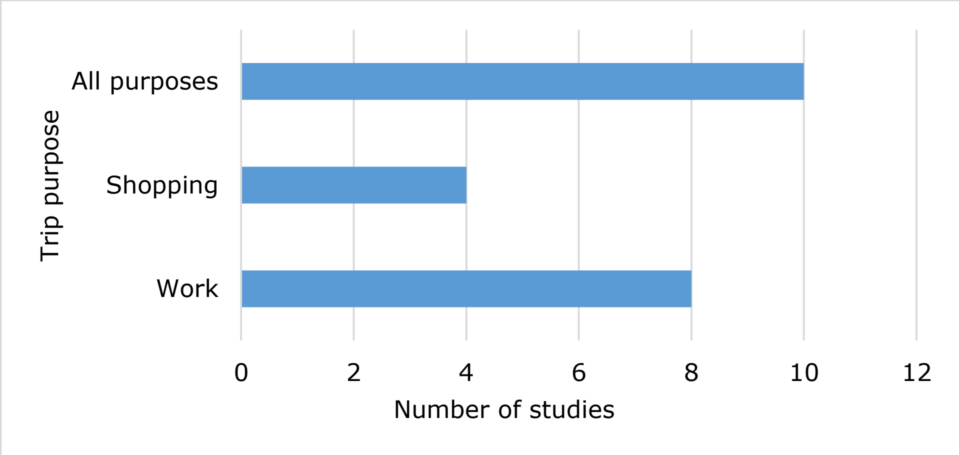

Figure 2.5. Parking choice behavior studied with respect to trip purpose

2.3.1.3. *Data collection approaches*

Data collection is an essential part of market research. An accurate type of data is required for investigating the identified problem. Data required for investigating parking choice behavior is collected through stated preference (to investigate intended behavior) or reveal preference (to investigate actual behavior) methods. In a few studies, a combination of stated and reveal preference approaches has been identified. Some of the studies used secondary data sources (data already collected by other researchers for same purpose) for investigating parking choice behavior of car drivers but it can be noticed that stated and revealed preference methods have been used throughout the literature. Other type of data collection approaches include face to face in-depth or structured interviews with drivers, computer based laboratory simulations or Drivers' logs. Type of data varies depending on the purpose of investigation. Stated preference method is used to collect user's response to hypothetical scenarios whereas revealed preference method involves information based on actual decisions made by people. It can be noticed that (Teknomo and Hokao, 1997) used an analytical hierarchy process. Table 2.2. explains in detail data collection methods used in different studies to investigate parking choice.

Table 2.2. Type of data collection approach used for analyzing parking choice behavior

Study	Data collection method
(Axhausen & Polak, 1991), (Hensher and King, 2001), (Bonsall & Palmer, 2004), (Hess & Polak, 2004), (Clinch & Kelly, 2006), (Harmatuck, 2007), (Borgers et al, 2010), (Cools, van der Waerden, and Janssens, 2013) and (Chaniotakis & Pel, 2015)	Stated preference
(Gillen, 1978),	Revealed preference.

(Van Der Goot, 1982), (Coppola, 2002) (van der Waerden and Borgers, 1995), (Brooke et al, 2014)	
(Bradley, Kroes, & Hinloopen, 1993), (Hunt & Teply, 1993), (Miller, 1993), (Lambe, 1996), (Tsamboulas, 2001) (Matsumoto & Rojas, 1998)	Used combination of both stated and revealed preference approaches.

2.3.1.4. Statistical Analysis

Different types of models can be used in parking choice analysis. The selection of a statistical analysis depends on the purpose of investigation. Nested choice models, multinomial and mixed multinomial models can be used for investigation of parking choices available alternatives. Binary logit models can be used where only two alternatives exist. Some of the studies have also used combination of models to investigate parking choice behavior e.g. (Lambe, 1996) used Multinomial logit and probit model. (Brooke et al, 2014) used multilevel linear regression model. (Teknomo and Hokao, 1997), (van der Waerden and Borgers, 1995), (Axhausen and Polak, 1991) and (Matsumoto and Rojas, 1998) used Multinomial logit. (Miller, 1993), (Coppola, 2002) and (Hess and Polak, 2004) used nested logit model. (Gillen, 1978) and (van der Waerden and Timmermans, 2014) used binary logit model. (van ver Goot, 1982) used logit chance model. (Harmatuck, 2007), (Hess and Polak, 2004) and (Borgers, et al, 2010) used multinomial and mixed multinomial logit. (Chaniotakis and Pel, 2015) used multinomial logit, nested logit, and mixed logit. (Bonsall and Palmer, 2004) used multinomial logit and nested logit. (Cools et al, 2013) used bivariate probit model with multinomial logit model. Figure 2.6. shows highly used statistical models to investigate parking choices.

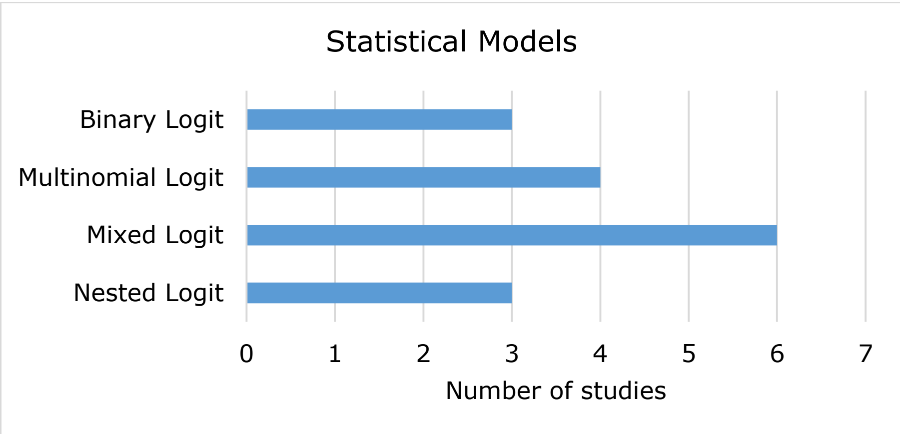

Figure 2.6. Types of statistical models used to investigate parking choice.

2.3.2. Network based Models of Parking

Explicit choice models also known as Network based models, are used to determine parking choice explicitly since parking choice is modelled by extending the simulation capability of the traffic assignment model. In these models, the road network is represented as a graph and user's choice is represented by means of a route choice model. Parking supply is modelled as a set of links instead of the connector links (such as arcs that connect the road links to the centroids). Each link represents an activity relevant to parking choice process and parking costs. This means that parking choice can be determined for a given parking facility, a parking access link, a parking link (per type), and pedestrian links (Bifulco 1993; Cascetta, 2001). This approach can be used to simulate parking and route choice together (Bifulco, 1993).

In the context of modelling parking choice, this approach investigates parking search problem as minimum cost path where the choice set is made up of the routes connecting the origin and destination of drivers' trip and routes passing through the available parking facilities (Dell'Orco, Ottomanelli, and Sassanelli, 2011). The resulting traffic assignment model is based on the theoretical assumptions of route choice. (Nour Eldin et al,1981), (Bifulco, 1993) and (Young, 2000) used this approach to solve out the network and parking related problems (Dell'Orco, Ottomanelli, & Sassanelli, 2003). Other examples network based traffic assignment models (Eldin and Ismail, 1981; Thompson and Richardson, 1998; Arnott and Rowse, 1999; Young and Weng, 2005; Leephakpreeda, 2007; Gallo, et al, 2011; Guo et al, 2013).

2.3.3. Agent based Parking Simulation Models

Agent based modelling is an interesting computational modelling approach for analyzing parking phenomena. It provides a dynamic platform to understand interactions between drivers, city environment and other road users. PARKAGENT (Benenson et al, 2008), SUSTAPARK (Dieussaert and Aerts, 2009), the parking choice model of (Waraich et al, 2012) and (vuurstaek et al, 2018) are agent based parking models discussed in the sections below.

2.3.3.1. PARKAGENT

PARKAGENT (Benenson et al, 2008) has given a new dimension to parking research as it can simulate the parking phenomena more explicitly. PARKAGENT is an agent-based parking simulation model for residential areas. The model works with parking search rules. An agent evaluates per iteration the parking availability and decides whether to park or to continue driving. The decision is based on a model that includes factors like search time, walking distance, and parking costs. As an agent-based model PARKAGENT has three basic elements (environment, agents and rules). The environment in PARKAGENT consists of several geographical layers (road network, parking places and buildings) of the city under investigation. PARKAGENT is capable to represent driver's parking behavior in a real-life city.

Rules of agent behavior

PARKAGENT model works on a set of rules that the agent follows while searching for a suitable parking space. The behavioral rules underlying PARKAGENT model are stated below (Benenson et al, 2008):

1. Driving towards the destination, estimating the parking supply.
2. Parking search and choice before reaching the destination and after the destination is missed.
3. Staying at the found parking place.
4. Leaving the parking place and driving out of the system.

An agent enters the system at distance $D_{awareness}$ from destination. Then it drives towards the destination, meanwhile estimating the parking supply and deciding in each time step if to park or to continue driving. Reaching a particular junction the agent, chooses the street segment that takes it to the junction closest to destination. The agent takes the shortest path between the current location and the destination. This route selection employs shortest path algorithm (Benenson et al, 2008). The agent begins searching for parking place at a distance $D_{parking}$. After finding a parking place the agent stays there for certain time and disappears from the system. The parking range and duration are defined at the beginning of the simulation. Drivers' route choice is based on shortest path algorithm. The agent's decision to find a free parking space and park the car, is calculated by equation (1) and (2). Figure 2.7 shows the agents' parking decisions based on expected free parking spaces.

$$P_{free} = \frac{N_{free}}{N_{free} + N_{occu}} \tag{1}$$

$$F_{\exp} = P_{free} * \frac{\text{Distance to destination}}{\text{Lenght of Parking place}} \tag{2}$$

Where,
P_{free} = Probability of selecting free parking space
N_{free} = Number of free parking spaces
N_{occu} = Number of occupied parking spaces
F_{exp} = Expected number of free parking places

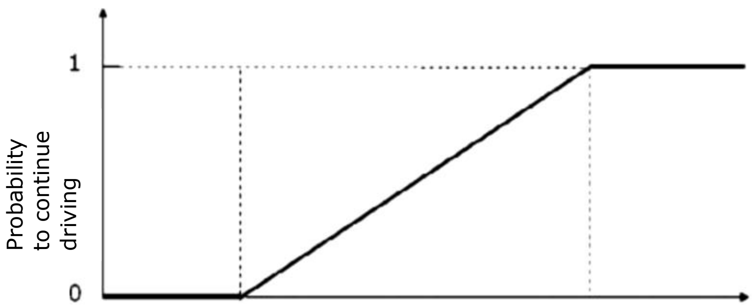

Figure 2.7. Car Drivers' Parking decision (Martens et al., 2010)

Expected number of free parking places F_{exp}

When the expected number of parking places is 1 or less than one, the car driver will always park at the first vacant parking place. For values in between 1 and 3 (or greater than 3) the driver continues to drive. The probability P(D) defines the chance that the car driver keeps on driving as shown in equation (3). The parking behavior of agents in PARKAGENT is shown in Figure 2.8.

$$P(D) = \frac{F_{\exp} - F_1}{F_2 + F_1} \qquad (3)$$

F_{exp} =1 (parks)
F_{exp} =3 (continue driving)
If the agent is not able to find a parking space on-street within the defined search time it disappears from the system. The agent can only search for an on-street parking space along the shortest path route which is fixed arbitrarily at the beginning of the simulation. Figure 2.8 shows the algorithm of PARKAGENT.

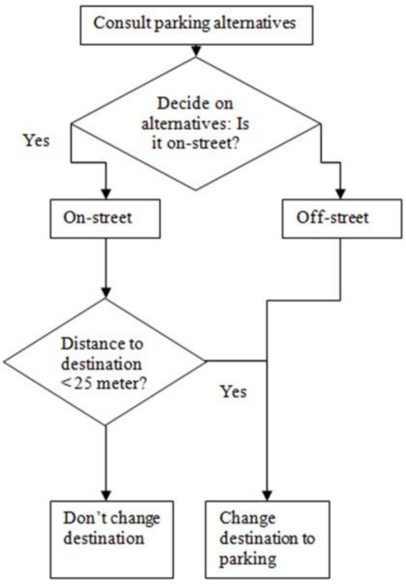

Figure 2.8. PARKAGENT, (Benenson et al., 2008)

Although PARKAGENT provides an overview of parking phenomena as the driving rules succeed to represent parking search mathematically. At the same time these rules are deficient to exhibit the actual parking choice behavior of agents, as it is assumed that individuals make choices rationally. To represent a realistic parking choice behavior of car drivers, use of discrete choice approach is indispensable. According to (Train, 2003), 'Discrete choice models can be used to understand and represent the behavioral process that leads to individual's decisions'.

Environmental factors and personal needs might also affect individual decisions (Khaliq et al, 2017).

2.3.3.2. SUSTAPARK

SUSTAPARK is a spatiotemporal tool to model parking search behavior. It consists of agents (car drivers), network, locations (origin and destination of trips) and parking places. Cellular automaton approach is used to spatially locate the agents on the network. Each agent in the system has its own activity schedule and search strategy. These activity schedules are obtain from travel survey data and are used to define the position of agent at a specific point in time. Each agent moves on the network and interacts with other agents in the traffic to perform different activities at different locations. The activity schedules are used to determine the shortest path from origin and destination that help to identify the parking search behavior. The agent follows a set of rules, which include agents entering the system, driving toward their destination, searching for parking, select a parking space and stay at the found parking place, and then leaving the parking place and the system. The basic purpose of this model is to simulate parking search behavior in detail keeping in view the characteristics of agents, their trip destinations and activity pattern.
The decision where to park is based on specific parameters such as access time, search time, egress time, expected parking fee available parking places, price, distance and search time (represented by equations 4, 5, 6 and 7). The model considers four alternatives on-street parking (free), on-street parking (paid), off-street parking in a parking lot, off-street parking in a garage. The free on-street alternative is the reference level and therefore has no dummy.

$$U_{on-street(free)} = \exp(\beta_0 + \beta_1.At + \beta_2.St + \beta_3.Et + \beta_4.Fee) \quad (4)$$
$$U_{on-street(paid)} = exp(\beta_0 + \beta_1.At + \beta_2.St + \beta_3.Et + \beta_4.Fee + I_{on-street\ (paid)} \quad (5)$$
$$U_{off-street(lots)} = \exp(\beta_0 + \beta_1.At + \beta_2.St + \beta_3.Et + \beta_4.Fee + I_{off-street\ (lot)}) \quad (6)$$
$$U_{off-street(garage)} = \exp(\beta_0 + \beta_1.At + \beta_2.St + \beta\ _3.Et + \beta_4.Fee + I_{off-street\ (garage)}) \quad (7)$$

Where,
U = Utility of alternative
β_0= Constant
At = Access time
St = Search time
Et = Egress time
Fee = Parking fee

The model loads spatial data such as roads and parking places (parking lots, private parking, and on-street parking) in the form of GIS files. The model also considers non-spatial data to determine parking choices such as stated choice data from the study of (Hess and Polak, 2005). The traffic flows on the network is done using a traffic simulator. Figure 2.9 shows the parking-decision strategy. The driver parks if the utility of a parking place is greater than a threshold.

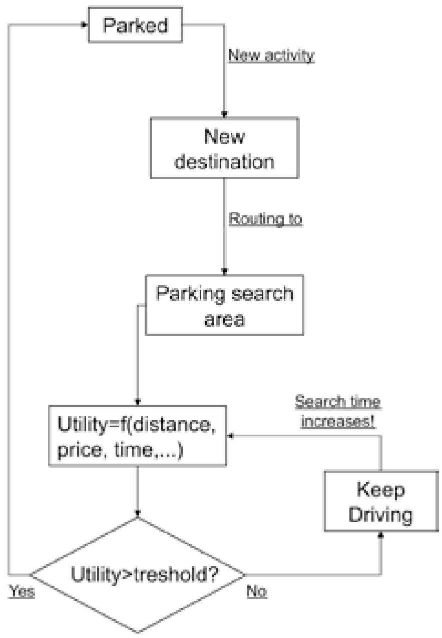

Figure 2.9. SUSTAPARK (Dieussaert et al, 2009)

The output obtain from the simulation of agents on the network consists of statistics such as time series, parking occupancy per street, parking zone bottlenecks, (average) parking search time per agent. These statistics can be combined with spatial network to produce maps.

2.3.3.3. Matsim based Parking search model (Waraich et al, 2012)

(Waraich et al, 2012) proposed an agent based parking choice model. The model runs on Matsim traffic simulation. It includes simulation of parking choice and parking occupancy. It uses daily activity schedules, along with street network and building facilities. The parking choice behavior of car drivers is modelled using several parking search strategies (i.e. simulation, scoring and re-planning). These parking strategies are actually the set of rules that an agent follows while approaching the activity location such as driving directly to a private parking, reserved parking, off-street parking, searching for parking on-street parking or first searching on-street and then going to a garage parking. These parking strategies also take into account individual characteristics of agents (such as disability of a person) that may influence their utility evaluation. All these parking strategies are executed in sequence. For each destination, an agent has a parking search strategy available; a search strategy is selected randomly at the beginning of simulation. The score of strategy is calculated at the end of iteration and is forwarded to MATsim simulation for feedback (i.e. identifying overall effect of parking strategy on traffic simulation). The strategy for next iteration is selected to be executed in the next iteration. MATsim simulation process optimizes the plans of each agent by scoring (i.e. assigning a utility by micro simulation resulting in traffic flow causing traffic congestion) and re-planning (i.e. maximizing the utility of its daily plan by changing routes, working time, travel mode, or location choice). Plans with higher score have more chance of reselection.

The parking choice algorithm applied in this model is presented in Figure 2.10. The algorithm depicts parking choice decision for a given destination. The algorithm loads all the parking spaces located near a destination. This set of parking spaces contains all the occupied and unoccupied ones. The algorithm performs a filtering process by removing all the occupied parking spaces, parking spaces not preferred by the agent and all other spaces for which the agent is not eligible (e.g. reserved parking or private parking). In case the set of parking spaces gets empty after filtering process, the algorithm collects a larger set of parking spaces by extending the distance from the destination. A utility score is calculated for each parking space according to a utility function as described in (Equation 8) and the parking space with the highest utility score is assigned to the agent. After selecting a parking space, the utility score of parking choice is also added to the overall utility score of agent in MATsim (represented by equation 9). After this assignment, the parking space is marked as occupied by the agent and is no longer available for other agents.

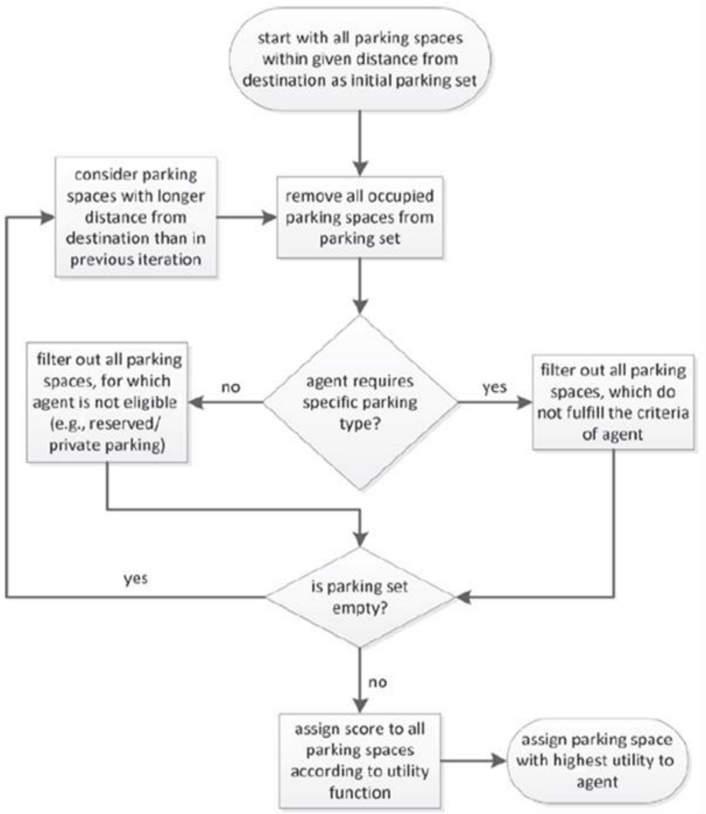

Figure 2.10. Parking choice algorithm (Waraich et al, 2012)

The model makes decisions on two levels. On the first level the decision is based on the parking supply (parking occupancy, reserved/private parking available and agent's preferences). On the second level the choice of space is based on the individual valuation of an agent with respect to parking space characteristics such as price and walking distances which are considered for calculating utility function (meaning parking choice is done in two steps, at first the agent makes a decision about its own preferences and later analyses the space with respect to parking space characteristics i.e. price and distance).
Equation 8 shows the parking choice decision of an agent *i*. The cost component can also include agent's beta (which depends on an agent's personal characteristics and other information such as activity duration etc.), parking fine and illegal parking.

$$U_{parking,i} = U_{Pcost,i} + U_{PsearchTime,i} + U_{Pwalk,i} + \in_i \tag{8}$$

Where,
$U_{parking,i}$ = Decision to park
$U_{Pcost,i}$ = Parking decision associated with parking cost
$U_{PsearchTime,i}$ = Parking decision associated with search time
$U_{Pwalk,i}$ = Parking decision associated with walking distance

The parking utility is then added to the overall utility function in Matsim shown in equation 9.

$$U_{plan\,,i} = \sum U_{travel\ time,i} + U_{Travel\ cost,i} + U_{perform\ activity,i} + .. + \sum U_{parking,i} \tag{9}$$

The proposed parking search model is the first optimal parking choice model because it is using utility maximization theory which can influence mode choice and long term decisions of agents on local parking conditions. This model is also capable to account for influence of parking shortages on mode choice and location choice. Previous models deliver too high search times which can be avoided using the algorithm that evaluates all parking strategies separately several times over the iterations (Waraich et al, 2013). However the model does have a drawback, is that it only contains parking choice not search, meaning parking occupation is simulated based on the fact that the driver has perfect knowledge of the environment of destination and no parking search is performed.

2.3.3.4. SimPark

SimPark is an agent-based micro-simulator (Vuurstaek et al, 2018). The goal of this model is to simulate effects of parking policies on traffic flow and personal schedules. The model does not take into account individuals' parking strategies. Cars are parked either on-street or in a privately owned garage. All these parking facilities have their own set of rules, SimPark includes rules and polices of all the parking facilities which makes it an excellent tool for policy makers.

The model requires input data such as schedules, network, vehicles, parking facilities and parking regulations. The schedules describing the activities and trips of individuals are predicted by FEATHERS (Vuurstaek et al, 2018). The model also supports a wide variety of vehicle specifications because parking places have different sizes or reservations for specific types of vehicles. This is done with the help of MATSim as it provides the ability to specify vehicle attributes such as width, length, engine fuel type and capacity.

The movement of people throughout the network is an important component of agent based simulation. For this purpose, network is obtain from OpenStreetMap (OSM). The evaluation of parking policies related to parking infrastructure can be done in several models. SimPark allows for more detailed and elaborated parking simulations than existing models such as specifying fixed hourly rates. The model is still under development and is not operational yet. The next steps include the development of accurate parking strategies that capture the parking choice behavior of people. Once these strategies are present, simulations can be conducted and policies can be investigated.

2.4. Conclusions and Discussion

This chapter provides an overview of parking choice related studies. Different categories of parking models that have been developed so far are highlighted in this chapter along with their purpose of development and working. Three main types of parking models (discrete choice models, network based models and agent based models) have been discussed in detail along with their corresponding examples. All these models are more or less capable of representing the parking search process of car drivers including the decision making process leading to the choice to park. However, the phenomenon of parking choices is based on limited behavioral principles (i.e. the process of car driver's parking choice decision is inadequate, as it should be based on their assessment of the available alternatives). To evaluate parking measures in detail, a more comprehensive model for predicting car drivers' on-street parking decisions is required.

The aim of this chapter is to highlight factors related to parking choice mentioned in different studies in order to obtain a complete overview of parking literature and to identify the gaps in the past research studies. It can be noticed that several studies have employed stated preference methods along with discrete choice models for analyzing the driver's behavior with respect to certain factors such as cost, walking distance to destination and search time. Irrespective of parking type, parking duration, etc. parking cost and distance to destination are considered as the most important factors considered by car drivers while choosing a parking space. Most of these factors are of significant importance in the context of parking policy making and design of parking facilities. It can be noticed that most of the studies collected car drivers' parking preferences using stated choice or revealed choice approach. The use of stated choice approach for investigating on-street parking preferences of car drivers' is limited. Large number of studies used Mixed logit and Multinomial logit models to statistically prove the significance of selected factors. A through study of literature reveals that most of the studies have evaluated parking choice keeping in view work and shopping activity, as these two activities contribute to parking issues (such as search traffic) in congested inner city areas.

In a nutshell, it can be observed that on-street parking choice of car drivers needs significant attention, because people find it convenient to park on-street rather parking off-street (Marshall, 2014). Providing this overview was necessary to bring in attention that work related parking choices of car drivers has been considered important but the decisions of car drivers with respect to parking and road conditions is not well detailed. Also the mental process of parking choice behavior (i.e. how a car driver evaluates a particular road situation while driving in order to select the optimal parking place) has not been explored in the literature. Therefore, it is suggested to design a research strategy in order to collect car drivers' preferences regarding on-street parking and identify which of the factors related to parking and road trigger car drivers' parking choices. (This strategy is detailed in the next chapter).

Understanding how people make parking decisions is crucial for smart parking management. It provides two way benefits; provision of parking facilities that meet drivers' needs and meeting the goals of mobility management by providing safety, accessibility and livability in cities. It can be suggested that future research should focus more on on-street parking to devise smart solutions for better parking management.

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3. Investigation of On-Street Parking Decisions

This chapter is based on a paper titled as 'Modelling car drivers' on-street Parking preferences using hierarchical Information Integration'. The investigation of car drivers' parking decisions using a stated choice experiment, based on the method of integrated hierarchical information integration has been detailed in different sections of this chapter.

3.1. Abstract

Rising issues in urbanization and transportation urge municipalities to optimize the use of on-street parking spaces in order to meet local needs and complement the role of available off-street parking. In this chapter car drivers' on-street parking decisions have been investigated using a stated choice experiment, based on the method of integrated hierarchical information integration (HII). According to this approach, a large set of parking related attributes and attribute levels are grouped into two higher order decision constructs, which are presented as hypothetical street segments. The respondents were asked if they would park their car in the street segment with the listed attributes. The collected data is used to estimate the parameters of a standard multinomial logit model. This study differs from previous studies as a large range of attributes is examined, including the parking situation and the road conditions in a street segment along with some features of off-street parking facilities present in the vicinity of the street segment. The results indicate that the contextual variables such as 'walking distance to destination' and 'parking cost' are key attributes that the car drivers consider while making on-street parking decisions, while street level attributes such as 'occupancy', 'security' and 'surrounding activities' seem to have only a minor impact. The study contributes scientifically by employing HII technique for investigating parking choices while practically the study contributes to the existing body of literature by showing the influence of parking and road conditions on car drivers parking decisions. The study concludes with an outlook of how these insights into car drivers' parking choice process can be used by local authorities to reduce cruising in urban areas. Moreover, these findings can be integrated in multi-agent systems to investigate car drivers' movements in urban areas.

3.2. Introduction

Local area parking management policies affect the amount and location of parking supply, the access to parking spaces, and the parking tariffs (McShane and Meyer, 1982). Parking spaces are increasingly becoming a premeditated commodity and an over-consumed public good in urban areas (Broaddus, 2009). The challenge of managing parking spaces in the urban areas of a multi-modal transportation system is a critical issue for transport analysts and urban planners. The use of the urban road network for parking purposes is a very convenient mean for parking supply. With a variety of planning measures, local governments are trying to optimize the use of the urban road network for extending the parking supply in their cities. These measures are also used to manage on-street parking, as it affects the traffic situation of the city directly. In addition to this, dealing with underutilization of off-street parking facilities due to high levels of cruising for cheap on-street parking is a big challenge for local authorities concerning parking management in metropolitan cities (Shoup, 2006; Martens et al, 2010). To achieve these goals, the factors that influence car drivers' on-street parking choice behavior need to be identified. The relationship between parking supply and demand has been investigated in the existing literature using different approaches such as (Arnott and Rowse, 1999; Eldin and Ismail, 1981; Thompson and Richardson ,1998; Leephakpreeda, 2007 ; Benenson, et al, 2008; Waraich and Axhausen, 2012 (Arnott and Rowse, 1999; Eldin and Ismail, 1981; Thompson and Richardson ,1998; Leephakpreeda, 2007; Benenson, et al, 2008; Waraich and Axhausen, 2012; Gallo, 2011; Guo, 2013). In behavioral research significant attention has been paid to car driver's parking choice behavior, as parking choice has a high impact on travel behavior of individuals (such as mode choice and route choice). It is considered crucial for parking management, which is an element of broader transport demand management strategy. Awareness of parking choice process enables implementation of measures to address issues created by car drivers' cruising for parking (Brooke, 2014). In the past, several studies of car drivers' preferences regarding parking in the urban transport system have been presented. The decision whether or not to choose on-street parking is quite complex. However, the collection of data to infer the decision making process of car drivers is a challenge. Several previous studies have used the stated choice approach for identifying parking related attributes to both on-street and off-street parking facilities. These studies include (Axhausen and Polak, 1991; van der Waerden and Oppewal, 1995; MuConsult, 1997; Hensher, and King, 2001; Bonsall and Palmer, 2004; Hess and Polak, 2004; Hess and Polak, 2009; Golias et al, 2002; van der Waerden et al, 2006; van der Waerden et al, 1993).

Similar to off-street parking, there are several factors that influence car drivers' on street parking choice decisions. Only a few studies investigated on-street parking decisions of car drivers using stated choice approach; (Borgers et al, 2010 and Clinch and Kelly, 2006). The major focus of the above mentioned studies was to investigate a limited set of factors related to the parking context as the traditional stated choice experiments can handle only a limited number of attributes. Therefore, the integrated hierarchical information integration (HII) approach has been employed to investigate the effect of a larger set of parking and street related attributes on parking decisions. This large set of parking related attributes enhances the possibilities for the local authorities to design parking policies efficient enough to cater the problems related to on-street parking such as illegal parking and double parking (Chaniotakis and Pel, 2015).

This chapter presents an on-street parking choice analysis designed using integrated hierarchical information integration method proposed by Louviere (Arnott, 2006). In this approach, it is assumed that people make complex decisions by cognitively grouping decision attributes into rational subsets. These subsets of attributes can be categorized into decision constructs. The decision constructs depict descriptive summary labels for coherent sets of attributes that define alternatives in the study. In principle, each decision construct is evaluated separately. For the current study, the evaluations of each decision construct are integrated in a single choice model. The integrated choice model estimated from concatenated sub-experiments can be used to predict the utility of alternatives.

Thus, the overall preference or choice is determined by integrating the evaluations of each decision construct. In this way, the respondents use the high order decision constructs to simplify the evaluation of multi-attribute alternatives. The main advantage of this analysis is that participants are forced to make trade-offs in their decisions i.e. respondents are forced to make inferences about omitted attribute levels to analyze whether any attribute level would lead to rejection of an alternative. Therefore, it enables the researcher to model the human decision-making process in a realistic manner. Hierarchical information integration has also been applied to other disciplines, such as telecommunications (Louviere, 1984), out-door recreation (Louviere and Timmermans, 1990), residential choice (Molin, 1990; Molin et al, 2003), health-care (van Helvoort-Postulart et al, 2009) and freight mode choice (Norojono and Young, 2003). In the field of transportation, this approach has been applied for mode choice modelling in public transport (Richter and Keuchel, 2012) and choice of park-and-ride facilities (Bos et al, 2003) (this study focused to evaluate the attractiveness of parking and ride facilities, the major difference in this study and current study is that the respondents are asked to evaluate a parking facility before they start their trip not while driving. Moreover, the experiment also consisted of contextual variables such as weather, luggage, time of the day etc.). To the best of our knowledge, this is the first application of HII to model car drivers' on-street parking choice behavior. The practical implication of this approach is that a large number of attributes related to street parking can be used by the city managers to reduce parking search traffic by identifying preferable on-street parking conditions and stimulate use of off-street (details on selection of this approach are provided in discussion section). This increased knowledge of factors influencing car drivers' parking decisions can enhance urban parking policy applications with associated environmental and economic benefits (Axhausen and Polak, 1991). However, the current study aims to detail the process of car drivers' parking decisions in multi-agent systems (such as Martens et al, 2010) to make them more sophisticated as it is a difficult to predict drivers' parking choices. To achieve the stated goal, the remainder of this paper is organized as follows. First, attention is paid to previous parking studies that include parking related attributes. Next, the adopted research approach is outlined. This section is followed by a brief description of the data collection and sample composition. The analyses are described in the subsequent section. The paper ends with the conclusions and suggestions for future research.

3.3. Related studies

Individuals' parking choice decisions are complex and multi-faceted. Therefore, the process of selecting a parking space has been studied through several decades using different choice modelling approaches. Numerous studies have been conducted to analyze off-street parking choice behavior. These studies highlight the most important factors that influence car drivers' parking decisions (parking costs, parking type, search time, parking duration, trip purpose, walking distance to destination, etc.). Stated choice experiments have been used in several parking choice studies to highlight the significant attributes/factors that influence off-street parking choice behavior of car drivers. (Axhausen and Polak, 1991) used stated choice approach and identified the significance of access time, search time, egress time, parking fee, expected illegal parking fine using multinomial logit model. (van der Waerden and Oppewal, 1995) used stated choice technique to identify car drivers' parking preferences with respect to off-street parking and found that parking cost and walking distance are the most significant attributes in the context of shopping trips. (MuConsult, 1997) investigated the relationship between walking distance and willingness to pay for parking using stated choice approach. (Hensher and King, 2001) investigated factors related to off-street parking such as hours of operation, a tariff schedule, and access time to the final destination using stated choice approach. (Bonsall and Palmer, 2004) investigated factors such as parking fee, walking time, number of spaces, number of car parks passed, last car park used, income, and gender using stated choice approach in the context of business and shopping trips. (Hess and Polak, 2004) used stated choice approach to determine car drivers' parking choice in the context of work and shopping trips. The factors included in this study were access time, search time, egress time, parking fee, and expected fine illegal parking. (Golias et al, 2002) identified that most of time related factors such as search time for a parking space, duration of parking and walking time from the parking space to the final destination have a significant impact on parking choice. (van der Waerden et al, 2006) investigated attitudes and preferences of car drivers' with respect to a set of possible parking measures.

A limited number of studies focused on car drivers' on-street parking choice decisions. (Clinch and Kelly, 2006) used stated choice to identify car drivers' parking preferences in the context of on-street parking. The factors studied include walking distance between parking and home, visibility of the car, motorized traffic in residential street, and security. A similar approach was adopted by (Chaniotakis and Pel, 2015). They designed a stated choice experiment to examine the significance of factors such as parking type, walking distance to destination, travel time, parking fee related to on-street parking decision of car drivers. Findings of all these studies show that major factors affecting choice of a parking space are parking cost and walking distance to destination, but all of these studies focused to investigate a limited number of attributes related to parking space rather than attributes related to the parking situation and road conditions of street such as speed limit, surrounding activities and available parking spaces, etc. This is important because a limited set of attributes provide limited possibilities for urban planners to devise effective policy measures, therefore a large set of parking related attributes are required to widen the range of parking policies. This lack of insights resulted in the present study.

3.4. Research design

The methodology adopted for this research can be explained as follows. First, the relevant attributes and attribute levels were identified related to a regular street segment. The selection of attributes was done through rigorous effort. Initially, a long list (containing twenty-five attributes) of attributes related to on-street parking was prepared based on an extensive literature review. In order to reduce respondents' burden, it was decided to reduce the number of identified attributes to fifteen. The identified attributes were then grouped into two separate decision constructs (categories) i.e. parking situation and road conditions. The attribute levels were defined keeping in view the literature and common practice in Belgium. The overview of attributes, attribute levels and constructs is presented in Figure 3.1. (The Figure 3.1 is explained in the text below).

Attributes	Attribute Levels	
(On-street) Parking cost	Free 1 euro/ hour 2 euro/ hour	On-street parking related attributes
Distance between parking location and destination	100m 200m 300m	
Expected Parking duration	Less than 60 min 60-120 min More than 120 min	
Payment options	Cash, Cash & Bankcard Cash, Bankcard, Smartphone	
Number of streets already visited	No streets 1 street 2 or more streets	
Distance to off-street parking place	100m 200m 300m	Off-street parking related attributes
Off-street parking tariff	0.5 euro/hour 1.5 euro/hour 2.5 euro/hour	
Average available parking spaces per 100 meter	10 spaces/100 m 15 spaces/100 m 20 spaces/100 m	Attributes presenting detailed **Construct 1**: Road conditions
Surrounding activities	House Shopping Playground/school	
Speed limit	20kmph 40kmph 60kmph	
Occupancy rate	Low, occupancy, 50% Medium occupancy,75% High occupancy, 100%	Attributes presenting detailed **Construct 2**: Parking situation
Available security	Nothing CCTV camera Guards	
Maximum parking duration	2 hours 4 hours Unlimited	
Road conditions (Level of convenience)	High Medium Low	High-order description of decision constructs (Global attributes)
Parking situation (Level of convenience)	High Medium Low	

Figure 3.1. Constructs, attributes and attribute levels

Different experimental designs were developed for each construct such that each design included a detailed description of one decision construct while the other decision construct is added to the design as a ‘global attribute’. This process makes each choice task quite detailed, consisting of eleven attributes in total; seven general parking related attributes, three attributes of detailed construct, and one global attribute (high-order description of decision construct treated as additional attribute, replacing three detailed attributes). Figure 3.1. shows the attributes, attribute levels and constructs used in the design of experiment. The first five attributes are related to on-street parking in general, and include on-street parking costs, walking distance between parking location and final destination, expected parking duration (the length of time expected by the driver to park the car), modes of payment available for paying on-street parking costs, and the number of streets visited by the driver before entering the street segment. The other two attributes are related to the closest off-street parking facility: off-street parking tariffs and walking distance between off-street parking facility and final destination. The decision construct ‘road conditions’ includes attributes that explain in more detail the condition of the street segment in terms of average number of parking spaces available in the street segment, surrounding activities indicating the type of land-use present in the street segment, and the allowed speed limit in the street segment. The decision construct ‘parking situation’ includes the attributes occupancy rate, presence of security features (i.e. CCTV cameras and guards), and the maximum parking duration allowed in the street segment. The global attribute was listed as ‘level of convenience’ represented by three levels (high, medium and low). These levels depict the convenience (ease) of parking in the street segment. Level of convenience explains the contribution of decision construct in overall judgement of given situation (i.e. the respondent has to consider if level of convenience provided by favorable road conditions affect parking decisions significantly or not). For example, in the construct ‘parking situation' a 'high convenience' means that the parking situation is very favorable for parking meaning that the street segment has a low occupancy rate, with multiple payment options. A level 'low convenience' indicates that the street segment is not favorable for parking referring to limited parking duration allowance or high occupancy rate. A similar reasoning is valid for the other decision construct. The basic logic to list the global attributes as decision variables is to assess if ‘road conditions’ or ‘parking situation’ as a whole affect parking decisions. Some studies in the literature include similar approach (van Helvoort-Postulart et al, 2009; Norojono and Young, 2003). The combinations of attribute levels and decision construct levels are presented as choice profiles (tasks) to the respondents. The responses obtained from the experiment are analyzed using multinomial logit regression analysis. Furthermore, the parameters of all attributes are estimated simultaneously.

3.4.1. Questionnaire design

An online questionnaire was designed for collecting the stated choice data. The questionnaire consisted of three parts and was constructed using an online system developed by the Eindhoven University of Technology (Figure 3.2). Two screening questions were asked at the beginning of the questionnaire, to select respondents who owned one or more cars and had some experience with on-street parking in urban areas. The first section of the questionnaire was related to car drivers’ experiences with on-street parking. This section included questions regarding on-street parking issues faced by the respondents, search time, parking purpose, parking frequency, walking time between parking place and final destination, parking information sources, preference for on-street and off-street parking, and which street they find most difficult to park at. The second section consists of the hypothetical choice situations. At the beginning of each section a detailed explanation was provided to prepare the respondents regarding the forthcoming questions. The context of parking decision was mentioned in the explanation of section 2. The respondents were asked to assume that they are driving from their home to a destination (generic) located in the inner city, while driving they enter a street segment to search for a suitable parking space (Figure 3.3).

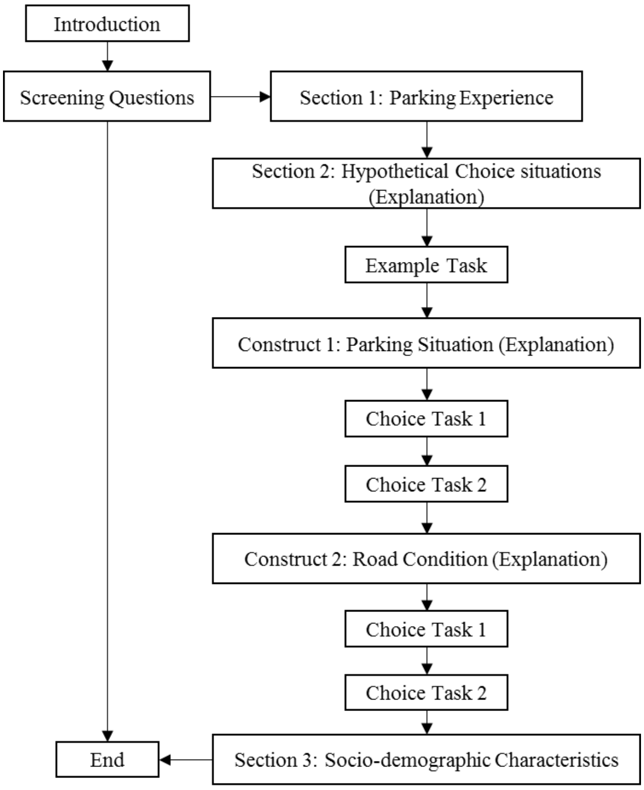
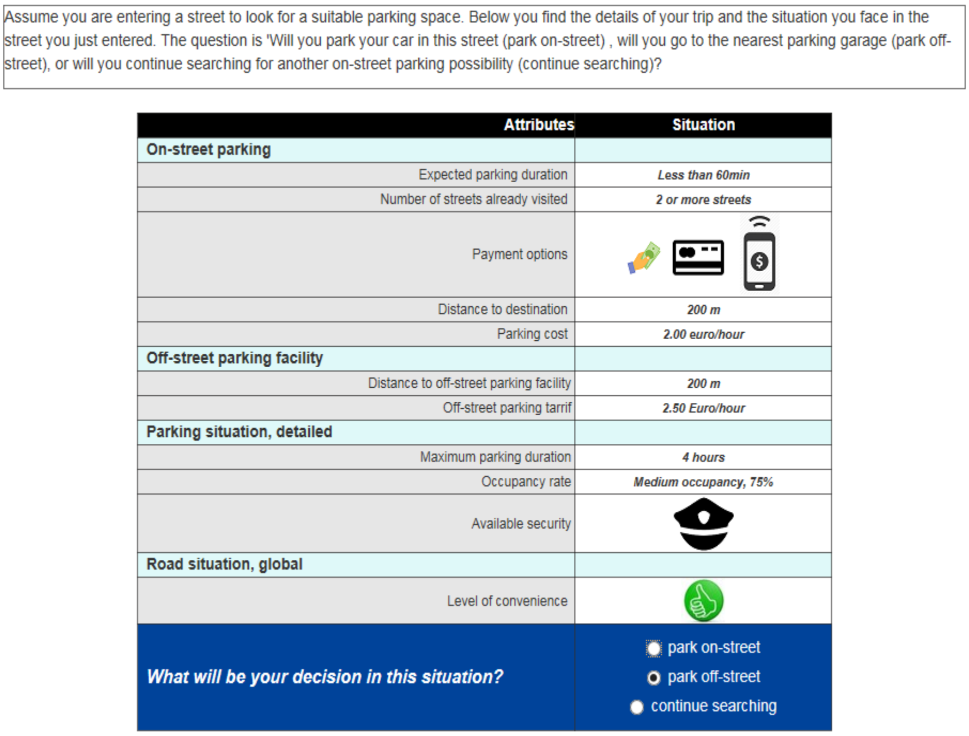


Figure 3.2. Questionnaire structure and routing

The choice tasks were designed using a 3^{11} fractional factorial design. Only main effects were considered in this experiment to limit the number of generated hypothetical profiles. In total, twenty-seven efficient profiles were prepared using SAS %Mktex macros (%Mktex macros are used to create efficient factorial designs in SAS) (Kuhfeld, 2013). These profiles show a well-balanced subtraction from the full factorial design. The choice task consisted of the presented on-street parking context attributes, a detailed description of one decision construct, and a global attribute representing other decision construct. Per construct two choice tasks were presented to each respondent, this makes a total of four choice tasks per respondent. The details of the hypothetical choice situation are presented in the form of choice tasks (profile consisting attributes and corresponding attribute levels). For making the choice task more understandable for the respondents (He and Gao, 2015), it was decided to include some pictures and colored symbols in the task. The basic aim of adding pictures/symbols was to reduce the complexity of the task for the respondents. Before presenting the choice tasks to the respondents, a detailed explanation of attributes, attribute levels, and constructs along with the pictures used in the choice tasks (Figure 3.3) was included in the questionnaire. A hypothetical scenario is described at the beginning of the experiment. A small description regarding the context in which the parking decision has to be made, is provided in the explanation section of the questionnaire. In the explanation section, it is mentioned that the focus of this research is on short term trips to an inner city (city center) without considering any time pressure. At the end of the task the respondent has to indicate her/his decision: park on-street in the presented street segment (parking on-street), go to the nearest off-street parking facility (park off-street), or continue searching for another on-street parking possibility (continue searching). The last section of the questionnaire was related to personal characteristics (age, income, gender, education) of the respondents.



Assume you are entering a street to look for a suitable parking space. Below you find the details of your trip and the situation you face in the street you just entered. The question is 'Will you park your car in this street (park on-street) , will you go to the nearest parking garage (park off-street), or will you continue searching for another on-street parking possibility (continue searching)?

Attributes	Situation
On-street parking	
Expected parking duration	*Less than 60min*
Number of streets already visited	*2 or more streets*
Payment options	
Distance to destination	*200 m*
Parking cost	*2.00 euro/hour*
Off-street parking facility	
Distance to off-street parking facility	*200 m*
Off-street parking tarrif	*2.50 Euro/hour*
Parking situation, detailed	
Maximum parking duration	*4 hours*
Occupancy rate	*Medium occupancy, 75%*
Available security	
Road situation, global	
Level of convenience	
What will be your decision in this situation?	park on-street park off-street continue searching

Figure 3.3. Example of presented choice task

3.4.2. Model specification

The car drivers' choices are analyzed using the standard Multinomial Logit (MNL) model. Traditionally, the 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 below e.g. (Hensher and Johnson, 1981).

$$P_{qi} = \frac{e^{\mu V_{qi}}}{\sum_{j}^{J} e^{\mu V_{qj}}} \qquad (10)$$

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 10);
μ is a scale parameter, usually assumed to be equal to 1.0.

$$V_{qi} = \sum_{k} \beta_k \cdot X_{qik} \qquad (11)$$

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 model parameters are estimated using NLOGIT version 5. The choices of car drivers' (park on-street, park off-street, and continue searching) are used as dependent attribute. The alternative 'continue searching' was used as base alternative. In this study, dummy coding is used to represent all effects of the attribute levels. Therefore, part-worth utilities of all base attribute levels is zero.

3.5. Data collection

The data used to estimate the model was collected using members of the marketing panel of PanelClix (www.panelclix.be). The aim of the panel is to create a platform for members, willing to participate in different marketing related studies. In April 2017, Belgian members of the panel were invited to fill out the online questionnaire. In total, 548 respondents completed the questionnaire. The characteristics of the respondents are presented in Table 3.1. Most of respondents in the sample have a medium education level and an income lower than 5,000 euros. The sample characteristics show that the group of respondents is well representative of the reference population (basic descriptive analysis of data is detailed in discussions section).

Table 3.1. Personal characteristics of research sample (N=548)

Characteristics	Level	Frequency	Percentage
Gender	Male	332	61
	Female	216	39
Age	Less than 45 years	261	48
	More than 45	287	52

Education	Medium High	289 259	53 47
Income	Less than 5000 euros More than 5000 euros	285 263	52 48
Total		548	100

3.6. Analysis and Results

Table 3.2 presents the results of the model estimation. The log-likelihood ratio statistic (LRS) was used to test the estimated model against the null-model (a model with all coefficients equal to zero resulting into equal probabilities for all included alternatives). The test of the LRS-value indicates that the estimated model performs significantly better than the null model (Hensher and Greene, 2005). The LRS-value is equal to 999.70 while the critical chi-square value for 62 degrees of freedom is equal to 499.852 at the confidence level of 95 percent. The model has a McFadden's Rho-square value of 0.275 which indicates that the estimated model is well able to predict the observed choices. Only a few attributes are significant at the conventional level (95 percent), such as 'on-street parking cost', 'off-street parking tariff', 'expected parking duration', 'maximum parking duration', 'surrounding activities' and 'speed limit'. The significant parameters are in anticipated direction. This result might indicate that car drivers do not consider 'available security' or 'payment options' while looking for a parking space on-street. The negative signs of the estimated parameters (e.g. in the case of parking cost and occupancy rate), suggest that low cost and less occupancy rate stimulate car drivers to park on-street. Similarly, 'average available parking spaces per 100meter', 'number of streets already visited' and 'off-street parking tariff' have negative signs. Therefore, the probability of considering a street segment for parking on-street increases with more spaces available per 100meters, less number of streets visited and at a higher off-street parking tariff. The model also predicts that the decision to park off-street depends on the 'parking cost' of the off-street parking facility, 'maximum parking duration' and the 'surrounding activities' in the street segment. According to the parameter estimates, if shops are located in the street segment, the maximum parking duration is 2 hours and the off-street parking tariff is low then the probability that a car driver parks off-street increases. Moreover, the global attribute representing decision constructs do not show any influence on car drivers' parking choice. All the significant attributes are presented in bold. In general, it can be concluded that all part-worth utilities are in the anticipated direction, giving face validity to the estimated model.

Table 3.2. Estimated part-worth utilities

Choice	Attributes	Level values	Part-worth utilities	Significance
Park on-street	**On-street parking facility**			
	Intercept		1.2577	**0.000**
	(On-street) Parking cost	Free 1.00 euro/hour* 2.00 euro/hour	0.4047 0** -0.6400	**0.039** **0.001**
	Distance between parking location and destination	100m 200m 300m*	0.1283 0.2594 0	0.488 0.186
	Expected Parking duration	Less than 60 min 60-120 min* More than 120 min	-0.4156 0 -0.1976	**0.033** 0.3275
	Payment options	Cash, Cash and Bankcard, Cash, Bankcard, Smartphone *	0.0237 0.1454 0	0.900 0.447
	Number of streets already visited	No streets 1 street 2 or more streets*	-0.0686 0.1197 0	0.536 0.719
	Off-street parking facility			
	Distance to off-street parking place	100m 200m 300m*	0.0536. 0.1224 0	0.777 0.522
	Off-street parking tariff	0.50 euro/hour 1.50 euro/hour 2.50 euro/hour*	0.0834 -0.0510 0	0.668 0.770
	Road Conditions			
	Average available parking spaces per 100meter	10 spaces/100 m* 15 spaces/100 m 20 spaces/100 m	0 -0.459 0.0054	 0.857 0.983
	Surrounding activities	House Shopping Playground/school*	-0.0426 0.3628 0	0.865 0.163
	Speed limit	20 km/h 40 km/h 60 km/h*	0.5208 0.3825 0	**0.042** 0.123
	Parking situation			
	Occupancy rate	Low, occupancy,50% Medium, occupancy,75%* High occupancy, 100%	0.4080 0 -0.1182	0.102 0.625

	Available security	Nothing CCTV camera* Guards	0.3690 0 0.0019	0.144 0.994
	Maximum parking duration	2 hours 4 hours Unlimited*	-0.0937 0.3496 0	0.175 0.698
	Decision construct levels			
	Level of convenience for parking situation	Low Medium* High	-0.3366 0 0.2948	0.158 0.255
	Level of convenience for road condition	Low Medium* High	-0.2709 0 0.1427	0.265 0.603
Off-street parking facility				
Park off-street	Intercept		0.4177	0.267
	On-street parking cost	Free 1 euro/ hour* 2 euro/ hour	-0.3718 0 -0.0174	**0.071** 0.926
	Distance between parking location and destination	100m 200m 300m*	-0.0916 0.0948 0	0.627 0.633
	Expected Parking duration	Less than 60 min 60-120 min* More than 120 min	-0.5102 0 -0.2991	**0.010** 0.145
	Payment options	Cash Cash and Bankcard Cash, Bankcard, Smartphone*	0.0891 0.0475 0	0.644 0.809
	Number of streets already visited	No streets 1 street 2 or more streets*	-0.1215 0.0471 0	0.532 0.812
	Off-street parking facility			
	Distance to off-street parking place	100m 200m 300m*	0.2407 0.1809 0	0.212 0.357
	Off-street parking tariff	0.5 euro/hour 1.5 euro/hour 2.5 euro/hour*	1.3776 0.7505 0	**0.000** **0.000**
	Road conditions			
	Average available parking spaces per 100meter	10 spaces/100 m* 15 spaces/100 m 20 spaces/100 m	0 0.0109 -0.0475	 0.967 0.857
	Surrounding activities	House Shopping Playground/school*	0.4438 0.5200 0	**0.085** **0.054**
	Speed limit	20km/h 40km/h 60km/h*	0.1672 0.0029 0	0.524 0.991

	Parking situation			
	Occupancy rate	Low, occupancy,50% Medium, occupancy,75%* High occupancy, 100%	0.2207 0 0.1234	0.393 0.615
	Available security	Nothing CCTV camera* Guards	0.1622 0 0.0642	0.532 0.793
	Maximum parking duration	2 hours 4 hours Unlimited*	0.0945 0.4627 0	0.700 **0.079**
	Decision construct levels			
	Level of convenience for parking situation	Low Medium* High	-0.1014 0 0.2604	0.679 0.330
	Level of convenience for road condition	Low Medium* High	0.0938 0 0.1892	0.707 0.507
Goodness-of-fit Log-likelihood of the null model, LL(0) Log-likelihood of the optimal model, LL(B) LRS=-2[LL(0)-LL(B)] McFadden's Rho-Square MNL McFadden's adjusted Rho-Square MNL	 -2416.947 -1917.095 999.704 (df = 62) 0.275 0.264			

* Base attribute level, ** part-worth utilities of dummy base levels

3.7. Conclusions

In this paper, the car drivers' preferences for on-street parking are outlined by applying integrated hierarchical information integration approach (HII). A stated choice experiment was formulated to investigate the influence of various attributes related to both parking situation and road conditions of street segments on car drivers' on-street parking choice decisions. An integrated choice model (both constructs estimated jointly) was estimated to identify the part-worth utilities and significance levels of attributes using standard multinomial logit model (MNL). A large set of insignificant attributes show that respondents are focusing on a limited set of attributes (the significant ones) while making parking decisions. This means that the insignificant attributes do not actually affect car drivers' parking decisions. It is important to mention the insignificant attributes because the part-worth utilities are necessary to describe the effect of each attribute level on choice. The results of applying the HII method show that if speed limit is decreased (e.g. 20kmph) car drivers' will tend to park on-street rather than cruising for parking. Other attributes (for example, security, payment options, etc.) seem to be less important in respondents' evaluation of road conditions. The results also indicate that besides parking cost, expected parking duration, maximum parking duration, speed limit and also surrounding activities play a considerable part when determining car drivers' parking preferences. The part-worth utilities of the attributes in the choice model show that car drivers' are more willing to park on-street if the expected parking duration is low (e.g. less than 60 minutes). Car drivers' will prefer to park off-street if surrounding activities in the street include shops or residence.

Moreover, this approach highlights preferable on-street parking conditions that can help planners to reduce cruising for parking. A large set of parking related attributes broaden the range of possible parking policies, as parking choice has wide implications for parking and traffic policy. Nowadays, municipalities are employing parking policies that restrict streets for on-street parking and direct car drivers' to other streets or off-street parking facilities. Such policies are inducing search traffic as more time is required by car drivers' to find an optimal parking place and also more time is required to walk from selected parking space to final destination. Therefore, this approach can identify which other measures cities can take to reduce such issues. Moreover, this approach reduces respondents' biasness as a large set of attributes divides respondents' attention to several parking related attributes. It is recommended, to set up more studies where this approach can be employed to produce better results. The results of the study can also be used to develop more sophisticated agent-based parking models.

3.8. Discussion

This chapter provides a detailed strategy for collecting car drivers parking preferences with respect to on-street parking. The goal was to design a choice experiment for investigating car drivers' on-street parking choices using stated choice approach. While designing the choice experiment a large number of attributes were considered that were directly related to on-street parking. After brain storming we reduced the number of attributes to 15 as the most important ones to be considered in the design of choice task. It was decided to keep the number of attributes to 15 but the issue while designing such a task was that traditionally stated choice approach can only handle small number of attributes in order to include all the selected attributes in the task we had to look for alternative ways, therefore after thorough study of the literature we came to know that there exists a technique to handle the large set of attributes in the same choice task using stated choice. The method adopted is known as hierarchical information integration this technique has been used in several other disciplines of telecommunication and medicine etc. for collecting preferences of the target group. Other approaches such as trade-off procedure, the Bridger approach, the pairwise design method, uniform design were discarded because stated choice approach is more comprehensive (it is a controlled method and can include hypothetical situations). A controlled method (presenting different situations to each person) for dealing with large number of attributes and hypothetical situations was required, there is evidence in the literature that hierarchical information integration (HII) has provided useful results when combined with stated choice experiments. Alternative methods include revealed observations, counts and face-to-face questionnaires. According to this approach, the attributes are combined under different constructs and the descriptive label of some major attributes are presented as global attributes that define the overall situation. Thus, the respondents do not focus on few attributes rather they decide about their preference based on the overall presented situation this helps to reduce respondent biasness. The next task was to design the task and how to make it more connected to on-street parking situation. The goal was to present a road situation to the respondent who has to imagine that he is driving in the street going towards his destination having knowledge of the area and on-street parking experience. Hence, it was decided to present the choice task with a brief description of the road situation the respondent is assumed to be driving in. Thus, a combination of ten attributes along with the one condition detailed while the other decision construct presented as global attribute was presented to the respondents. The respondents were also provided with an example task before filling in the actual tasks. Two choice task were presented per construct i.e. each respondent was presented 4 choice tasks in total. The choice tasks were selected randomly but the each profile was presented in almost the same frequency by the Berg system (online questionnaire). The number of profiles was determined using SAS efficient design macros. 27 profiles were extracted using SAS Mktex macros as each attribute has 3 levels making 3^{11} fractional factorial design. These are well balanced profiles. Similarly the sample size was determined using formula given by (Rose and Bliemer, 2013) and is shown in (Equation 12). This formula was used for deciding sample size for stated choice experiments.

$$N \geq 500.\frac{L^{max}}{J.S'} \qquad (12)$$

Where,
L^{max} is the number of levels for any of the attributes
J is the number of alternatives in a choice task
S' number of choice tasks

The total number of filled questionnaire was 548, which is sufficient for the given number of choice tasks (according to equation 12). The company PanelClix was hired to get the desired sample size characteristics**.** The population refers to car drivers who are visiting a city center and are looking for a free parking space. While the sample consisted of Belgian members of 'PanelClix' who had experience with on-street parking in inner city areas. A well balanced sample means that the respondents from all categories of age, income, gender and education fill o the questionnaire. Analysis reveal that around 49 % of the respondents chose to park on-street, 40% choice to park off-street while 11% selected to continue search as overall evaluation of the questionnaire considering all the choice tasks presented.

It can be noticed that the number of male respondents is a bit higher than the number of female respondents this is because of the fact that men are more interested in parking related studies or may be because female respondents did not opt for filling the questionnaire. Similarly, most of the respondents who filled in the questionnaire has a medium education level and belongs to an income group earning less than 5000 euros (originally there are 8 education levels defined in the questionnaire and 5 levels of income but for the sake of simplification we have divided the categories in low and high income level to be used for building separate models in future, these equal sized categories have acceptable number of observations). On average the respondents took 5 minutes to complete the survey (3-8 minutes in general), any questionnaire filled in time less than 3 minutes was not considered in the analyses. In total 674 respondents filled in the questionnaire, 579 filled it in completely while due to some ambiguities based on duration of questionnaires 31 were removed.

After data collection the first step was to conduct descriptive analysis. In the first section of the questionnaire, the respondents were asked questions related to their parking experiences such walking time between parking place and final destination, parking information sources and parking frequency. Around 49% of the analysis reveal that the respondents walked to the final destination for less than 5 minutes, 39% walked from 5–10 minutes while 12% walked for more than 10 minutes. Around 60% of the respondents used mobile applications while 40% used signage for getting parking information. Similarly, 56% reported to park on-street in all week days, 34% parked on-street 2-3 times during a week while 10% reported only once per month. Other information in this section was related to weather and travel group characteristics. The results reveal that in extreme weather conditions such as in hot and rainy weather people prefer to park off-street while during normal weather conditions people prefer to park on-street. The responses from the questionnaire also revealed that people prefer to park on-street when they are alone. These results show parking choices of respondents keeping in view their daily parking experiences (detailed descriptive analysis is placed in Appendix III).

For the first exploration of second section of questionnaire (the hypothetical situations), MNL was considered. Dummy coding was used to code data in NLOGIT software. The results of the model indicate that only a few number of attributes are significant but it should be noticed that all other attributes do have an impact on parking choices even their effect on car drivers' parking choices is minimal. The attributes such as expected parking duration, parking costs, speed limit and surrounding activities turn to be significant, meaning that these road related attributes can be controlled by the municipalities (i.e. parking duration can be fixed for particular hours for reducing the occupancy in s street etc.), or certain parking policies can be formulated using these road related factors to address issues related to on-street parking such as cruising, congestion, fuel wastage etc. An important policy related factor such as speed limit is not highlighted in the literature. The surrounding activities on the road show the effect of land use on parking choices, as discussed in the previous chapters that land use is strongly connected to transport. All these factors highlight the importance of study and its contribution in the existing literature. The study contributes scientifically by employing HII technique for investigating parking choices while practically the study contributes to the existing body of literature by showing the influence of parking and road conditions on car drivers parking decisions.

The internal validation of the model was done using the log likelihood statistics. Since the optimal model performs better than the null model therefore it was claimed that the model results are valid. The basic aim of designing this choice task was to present a situation of a road segment to the driver who is driving in the street and how does he react to the dynamic situation of the street? Do the listed factors trigger them to continue searching? Other implicit models do not present real world situations hence do not provide optimal evaluation of parking policy. The current model presents a real world situation although it does not include real traffic flow simulation still it is presents a unique strategy for depicting car drivers decisions in response to certain road related factors that can be controlled such as occupancy, speed limit and parking duration. Due to the presentation of this real situation i.e. identification of car drivers preferences while driving in street the model can be used in developing multi-agent simulations. A more detailed investigation of the data is required therefore advanced models such as latent class or mixed logit models would be used to explore the choices of car drivers in more detail. The next chapter shows a detailed investigation of the preferences identifying the individual taste differences among respondents to check which attributes affect decisions at individual level.

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4. Detailed Modeling of On-street Parking Decisions

This chapter is based on a paper titled as 'Forecasting Car Drivers' On-Street Parking Choice Decisions while driving in a Downtown Area'. In this chapter, a more detailed model is proposed to investigate cars drivers' on-street parking decisions considering dynamic features of streets.

4.1. Abstract

Several parking choice models have been developed in the past. Most of these models were related to off-street parking choice. Limited attention has been paid to car drivers' on-street parking choice behavior. The outcomes of both types of parking models (either focusing on on-street or off-street) are not well able to predict the parking choice decision process of car drivers' while driving in a downtown area. This paper describes a framework of a behavioral model, sensitive enough to investigate car drivers' parking decisions while driving in a downtown area. The model considers the attributes describing both the parking and road conditions in a road segment. The proposed model assumes that parking choice decisions are mainly based on features associated to parking and road conditions that a car driver faces when entering a street. A stated preference experiment was designed to collect respondents' preferences related to preferred parking facility. A set of hypothetical parking and road conditions was presented in the form of choice tasks. The collected data is analyzed using a mixed multinomial logit model. The results from the model estimation show that almost all the presented attributes such as parking costs, walking distance to destination, maximum parking duration, expected parking duration, speed limit, number of streets visited and surrounding activities play a considerable role when determining car drivers' parking preferences. Moreover, the paper ranks the relative importance of the attributes and presents a model which can raise policy applications by highlighting such parking and road conditions that induce search traffic, resulting in demonstration of how through adjustment of values of these road related parking factors, the number of cruising cars can be reduced.

4.2. Introduction

On-street parking has the highest impact on a city center. It affects parking demand, land use, vehicle speed, road and pedestrian safety, the environment, accessibility, and travel behaviors (Marshall, 2014; Vasconcelos and Farias, 2017). The literature contains empirical evidence that 30% of cars traveling on downtown city streets end up in cruising for parking during a business day (Arnott and Williams, 2017). This is because on-street parking spaces are highly accessible and convenient to several destinations (Litman, 2006). Cruising is considered as a natural behavior of drivers, it is actually their exploration for more affordable and convenient on-street parking (Lee, Agdas, and Baker, 2017).

Although there is little academic research on this subject, it cannot be neglected that on-street parking has the potential to worsen congestion in city center, in terms of traffic accidents, or increase in travel time due to cruising for parking

(Shoup, 2006). Cruising creates a random queue of cars impeding traffic flow (Arnott and Inci, 2010). The traffic induced due to high level of cruising in urban areas is a critical issue for transport analysts and urban planners, as it impedes traffic movement along major routes (Marsden, 2014). Efficient parking management in urban areas can only be achieved by carefully designing the parking policy that not only coincides with overall transport policy goals but also positively affects behavior of car drivers. With parking policy, transport planners aim to regulate traffic flows in congested areas, thus enhancing accessibility and live ability of these areas. Parking policies highly influence urban traffic flows and are able to cause modal shift (Tsamboulas, 2001). Most strategies to mitigate cruising are related to adjustment of on-street parking prices which enhance economic efficiency, demand management and provide an ideal 85% occupancy rate (Arnott and Inci, 2006; Shoup, 2013; Shoup, 2006). Research shows that cruising is not random. It is obvious in large cities that receive more car trips, particularly for shopping and leisure activities. In order to reduce parking search, it is necessary to investigate the underlying factors related to car drivers' on-street parking decisions and analyze their effects. A thorough study of literature indicates that changes in the parking policy changes travel demand, i.e. parking policy directly affect behavior of private car drivers (who travel and at the end park their car at the desired destination) constituting the highest proportion of parking demand. Therefore, the relation between parking policy measures and parking choice needs to be analyzed in more detail.

This paper describes a model proposed to investigate cars drivers' on-street parking decisions considering road conditions. The model is designed to evaluate parking decisions of car drivers' for trips to the city center by considering time pressure and parking pressure. Existing literature focuses on models explaining mainly off-street parking choices of car drivers, but none of the studies aid in investigating car drivers' parking decisions keeping in view the actual parking conditions of road. The model is capable of investigating car drivers' reactions who are facing certain parking and road conditions in a street. The basic aim is to identify preferable street situations that induce search traffic which can later be avoided using relevant parking measures. This means that on-street parking is considered as a tool to achieve convenience and accessibility in the city center.

The current paper contributes to the existing body of research in two ways. Firstly, the model is able to acknowledge relevant parking and road conditions of streets. Secondly, the model can be used to investigate reactions of car drivers when facing certain parking and road conditions in a street while searching for a free parking space. Until now, the existing literature highlights only a limited set of attributes thus parking decisions of car drivers in response to changes in parking policy cannot be predicted. This indicates new findings in contrast to the existing literature. This paper is organized as follows. Section 3 discusses the conceptual background of the study. Section 4 presents the adopted research design. The model output is presented and explained in more detail in section 5. Finally, the conclusions and corresponding recommendations are presented in section 6. The review of related work is as follows.

4.3. Related work

Most of the literature reviewed discusses that 'walking time' and 'parking costs' as the main determinants of the cruising behavior in the context of both on-street and off-street parking (Miller, 1993; van der Waerden and Oppewal, 1995; MuConsult, 1997; Bonsall and Palmer, 2004; Hess and Polak, 2004; Brooke, Ison, and Quddus, 2014; Chaniotakis and Pel, 2015; Pel and Chaniotakis, 2017). It seems that in case of short term trips (e.g. shopping and recreation trips) to city center cruising has a spatial and time component. Cruising time increases with travel duration as well as with parking duration (van Ommeren, 2012). Several other characteristics that significantly affect off-street parking choice include access time, search time, egress time, expected illegal parking fine, parking time restriction, occupancy rate, type of parking, willingness to pay for parking, hours of operation, a tariff schedule, number of spaces, number of car parks passed, last car park used, duration of parking, car availability, travel time, costs for car, costs for transit, income and gender (Axhausen and Polak, 1991; Van Der Goot, 1982; MuConsult, 1997; Hensher and King, 2001; Golias et al, 2001; Miller, 1993; Bonsall and Palmer, 2004). In most of parking choice related studies, the researchers employed stated choice approach for data collection and used discrete choice models (e.g. Binary logit, Nested Logit, Multinomial logit model, Mixed Multinomial Logit) for data analysis i.e. (Lambe, 1996 ; Teknomo and Hokao, 1997; Matsumoto and Rojas, 1998; Van der Waerden, Borgers, and Timmermans, 1998; Van der Waerden, Borgers, and Timmermans, 2000; Tsamboulas, 2001; Coppola, 2002; Harmatuck, 2007; Van der Waerden and Timmermans, 2014). There are several other approaches that have been employed to study car drivers' parking choice behavior such as the possibility theory that has been used to investigate car drivers' parking choice behavior with respect to different parking policies (Dell'Orco, Ottomanelli, and Sassanelli, 2011). Similarly, Probit-User Equilibrium type traffic assignment model has been used to study congested road network and parking supply (Bifulco, 1993).

A thorough study of existing parking literature indicates that the use of stated choice approach to study car drivers' on-street parking choice decisions is limited. Various time related, price related and socio-demographic factors that influence car drivers' on-street parking search such as walking distance between parking and home, parking type, travel time, parking fee visibility of the car, motorized traffic in residential street, vehicle age, and security have been investigated using stated choice approach (Brooke, Ison, and Quddus, 2014; Ibeas, dell' Olio, Bordagaray, and Ortúzar, 2014; Chaniotakis and Pel, 2015; Pel and Chaniotakis, 2017).

Major studies explaining models representing the parking search behavior of car drivers using other approaches such as behavioral modelling framework, traffic assignment or network based simulation models, agent-based parking simulation model include (Eldin and Ismail,1981; Thompson and Richardson, 1998; Arnott and Rowse, 1999; Young and Weng, 2005; Leephakpreeda, 2007; Benenson et al, 2008; Gallo, et al, 2011; Waraich et al, 2012; Steenberghen, Dieussaert, Maerivoet, and Spitaels, 2012; Guo et al, 2013). Studies demonstrating hierarchy of parking models based on their purpose of use such as parking design models, parking search models, parking choice models, parking allocation models and parking interaction models (Young and Taylor, 1991; Young, 2008) also constitute an important part of parking literature. Findings of all these studies show that major factors affecting choice of a parking space are parking cost and walking distance to destination, but all of these studies focused to investigate limited set of attributes related to parking space rather than attributes related to the parking situation and road conditions of street such as speed limit, surrounding activities and security etc. The conceptual background of the problem under investigation has been explained in the section below.

4.4. Conceptual background

For a better understanding of on-street parking choices, it is important to have more insights into the reactions of car drivers who are facing parking and road conditions in a street. In particular, we are interested in identifying the parking and road conditions that people face when driving around looking for suitable parking place. Parking choice is typically modelled as a function of parking spot attributes. In this research, we consider parking attributes such as occupancy rate, parking duration and security along with road attributes such as speed limit and surrounding activities as factors influencing parking decisions. Such an approach clarifies specific parking and road conditions that induce search traffic. The aim is to provide a strong and empirical evidence regarding car drivers' on-street parking decisions so that parking policies can be framed in accordance with car drivers' behavior so that the issue related to cruising for parking can be minimized. In the present study, we try to conceptualize when car drivers are driving towards their destination they continuously enter streets and in each street they look for parking opportunities, keeping in view the existing parking and road conditions. It is assumed that all car drivers have three parking options available: (i) either they will park on-street (in the street they visited currently), (ii) park in a (off-street) garage, or (iii) continue to search for another parking alternative (in an adjacent street). Based on these assumptions prediction of car drivers' on-street parking choices can be conceptualized using the following framework shown in (Figure 4.1). This framework is more detailed in the section of research design.

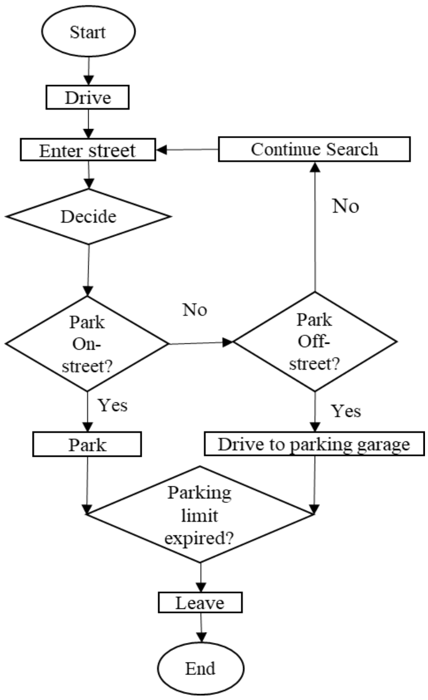

Figure 4.1. Conceptual framework for predicting car drivers' on-street parking choice

4.5. Research design

A stated choice experiment using some basic principles of Hierarchical Information Integration (HII) is designed to investigate car drivers' on-street parking decisions. A major conclusion of the above mentioned studies was that these studies investigated a limited set of attributes related to the parking context as the traditional stated choice experiments can handle only a limited number of attributes. To investigate a larger set of parking and street attributes on car drivers' parking decisions, the integrated HII approach has been employed. According to this approach, it is assumed that people make complex decisions by cognitively grouping decision attributes into rational subsets. These subsets of attributes can be categorized into decision constructs. The decision constructs depict descriptive summary labels for coherent sets of attributes that define alternatives in the study (Khaliq et al, 2018). This approach was proposed by (Louviere, 1984); (Louviere, 1990) and (Molin, Oppewal and Timmermans, 2003).The set of parking and road related attributes enhance the possibilities for local authorities to design various parking policies efficient enough to cater the problems related to on-street parking such as illegal parking and double parking (Arnott, 2006). In an online questionnaire, parking and street conditions are presented and for each conditions the respondents are asked to indicate their choice (park on-street, park in a parking garage, continue search), shown in Figure 4.2 and Figure 4.3. The choice tasks contain attributes related to parking (maximum parking duration, occupancy rate, available security) and road conditions (surrounding activities, speed limit, average parking spaces per 100m).

Assume you are entering a street to look for a suitable parking space. Below you find the details of your trip and the situation you face in the street you just entered. The question is 'Will you park your car in this street (park on-street), will you go to the nearest parking garage (park off-street), or will you continue searching for another on-street parking possibility (continue searching)?

Attributes	Situation
On-street parking	
Expected parking duration	*60-120 min*
Number of streets already visited	*2 or more streets*
Payment options	
Distance to destination	*100 m*
Parking cost	*1.00 euro/hour*
Off-street parking facility	
Distance to off-street parking	*200 m*
Off-street parking tarrif	*1.50 euro/hour*
Road situation, detailed	
Available parking spaces per 100 meter	*20 spaces/100 m*
Surrounding activities	*Playground/school*
Speed limit	*40 mph*
Parking situation, global	
Level of convenience	
What will be your decision in this situation?	park on-street park off-street continue searching

Figure 4.2. Example of choice task explaining road conditions

Assume you are entering a street to look for a suitable parking space. Below you find the details of your trip and the situation you face in the street you just entered. The question is 'Will you park your car in this street (park on-street) , will you go to the nearest parking garage (park off-street), or will you continue searching for another on-street parking possibility (continue searching)?

Attributes	Situation
On-street parking	
Expected parking duration	*Less than 60min*
Number of streets already visited	*2 or more streets*
Payment options	
Distance to destination	*200 m*
Parking cost	*2.00 euro/hour*
Off-street parking facility	
Distance to off-street parking facility	*200 m*
Off-street parking tarrif	*2.50 Euro/hour*
Parking situation, detailed	
Maximum parking duration	*4 hours*
Occupancy rate	*Medium occupancy, 75%*
Available security	
Road situation, global	
Level of convenience	
What will be your decision in this situation?	park on-street park off-street continue searching

Figure 4.3. Example of choice task explaining parking situation (Khaliq et al, 2018)

The designed choice tasks were presented in an online questionnaire. The respondents were asked to assume that they are driving from their home to a destination (generic) located in the inner city. While driving they enter a certain street segment to search for a suitable parking space (shown in Figure 4.1). The choice tasks were designed using a 3^{11} fractional factorial design. The adopted design consisted of 27 profiles considering that only main effects are considered in this experiment (Khaliq et al, 2018). The attribute levels were defined keeping in view the literature and common practice in Belgium. The first five attributes are related to on-street parking in general, and include on-street parking costs, walking distance between parking location and final destination, expected parking duration (the length of time expected by the driver to park the car), modes of payment available for paying on-street parking costs, and the number of streets visited by the driver before entering the street segment. The other two attributes are related to the closest off-street parking facility: off-street parking tariffs and walking distance between off-street parking facility and final destination. The attributes 'Level of parking convenience' and 'Level of road convenience' depict an overall level of parking convenience provided by street segment. Although, time of day is not included in the task, occupancy is included that might be connected to time of day (high occupancy in peak hours, low in off-peak hours). In addition, parking duration is also included as a replacement for time limit in the task. Attributes such as expected parking duration and maximum parking duration depict parking pressure (urge to park with allowed time). In this approach, two attributes number of parking spaces per 100 meter and occupancy rate of parking spaces represent supply. A high occupancy rate means that the occupancy comes close to 100 percent. If a car driver experiences this as a problem he/she will indeed choose the first available parking place. The data was collected using PanelClix (www.panelclix.be). Only Belgian members of the panel (having experience with parking in inner city areas) were invited to fill in the questionnaire. In total, 548 responses (same dataset as used in the previous chapter) were collected (same data set has been analyzed). The collected data is analyzed using Mixed Multinomial Logit Model, which is detailed in the next section.

4.6. Analysis and Interpretation

The preferences collected through questionnaire are analyzed using Mixed Multinomial Logit Model (MMNL) to describe the various components of the respondents' choice behavior. Mixed logit model allows checking for heterogeneity across respondents and substitution effects between alternatives which might improve estimation results. MMNL can estimate any random utility model because of its highly flexible structure (McFadden and Train, 2000); (Swait and Louviere, 1993) and (Revelt and Train, 1999). In contrast to standard Multinomial Logit (MNL) models, Mixed Logit (MMNL) models allow for random taste variation in the population of decision makers and can derive probabilities from utility maximization. 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 and Polak, 2009). The specification of the MMNL model can be generalized for repeated choices by each sampled decision maker (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 13.

$$U_{qit} = \beta_k x_{qikt} + \varepsilon_{qikt} \quad (13)$$

where
x_{qik} represents the value of attribute k of alternative i for individual q;
β_k represents parameters of attribute k;
ε_{qik} is assumed to be an independent and identically distributed (across alternatives) type I extreme value error term.

Mixed logit model can also be used without random-coefficients interpretation by representing error components that create correlations among the utilities for different alternatives (Train, 2003). To avoid IIA in MMNL an additional random variable can be included with zero mean and standard deviation σ. The estimated standard deviation of this random component is a measure that represents the correlation between similar alternatives. The standard deviation of a parameter indicates preference heterogeneity in the sampled population (Hensher et al, 2005). This is often referred to as unobserved heterogeneity (shown in Equation 14):

$$U_{qi} = \beta_k x_{qik} + \mu_k z_{qik} + \varepsilon_{qjk} \quad (14)$$

Where: x_{qi} and z_{qi} are vectors of observed variables of alternative *i*.
β_k is a vector of fixed coefficients.
μ_k is a vector of random terms with zero mean and standard deviation.
ε_{qik} is a is a random term with zero mean that is IID over alternatives and does not depend on underlying parameters or data.

In each choice situation, the respondent chooses the alternative that provides the greatest utility. In the current study, four choice situations (tasks) were presented to each respondent. After evaluating the task, the respondent had to indicate one of the alternative as his/her parking decision (park on-street, park off-street and continue search) with respect to presented choice situation (shown in Figure 4.2 and 4.3). The collected data is analyzed using Mixed logit model. NLOGIT version 5 is used to estimate the model (Econometric Software Inc., 2012). The choices of car drivers' (park on-street, park off-street, and continue searching) are used as dependent attribute. The alternative 'Continue searching' was used as base alternative. In this study, dummy coding is used to represent all effects of the attribute levels. Therefore, part-worth utilities of all base attribute levels is equal to zero. The coding scheme used in the model estimation is presented in Table 4.1. The results of model estimation process are presented in Table 4.2. To evaluate the model estimates, the log-likelihood function is used. In addition to the LRS, an index called McFadden's Rho-Square, is calculated based on Log-likelihood of the null model, LL(0) and Log-likelihood of the optimal model, LL(β). Basically, the value of McFadden's Rho-Square 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 Rho^2 of 0.3 or higher represents a 'decent' fit for a discrete choice model all these values are indicated in Table 4.2.

Table 4.1. Attributes and attribute levels with corresponding coding scheme

Attributes	Levels	Coding (dummy)
Payment options	Cash	1 0
	Cash-credit	0 1
	Cash-credit-phone	0 0
Distance Off-Street	100 meter	0 1
	200 meter	1 0
	300 meter	0 0
Off-street tariff	0.50 euro	1 0
	1.50 euro	0 1
	2.50 euro	0 0
Streets visited	None	0 1
	One	1 0
	2 or more	0 0
Expected duration	> 120 minutes	1 0
	60-120 minutes	0 0
	< 60 minutes	0 1
Parking costs	Free	1 0
	1.00 euro/hour	0 0
	2.00 euro/hour	0 1
Distance destination	100 meter	0 1
	200 meter	1 0
	300 meter	0 0
Parking situation	Low	1 0
	Medium	0 0
	High	0 1
Maximum parking duration	**Unlimited**	0 0
	4 hours	1 0
	2 hours	0 1
Security	Nothing	1 0
	Guards	0 1
	CCTV camera	0 0
Occupancy rate	Low	1 0
	Average	0 0
	High	0 1
Road Condition	Low	1 0
	Medium	0 0
	High	0 1

Activities	Houses Shops **Play garden**	1 0 0 1 0 0
Parking space/100 meter	**10 space** 15 spaces 20 spaces	0 0 0 1 1 0
Speed limit	20 km/hour 40 km/hour **60 km/hour**	0 1 1 0 0 0

Table 4.2. Estimation results from Mixed Multinomial Logit

Alternatives	**Attributes**	**Attribute Levels**	**Mean**	**Standard deviation**[1]
PARK ON-STREET	**On-street parking facility**			
	Intercept		1.5176**	3.4640***
	(On-street) Parking cost	Free **1.00 euro/hour** 2.00 euro/hour	1.63454*** 0 -1.96981***	
	Distance between parking location and destination	100m 200m **300m**	0.7599* 0.6035 0	2.3128**
	Expected Parking duration	Less than 60 min **60-120 min** More than 120 min	0.0549 0 -0.2484	
	Payment options	Cash, Cash and Bankcard, **Cash, Bankcard, Smartphone**	0.1255 0.6487 0	
	Number of streets already visited	No streets 1 street **2 or more streets**	0.7476 0.1732 0	2.7904***
	Off-street parking facility			
	Distance to off-street parking place	100m 200m **300m**	-0.0325 -0.0246 0	1.0442
	Off-street parking tariff	0.50 euro/hour 1.50 euro/hour **2.50 euro/hour**	0.1209 -0.7793* 0	
	Road Conditions			
	Average available parking spaces per 100meter	**10 spaces/100 m** 15 spaces/100 m 20 spaces/100 m	0 0.6011 -0.0795	 1.7525 0.1604

[1] The blank cells in standard deviation column show attributes that could not be simulated due to the limitation of software.

	Surrounding activities	House Shopping **Playground/school**	-0.2863 0.7949 0	
	Speed limit	20 km/h 40 km/h **60 km/h**	1.2842** 0.7942 0	2.5238** 2.4995*
	Parking condition			
	Occupancy rate	Low, occupancy,50% **Medium, occupancy,75%** High occupancy, 100%	0.8423 0 -0.0224	
	Available security	Nothing **CCTV camera** Guards	0.4677 0 0.1750	
	Maximum parking duration	2 hours 4 hours **Unlimited**	0.5807 -0.3387 0	3.7980***
	Decision construct levels			
	Level of convenience for parking condition	Low **Medium** High	1.0570* 0 -1.0075*	1.6749 2.6451**
	Level of convenience for road condition	Low **Medium** High	-0.9491* 0 0.6483	
PARK OFF-STREET	**On-street parking facility**			
	Intercept		-0.2231	2.6525***
	On-street parking cost	Free **1 euro/ hour** 2 euro/ hour	-0.8255** 0 0.2713	
	Payment options	Cash, Cash and Bankcard, **Cash, Bankcard, Smartphone**	0.4545 0.0934 0	
	Number of streets already visited	No streets 1 street **2 or more streets**	0.00781 -0.3432 0	
	Expected Parking duration	Less than 60 min **60-120 min** More than 120 min	-0.3658 0 -0.7613**	
	Distance between parking location and destination	100m 200m **300m**	0.3822 -0.0569 0	
	Off-street parking facility			
	Distance to off-street parking place	100m 200m **300m**	0.5369 0.6698* 0	0.0447
	Off-street parking tariff	0.5 euro/hour 1.5 euro/hour **2.5 euro/hour**	3.6147*** 1.2825*** 0	3.8050***
	Road conditions			

	Surrounding activities	House Shopping **Playground/ school**	1.1307** 0.6234 0	1.5980* 1.6490**
	Speed limit	20km/h 40km/h **60km/h**	-0.2301 0.3596 0	0.3618
	Average available parking spaces per 100meter	**10 spaces/ 100 m** 15 spaces/100 m 20 spaces/100 m	0 -0.1202 0.0670	
	Parking Condition			
	Occupancy rate	Low, occupancy,50% **Medium, occupancy,75%** High occupancy, 100%	0.2747 0 0.4716	
	Available security	Nothing **CCTV camera** Guards	0.1746 0 0.4692	
	Maximum parking duration	2 hours 4 hours **Unlimited**	0.5215 0.1677 0	
	Decision construct levels			
	Level of convenience for parking condition	Low **Medium** High	-0.2202 0 0.7546	
	Level of convenience for road condition	Low **Medium** High	0.3281 0 0.5548	
Goodness-of-fit Log-likelihood of the null model, LL(0) Log-likelihood of the optimal model, LL(B) LRS=-2[LL(0)-LL(B)] McFadden's Rho-Square MMNL McFadden's adjusted Rho-Square MMNL		 -2416.9470 -2098.1977 637.486 (df = 79) 0.2880 0.2749		
***, **, * represents significance at 1%, 5%, 10% The categories in bold represent base levels, having 0 mean.				

The model has a McFadden's Rho-square value of 0.288 and an adjusted Rho-squared of 0.274, which indicates that the estimated model is well able to predict the observed choices (Swait and Louviere, 1993). In addition, it appears that the assumption of heterogeneity is supported by a significant standard deviation for a number of attribute levels. It can be noticed that the means and standard deviations of attributes such as 'on-street parking costs' ,'off-street parking tariff', 'distance between parking location and destination', 'level of parking convenience', 'level of road convenience', 'surrounding activities', 'expected parking duration', 'speed limit' and 'number of streets visited' are significant. This means that there is random taste variation across the respondents regarding these attribute levels. According to the parameter estimates, if speed limit is 40km/h, the expected parking duration is more than 120 minutes, and the off-street parking tariff is low (0.50 euro/hour) then the probability that a car driver parks the car in an off-street parking facility increases. Moreover, free parking, providing parking closer to destination and roads with reduced speed limits (preferable residential areas are the major conditions that induce parking search. Similar conditions that induce search traffic can be identified using the model results.

Keeping in view the street related attributes it can be suggested that if on-street parking need to be reduced attributes such as speed limit, expected parking duration and off-street parking tariff can be adjusted. Using a large set of attributes made it possible to reduce respondent's biasness of conventionally important attributes such as distance to destination and parking cost. The approach of hierarchical information integration (HII) force respondent to consider street situation as a whole while making parking decision rather than only focusing on cost and distance (Khaliq et al, 2018). It should be noticed that some of the attributes have negative signs this indicates a decrease in the utility of choice alternative. Lower utility of an alternative indicates a higher chance that the respondent will select other alternative for example, in case if the speed is low (20km/h), the probability to continue search is high. Therefore, it can be predicted that if it is intended to make people use an off-street parking at a certain road, speed limit of the road can be slightly raised (e.g. 40km/h). It also seems that a low 'level of road convenience' can induce parking search while probability to park on-street increases in case of favorable parking conditions in the street (e.g. low occupancy). Other inferences that can be drawn from the model results are that in case of residential streets, car drivers prefer to park on-street while a shopping street urge car drivers to search for suitable parking. Similarly, a high expected parking duration urge car drivers to cruise. In general, it can be concluded that overall road conditions (including all the presented attributes) directly affect parking decisions of car drivers. Moreover, this is the best performing model (some other attempts excluding/including other parameters did not work out well)

4.7. Conclusions

Factors affecting car drivers' parking choice decisions need to be identified for making successful parking policies. Nowadays, roads are crowded with parking search traffic. In order to reduce this search traffic, a thorough investigation related to car drivers' parking choice decisions is required. In the current study, respondents are inquired regarding their on-street parking preferences using a stated preference approach including the integrated hierarchical information integration technique. In the current research, it is assumed that car drivers make parking choices based on the prevailing parking and road conditions in the street such as the occupancy rate, speed limit, security and parking space availability. The data collected has been investigated using Mixed Multinomial Logit Model. The results of the model estimation show that besides parking costs and walking distance to destination, expected parking duration, speed limit and surrounding activities play a considerable role when determining car drivers' parking preferences. The model also shows that car drivers' prefer to park off-street if surrounding activities in the street include shops. One of the goals of the adopted approach is to look first if street conditions have influence (limited investigated in the past). If the estimates of MMNL-model are observed most of road related factors are significant which indicates that the street features do have an influence of car drivers' parking choice decisions. Certain other inferences that can be drawn from this research are related to policy implications. Keeping in view the existing literature attributes such as walking distance, price, search time, vehicle type, access time, etc. only provide limited knowledge related to car drivers' parking decisions, in order to raise the policy implications a detailed understanding of road related attributes is required, which are highlighted in the current research. The adopted approach has highlighted relative importance of the attributes resulting in demonstration of how through adjustment of values of these road related parking factors, the number of cruising cars can be reduced. In a nutshell, this type of data can be useful for decision makers to promote certain parking management strategies that complement built environment and urban planning strategies. Moreover, this research can further be used as a part of multi-agent simulation systems for predicting effect of change in parking policies on traffic situation of a city.

4.8. Discussion

The preferences of car drivers' collected in the last chapter were analyzed in the current chapter using the Mixed Logit model. Mixed logit model is considered the most advanced type of discrete choice model due to its ability to account for taste variation across individuals/decision-makers, the assumption of heterogeneity is supported by a significant standard deviation for a number of attribute levels. This means that the mixed logit model gives a quick indication of the impact of taste variation on the parameter estimates. Accommodating this heterogeneity leads to significantly different conclusions regarding the influence of substantive factors such as 'level of parking convenience', 'surrounding activities', 'expected parking duration', 'speed limit' and 'number of streets visited' on car drivers' parking choices.

The analysis reveals important differences in parking choices of car drivers' across different parking durations, speed limits and surrounding activities with respect to existing literature. This kind of information is useful for policy makers/ decision makers, who are involved in formulating policies. The current findings of the research provides policy makers with an overview related to parking choices of car drivers' both on individual (mixed logit estimates) and aggregate level (multinomial logit estimates). The MNL model is easy to estimate, but the model is not able to differentiate between individuals' tastes and assumes that every person is same. Random taste variation across decision makers give a more accurate representation of real world behavior than assuming the same taste for all decision makers (e.g., Hess and Polak, 2009). The significant standard deviations indicate that differences between respondents exist. If we compare the results of these both these models most of the significant attributes are common, but the McFadden's Rho-square (0.275) of MMNL shows that it performs better than the MNL (0.264) model. The log-likelihood value of the optimal MMNL model is equal to -2098.1977 (79 degrees of freedom) while the log-likelihood value of the optimal MNL model is equal to -1917.095 (62 degrees of freedom). The resulting LRS value of 362.21 is higher than the critical Chi-square value of 27.587 (17 degrees of freedom).

The analyses show that it is possible to describe the influence of both parking and road conditions on parking choice behavior using stated choice experiments and discrete choice models. The aim was to present a strategy to investigate car drivers' on-street parking decisions using traditional stated choice experiments. There is no study in the existing literature that is designed in such a way that it hypothetically presents a road situation and enquires the choice of driver while driving. This information is also beneficial for development of multi-agent systems, for simulating car drivers parking choice behavior using traffic simulation. In future research individual characteristics of respondents can be analyzed with respect to their parking choices. Also in this research Integrated Hierarchical Information integration approach has been employed in which two constructs are jointly analyzed but in future separate analyses can be conducted using the Original Hierarchical Information Integration (HII-O) in which two constructs can be analyzed separately.

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5. Simulating Car Drivers' On-Street Parking Decisions

This chapter is based on a paper titled as 'Simulating Car Drivers' Parking Choice Behavior in the context of Parking Measure Evaluation'. This chapter describes an application of a behavioral model, capable of investigating on-street parking choices of car drivers in response to changes in parking and road conditions due to parking measures. The detailed methodology is explained in the different sections of this chapter.

5.1. Abstract

Several agent-based parking simulation systems for simulating parking search behavior have been developed. All these models are more or less capable of representing the parking search process of car drivers including the decision making process leading to the choice to park. However, the phenomenon of parking choices is based on limited behavioral principles. To evaluate a variety of parking measures, a more comprehensive model for investigating car drivers' on-street parking decisions is required. This paper describes an application of an extensive behavioral model, capable of investigating on-street parking choices of car drivers in response to changes of parking and road conditions due to parking measures. The data for the estimation of the parameters is collected through stated preference experiment that focuses on car drivers' decision to park their car on-street in the visited street segment, to park the car in the nearest off-street parking facility, or continue to search for a more suitable parking location. The parking choices of car drivers are evaluated using a mixed multinomial logit model. With the results of the model estimation a simulation is setup to illustrate the working of the model when investigating the effects of parking measures. With the simulation the effects of (a) surrounding activities (b) speed limit (c) expected parking duration (d) the introduction of paid parking and an increase in on-street parking cost are evaluated. The simulation shows clearly the changes in probabilities of on-street parking, off-street parking, and continue to search due to the parking cost changes.

5.2. Introduction

Parking is one of the main concerns of transport and urban planners as it integrates land use and transport system. The traffic induced due to cars searching for parking is a critical issue that cannot be overlooked. In previous research, it is discussed that most drivers spend a significant time of their trip searching for a suitable space. Moreover, parking search traffic accounts for up to 30% of total traffic in city centers (Shoup, 2005; 2006). Efficient parking management in urban areas can only be achieved by carefully designing the parking policy that not only coincides with overall transport policy goals but also positively affects behavior of car drivers. With parking policy, transport planners aim to regulate traffic flows in congested areas, thus enhancing accessibility and quality of life in these areas.

In addition, local governments are trying to optimize the use of their road network to increase the supply of parking. On-street parking enhances accessibility to local businesses (shops, restaurants, etc.) located along city streets and occupies less land per space than off-street parking. However, the trade-off with search traffic cannot be ignored (Calthrop, 2002; Anderson and De Palma, 2004; Arnott and Inci, 2006). A variety of parking measures are available for planners such as parking freezes, restricted parking, shared parking, centralized parking, in-lieu parking fees and demand reduction (Khaliq, 2015). To ascertain the impact of parking measures, it is valued to identify how car drivers will respond to proposed parking measures. Therefore, it is extremely important to carefully analyze and evaluate these impacts in the light of parking policy goals. This urge makes it necessary to develop a tool that is capable of systematically analyzing on-street parking choices of car drivers using a set of quantifiable attributes relevant to policy makers. (Golias et al, 2002; Brooke, Ison, and Quddus, 2014) suggest that people have individual differences in their parking choices which will lead to parking uncertainty. In general, choices are considered as rational but it is very complex to determine car drivers' parking choices.

Some examples of agent based models include PARKAGENT developed by the group of Benenson (Benenson, Martens, and Birfir, 2008) , SUSTAPARK developed by the group of Steenberghen (Steenberghen, Dieussaert, Maerivoet, & Spitaels, 2012), and the parking model developed by the group of Waraich (Waraich, Dobler, & Axhausen, 2012). All these models are more or less capable of representing the parking search process of car drivers including the decision making process leading to the most preferred space to park. However, the phenomenon of parking choices is based on limited behavioral principles that can explain car drivers' parking decision process in detail. To evaluate a variety of parking measures, a more comprehensive model for predicting car drivers' on-street parking decisions is needed.

This paper describes an application of an extensive behavioral model, capable of predicting on-street parking choices of car drivers in response to changes of parking and road conditions due to parking measures. This model predicts car drivers' parking choices based on the principle of utility maximization. The initial model included 13 trip, parking, and road related attributes. The data for the estimation of the parameters is collected through a stated preference experiment and focuses on car drivers' decision to park their car on-street in the visited street segment, to park the car in the nearest off-street parking facility, or to continue searching for a more suitable parking location. The choices of car drivers are evaluated using a mixed multinomial logit model. The following attributes significantly contribute to the utility of on-street parking: the number of streets visited before entering the street, the expected parking duration, the distance between road segment and final destination, the costs of on-street parking, the costs of off-street parking, the level of parking convenience, the occupancy rate of parking spaces in a road, the level of road convenience, parking spaces availability and the maximum speed at a road. The utility of off-street parking is significantly influenced by the distance between road segment and nearest off-street parking, the costs of off-street parking, the expected parking duration, and the type of activity along the road. With the results of the model estimation a simulation is setup to illustrate the working of the model when investigating the effects of certain parking measures. More specifically, with the simulation the effects of (a) the introduction of an on-street parking tariff of 1.00 euro and (b) an increase of the on-street parking cost from 1.00 euro to 2.00 euro are evaluated. The simulation shows clearly the changes in probabilities of on-street parking, off-street parking, and continue to search due to the parking cost changes.

The remainder of this paper is structured as follows. First, the underlying problem of parking search behavior in urban areas will be detailed. Secondly, some details of various models that are included in the existing agent-based simulation systems are listed. In the next section, the details of the adopted research approach are described. This section also includes the model that is used for the simulation. The setup of the simulation and some results are presented in the following section. The paper ends with the conclusions and some recommendations for refining the model.

5.3. Related work

Modelling the process of parking is quite complex. This modelling complexity is reduced by the introduction of simulation models. Analysis of parking policies using simulation models is seeking attention in parking research. There are various types of simulation models i.e. implicit (Network based) or explicit (based on Random utility theory). These models can help policy makers to evaluate parking policies by viewing explicitly the current condition of parking and predicting future scenarios. A large number of studies can be found related to parking models. These parking models have been categorized in several ways. Based on the scale of examination area (Young and Taylor, 1991) categorized parking models in four distinguished levels from microscopic to macroscopic these include: parking lot level, parking zone level, sub regional level and urban level. All these models are used to study the parking behavior of car drivers on different levels of investigation. Another categorization of parking models is based on their purpose of use such as parking design models, parking search models, parking choice models, parking allocation models and parking interaction models (Young, 2005; 2008). Parking design models are used to design (calculate capacities and dimensions) and understand performance of the parking system. Parking search models investigate the search process car drivers undertake while searching for a suitable parking place, whereas parking choice models measure the reactions of car drivers with respect to parking supply. Parking allocation models are introduced to assign parkers to available parking facilities. Parking interaction models examine the response of people to new policies. Detailed overview of parking choice models is listed in the next sections.

5.3.1. Parking choice simulation models

Parking literature is flourished with studies where the researchers have identified factors (such as parking type, parking location, parking duration, travel purpose, and walking distance to destination) that influence car drivers' parking decisions (Axhausen and Polak, 1991); (Hensher and King, 2001); (Hess and Polak, 2004), (Brooke, Ison, and Quddus, 2014), and (Chaniotakis and Pel, 2015). Discrete choice models have been used in parking choice literature to highlight the significant attributes that influence parking choice behavior of car drivers. In one of the first studies, (Gillen, 1978) used binary logit model to identify the significance of parking cost and walking time in parking choice decisions. The main

findings of this study elaborated that cost is the major factor concerning parking choice. Some years later, (Van der Goot, 1982) identified that walking time has the major influence on parking choice for off-street parking facilities. The attributes investigated in this study were walking distance, parking time restriction, parking charges, occupancy rate and type of parking. (Axhausen and Polak, 1991) identified the significance of access time, search time, egress time, parking fee, and expected illegal parking fine using a multinomial logit model. (Bradley, Kroes, and Hinloopen, 1993) estimated a nested logit model to identify the significance of parking type, parking fee, search time and walk time. (Hunt and Teply, 1993) also used a nested logit model to evaluate parking choice the attributes walking distance, parking fee, accessibility and cleanliness. (Miller, 1993) used a nested logit model to evaluate parking choice related attributes such as car availability, travel time, costs for car, costs for transit, parking fee and walk time. Later, a behavioral modelling framework to represent the parking search behavior of motorists was presented by (Thompson and Richardson, 1998). Other studies that employed the discrete choice approach to study parking choice behavior include (van der Waerden and Borgers, 1995), (Lambe, 1996), (Teknomo and Hokao, 1997), (Matsumoto and Rojas, 1998), (van der Waerden and Borgers, 1995), (van der Waerden, Borgers, and Timmermans, 1998), (van der Waerden, Borgers, and Timmermans, 2000), (Tsamboulas, 2001), (Hensher and King, 2001)**,** (Coppola, 2002), (Bonsall and Palmer, 2004), (Clinch and Kelly, 2006), (Hess and Polak, 2004), (Harmatuck, 2007), (van der Waerden and Timmermans, 2014), (Brooke, Ison, and Quddus, 2014) and (Chaniotakis and Pel, 2015).
(Benenson et al, 2008) categorized parking models in spatially implicit and explicit categories. Spatially implicit models are static and emphasize on car drivers' parking destination choices while spatially explicit (simulation) models focus on parking search processes and choices on disaggregated level. Several other simulation models have been used to investigate different aspects of parking such as relationship between travel and parking behavior (Young and Weng, 2005), car-parking guidance model for finding the best parking facility (Leephakpreeda, 2007), relationship between parking supply and traffic assigned to street network of city (Gallo, et al, 2011); (Eldin and Ismail,1981); (Bifulco, 1993), and to study the issues of parking congestion caused by car drivers' search for a vacant parking space (Arnott and Rowse, 1999). Simulation models of (Lam et al, 2006), (Li et al, 2007) are some examples of proposed parking simulation models in the literature.

5.3.2. Agent-based parking simulation models

Agent-based modelling is an interesting computational modelling approach for analyzing parking phenomena (Gerritsen, 2015). It provides a dynamic platform to understand interactions between drivers, city environment, and road users. PARKAGENT (Benenson et al, 2008), SUSTAPARK (Dieussaert and Aerts, 2009), the parking models of (Waraich et al, 2012) and (Guo et al, 2013) are some agent-based parking simulation models mentioned in the literature.
PARKAGENT (Benenson et al, 2008) has given a new dimension to parking research as it can simulate the parking phenomena more explicitly. PARKAGENT applied to a neighborhood in Tel Aviv, is an agent-based parking simulation model for residential areas. The model works with parking search rules. An agent evaluates per iteration the parking availability and decides whether to park or to continue driving. The decision is based on model that includes factors like search

time, walking distance, and parking costs. In the Tel Aviv case, the researchers used the model to evaluate the effects of additional parking supply. SUSTAPARK (Dieussaert and Aerts, 2009) studied the effects of parking search behavior in traffic using an agent-based model; each agent interacts with other agents in the traffic. Each agent has its own day schedule. The search strategy is particular to each agent and specified by rules. Specific parameters determine the decision process where to park: access time, search time, egress time and expected parking fee. The model loads the roads and parking data from GIS layers. (Waraich et al, 2012) proposed an agent based parking search model that deals with several parking search strategies (i.e. simulation, scoring and re-planning) and identifies characteristics of each agent that may impact their utility evaluation. Thus, drivers' parking behavior can be represented in a more realistic way. (Guo et al, 2013) developed a network based model to simulate car drivers' parking search process, taking into account drivers' attitudes and psychological characteristics to search for available parking spot in their most desirable lot. The drivers make decisions keeping in view the characteristics of the parking system and the strategies of other drivers in the system. The overview of parking studies highlight several categories of parking models and their adopted approaches to interpret parking behavior that is necessary to consider when looking for improvement of existing parking models or proposing new ones. The following section will describe the methodology adopted for this research.

5.4. Research approach

In order to simulate car drivers' parking choice behavior in the context of parking measure evaluation, first a set of parameters are estimated using Mixed multinomial Logit (MMNL) model. The data for the estimation of the parameters is collected through a stated preference experiment. This data includes car drivers' decision to park the car on-street in the visited street segment, to park the car in the nearest off-street parking facility, or to continue searching for a more suitable on-street parking location. A detailed explanation of the data collection and analysis is presented in (Khaliq et al, 2018) (Chapter 3). Secondly, the utility and probability of each choice alternative are calculated. Later, the probability of each choice alternative is added and an average probability is calculated for each alternative. Figure 5.1 shows the stepwise application of simulation.

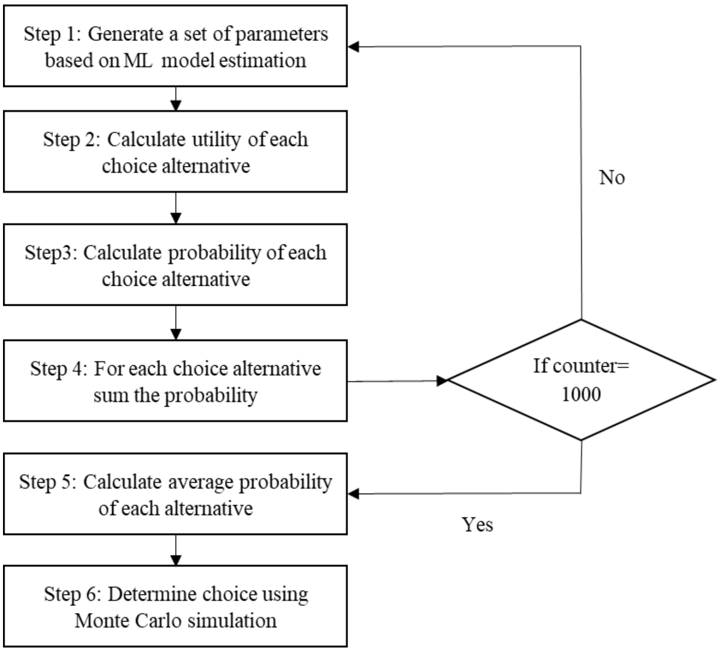

Figure 5.1. The stepwise simulation set up (van der Waerden, 2012)

5.5. Model estimation and Analysis

The data collected through an online questionnaire is analyzed using Mixed multinomial logit (MMNL) model. NLOGIT version 5 (Econometric Software Inc., 2012) is used to estimate the model. The data used in the analyses was coded with dummy coding scheme (shown in Table 4.2). MMNL can estimate any random utility model because of its highly flexible structure (McFadden & Train, 2000); (Swait & Louviere, 1993) and (Revelt & Train, 1999). In contrast to standard Multinomial Logit (MNL) models, MMNL models allow for random taste variation in the population of decision makers and can derive probabilities from utility maximization. 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 and Polak, 2009). The specification of the MMNL model can be generalized for repeated choices by each sampled decision maker (Train 2003). Repeated choices are common practice in stated preference surveys. The utility of alternative *i* for person *q* is presented in Equation 17.

$$U_{qi} = \beta_k x_{qik} + \mu_k z_{qik} + \varepsilon_{qjk} \tag{17}$$

Where: x_{qi} and z_{qi} are vectors of observed variables of alternative *i* for person *q*.

β_k is a vector of fixed coefficients *k*.

μ_k is a vector of *k* random terms with zero mean and standard deviation.

ε_{qik} is a random term with zero mean that is IID over alternatives and does not depend on underlying parameters or data. It is assumed to be independent over choice situations, alternatives, and individuals (Hensher, et al, 2005).

The choices of car drivers (park on-street, park off-street, and continue searching) are used as dependent attribute. The alternative 'Continue searching' was used as base alternative. The results of model estimation process are presented in Table 5.1. To evaluate the model estimates, the log-likelihood function is used. In addition to the LRS, an index called McFadden's Rho-Square, is calculated based on Log-likelihood of the null model, LL(0) and Log-likelihood of the optimal model, LL(β). Basically, the value of McFadden's Rho-Square 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 Rho^2 of 0.3 or higher represents a 'decent' fit for a discrete choice model all these values are indicated in Table 5.1. (This table is a repetition of Table 4.2. It is intentionally repeated to facilitate the readers, in order to understand the model application clearly without going back to chapter 4).

Table 5.1. Estimation of results from mixed multinomial logit model

Alternatives	**Attributes**	**Attribute Levels**	**Mean**	**Standard deviation**[2]
PARK ON-STREET	**On-street parking facility**			
	Intercept		1.5176**	3.4640***
	(On-street) Parking cost	Free **1.00 euro/hour** 2.00 euro/hour	1.63454*** 0 -1.96981***	
	Distance between parking location and destination	100m 200m **300m**	0.7599* 0.6035 0	2.3128**
	Expected Parking duration	Less than 60 min **60-120 min** More than 120 min	0.0549 0 -0.2484	
	Payment options	Cash, Cash and Bankcard, **Cash, Bankcard, Smartphone**	0.1255 0.6487 0	
	Number of streets already visited	No streets 1 street **2 or more streets**	0.7476 0.1732 0	2.7904***
	Off-street parking facility			
	Distance to off-street parking place	100m 200m **300m**	-0.0325 -0.0246 0	1.0442
	Off-street parking tariff	0.50 euro/hour 1.50 euro/hour **2.50 euro/hour**	0.1209 -0.7793* 0	
	Road Conditions			
	Average	**10 spaces/100 m**	0	

[2] The blank cells in standard deviation column show attributes that could not be simulated due to the limitation of software.

	available parking spaces per 100meter	15 spaces/100 m 20 spaces/100 m	0.6011 -0.0795	1.7525 0.1604
	Surrounding activities	House Shopping **Playground/school**	-0.2863 0.7949 0	
	Speed limit	20 km/h 40 km/h **60 km/h**	1.28421** 0.79421 0	2.5238** 2.4995*
	Parking condition			
	Occupancy rate	Low, occupancy,50% **Medium, occupancy,75%** High occupancy, 100%	0.8423 0 -0.0224	
	Available security	Nothing **CCTV camera** Guards	0.4677 0 0.1750	
	Maximum parking duration	2 hours 4 hours **Unlimited**	0.5807 -0.3387 0	3.7980***
	Decision construct levels			
	Level of convenience for parking condition	Low **Medium** High	1.05705* 0 -1.00758*	1.6749 2.6451**
	Level of convenience for road condition	Low **Medium** High	-0.9491* 0 0.6483	
PARK OFF-STREET	**On-street parking facility**			
	Intercept		-0.2231	2.6525***
	On-street parking cost	Free **1 euro/ hour** 2 euro/ hour	-0.8255** 0 0.2713	
	Payment options	Cash, Cash and Bankcard, **Cash, Bankcard, Smartphone**	0.4545 0.0934 0	
	Number of streets already visited	No streets 1 street **2 or more streets**	0.00781 -0.3432 0	
	Expected Parking duration	Less than 60 min **60-120 min** More than 120 min	-0.3658 0 -0.7613**	
	Distance between parking location and destination	100m 200m **300m**	0.3822 -0.0569 0	
	Off-street parking facility			
	Distance to off-street parking place	100m 200m **300m**	0.5369 0.6698* 0	0.0447

	Off-street parking tariff	0.5 euro/hour 1.5 euro/hour **2.5 euro/hour**	3.6147*** 1.2825*** 0	3.8050***
	Road conditions			
	Surrounding activities	House Shopping **Playground/ school**	1.1307** 0.6234 0	1.5980* 1.6490**
	Speed limit	20km/h 40km/h **60km/h**	-0.2301 0.3596 0	0.3618
	Average available parking spaces per 100meter	**10 spaces/ 100 m** 15 spaces/100 m 20 spaces/100 m	0 -0.1202 0.0670	
	Parking Condition			
	Occupancy rate	Low, occupancy,50% **Medium, occupancy,75%** High occupancy, 100%	0.2747 0 0.4716	
	Available security	Nothing **CCTV camera** Guards	0.1746 0 0.4692	
	Maximum parking duration	2 hours 4 hours **Unlimited**	0.5215 0.1677 0	
	Decision construct levels			
	Level of convenience for parking condition	Low **Medium** High	-0.2202 0 0.7546	
	Level of convenience for road condition	Low **Medium** High	0.3281 0 0.5548	
Goodness-of-fit Log-likelihood of the null model, LL(0) Log-likelihood of the optimal model, LL(B) LRS=-2[LL(0)-LL(B)] McFadden's Rho-Square MMNL McFadden's adjusted Rho-Square MMNL		-2416.9470 -2098.1977 637.486 (df = 79) 0.2880 0.2749		
***, **, * represents significance at 1%, 5%, 10% The categories in bold represent base levels, having 0 mean.				

The model has a McFadden's Rho-square value of 0.2880 which indicates that the estimated model is well able to predict the observed choices (Swait & Louviere, 1993). In addition, it appears that the assumption of heterogeneity is supported by a significant standard deviation for a number of attribute levels. It can be noticed that the means and standard deviations of attributes such as 'off-street parking tariff', 'on-street parking cost', 'level of parking convenience', 'level of road convenience', 'surrounding activities', 'expected parking duration', 'speed limit' and 'number of streets visited' are significant. This means that there is random taste variation across the respondents regarding these attribute levels. According to the parameter estimates, if speed limit is 40km/h, the expected parking duration is more than 120 minutes, and the off-street parking tariff is low

(0.50 euro/hour) then the probability that a car driver parks the car in an off-street parking facility increases. Moreover, free parking, providing parking closer to destination, roads with reduced speed limits (preferable residential areas), and without any security feature are the major conditions that induce parking search. Similar conditions that induce search traffic can be identified using the model results.

5.6. Model application

The results of the model estimation are used to predict the probability of car drivers' parking choices. The model is capable to determine car driver's parking choices related to the prevailing parking condition on a road segment. The car drivers' (agents) are allowed to pass by a street having certain attributes such as (occupancy, parking cost, surrounding activities, and payment options). Each driver agent in the model has its own characteristics such as (number of streets already visited, expected parking duration). The outcomes of the model predict the number of car drivers that will park on-street, park in a garage or will continue search. Since twenty-seven street conditions (profiles) were presented to the respondents, there were different predictions for different profiles. The predictions for condition (profile) 8 are given in Table 5.3 given below. Suppose that a car driver enters a road segment looking for a parking space. The car drivers expect to stay for more than 120 minutes, and started searching in this segment. All settings are defined in Table 5.2.

Table 5.2. Description of a specific condition that a car driver can face

Groups	Attributes	Levels before	Coding
On-street parking condition	Expected parking duration Number of streets already visited Payment options Distance to destination Parking Costs	More than 120 minutes None Cash and Credit 100 meter 1 euro per hour	1 0 0 1 0 1 0 1 0 0
Off-street parking facility	Distance to off-street parking Off-street parking tariff	200 meter 2.5 euro per hour	1 0 0 0
Parking condition, detailed	Maximum parking duration Occupancy rate Available security	2 hours Medium occupation Guards	0 1 0 0 0 1
Road condition detailed	Available parking spaces/100 m Surrounding activities Speed limit	15 spaces/100 m Shopping 20 kmph	0 1 0 1 1 0
Parking condition global	Level of convenience	Low convenience	1 0
Road condition, global	Level of convenience	Low convenience	1 0
Probability (after 1000 draws)	On-street parking Off-street parking Continue searching	0.39 0.33 0.28	

The results from prediction shows that if the road conditions are similar to the one presented on Table 5.2 most of the drivers will prefer to park on-street. Various other predictions of the model can be generated using the simulations work sheet in order to analyze the effect of change in several other attributes on parking decision of car drivers such as change in parking costs, speed limit, parking duration etc. All these model predictions are detailed in the next section.

5.7. Model predictions

The model predictions are based on the principles of the Monte-Carlo simulation. Monte-Carlo simulations are generated using Excel worksheet. The results of the simulation provide a range of possible outcomes to the decision-maker and the probabilities related to parking decisions of car drivers'. This simulation setup is able to illustrate the working of the model when investigating the effects of parking measures. More specifically, with the simulation the effects of (a) the introduction of an on-street parking tariff of 1.00 euro and (b) an increase of the on-street parking cost from 1.00 euro to 2.00 euro are evaluated. The simulations clearly show the changes in probabilities of on-street parking, off-street parking, and continue to search due to change in the parking cost. Several scenarios are generated using this simulation. The simulations are generated using 1000 random probabilities (N=1000), the section below provides the simulations for different parking measures (attributes).

5.7.1. Effect of parking measures on car drivers' parking decisions

Parking policy has a direct influence on travel demand. There are certain parking policy measures that trigger parking demand. These measures include parking restriction and pricing. However, there are other features that influence parking decisions of car drivers' that are highlighted in this study. The results from the model estimates predict that parking cost, surrounding activities, speed limit and parking duration significantly affect car drivers' parking choices. In the light of these results, following inferences are drawn.

(a) Introduction of paid parking

For a situation given in Table 5.3, if on-street parking costs are changed from 1.00 euro per hour to 2.00 euro per hour, the probabilities become 0.26, 0.38 and 0.36 respectively. For free parking the choice probabilities are 0.54, 0.20, and 0.26 respectively.

Figure 5.2 demonstrates the effect of paid parking on car driver's parking preferences (park on-street, park off-street and continue search). The choice probabilities predicted by the model are presented on the vertical axis while the decisions are indicated on the horizontal axis (keeping all other factors constant).

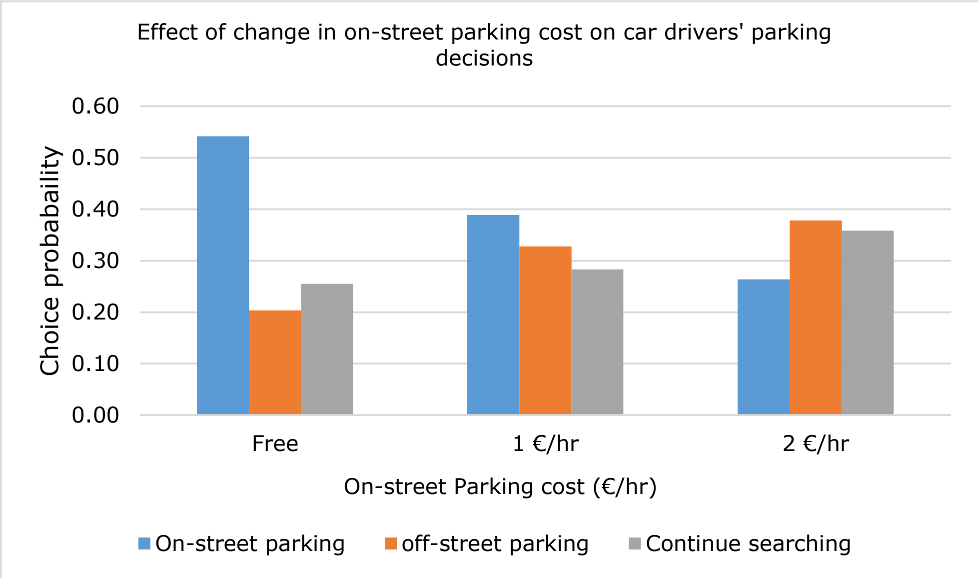

Figure 5.2. Car drivers' parking decisions with respect to change in on-street parking costs

It can be deduced that car drivers' prefer to park on-street if parking in a street is free. Introduction of paid parking schemes trigger drivers' either to park off-street or keep on looking in other streets which are freely available in the nearby neighborhood. The model predicts that parking cost of 1 euro/hour or 2 euro/hour increase the chance that drivers' park in an off-street parking garage but cruising is highest for on-street parking cost of 2 euro/hour.
Similar results can be drawn for identifying the effect of change in off-street parking costs on car drivers' parking decisions. It can be noticed in Figure 5.2, that price effects car drivers' parking decisions significantly even an increase of 1 euro/hour can trigger car drivers' to keep on searching or switch to on-street parking. Therefore, for a better utilization, prices of off-street parking garages should be controlled effectively.

Thus, paid on-street parking can increase utilization of off-street parking places but can also significantly increase search traffic. These model predictions can help policy makers to identify effect of change in parking prices on car drivers' parking decisions.

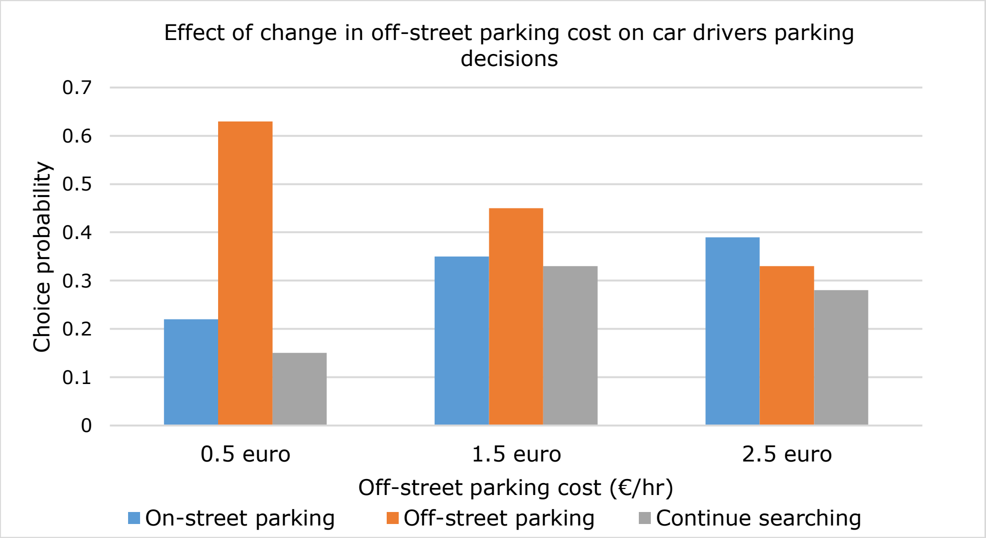

Figure 5.3. Car drivers' parking decisions with respect to change in off-street parking costs

(b) Land-use located on-street and parking duration

The model predicts that the land use activities in a street also have a strong impact on the car drivers' parking decision. The model identifies that cruising would be high in case of a roads having recreational and commercial activities such as sports stadium, playground, shopping malls etc. Whereas cruising is less in case of residential streets, as these streets always have parking space available, that is realistic as shown in Figure 5.4. Planners can reduce cruising by relocating land uses that create search traffic or can also suggest suitable parking options such as event based parking mobile applications that can help guide drivers to find optimal parking space in order to reduce cruising.

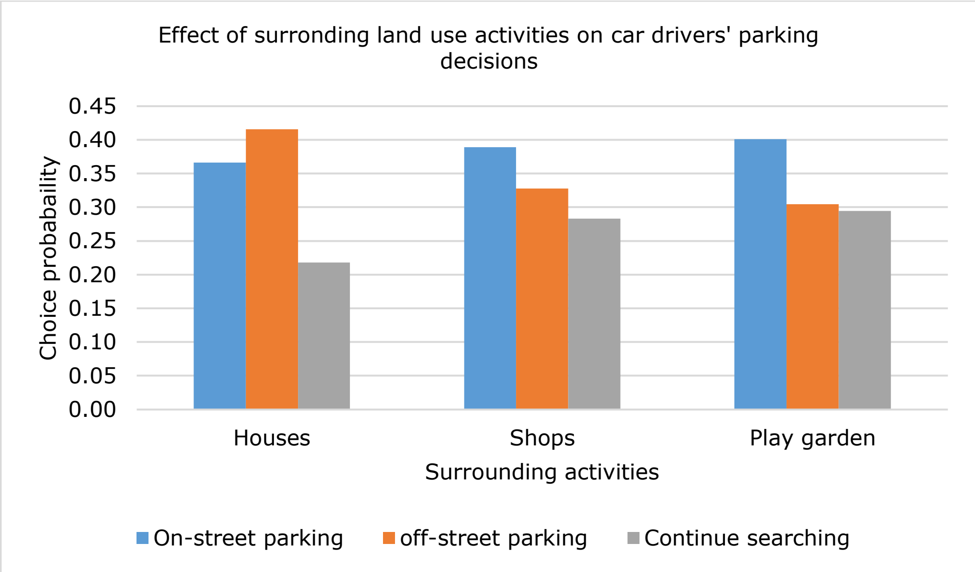

Figure 5.4. Car drivers' parking decisions with respect to different surrounding activities

Another result can be deduced from the model predictions i.e. car drivers' prefer to park off-street in case of residential street. For recreation and commercial activities car drivers' prefer to search for parking or park on-street while for visiting family and friends, car drivers prefer to park off-street.

(c) Parking Duration

The results from simulations also indicate that parking duration significantly affects car drivers parking decisions. Short term trips with duration less than 60 minutes induce large amounts of search traffic whereas for trips of longer duration e.g. more than 120 minutes, car drivers prefer to park in off-street parking garage (shown in Figure 5.5 and Figure 5.6).

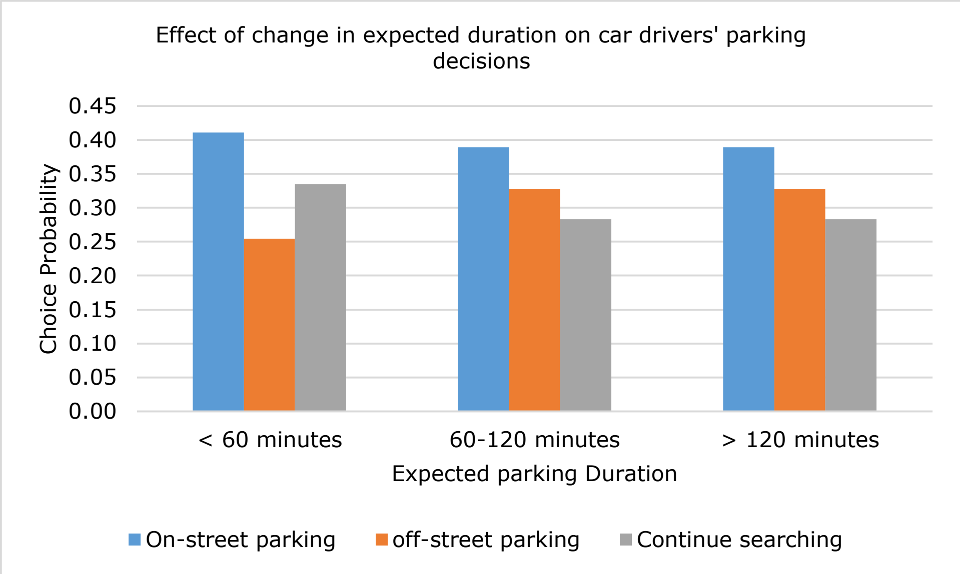

Figure 5.5. Car drivers' parking decisions with respect to change in expected parking duration

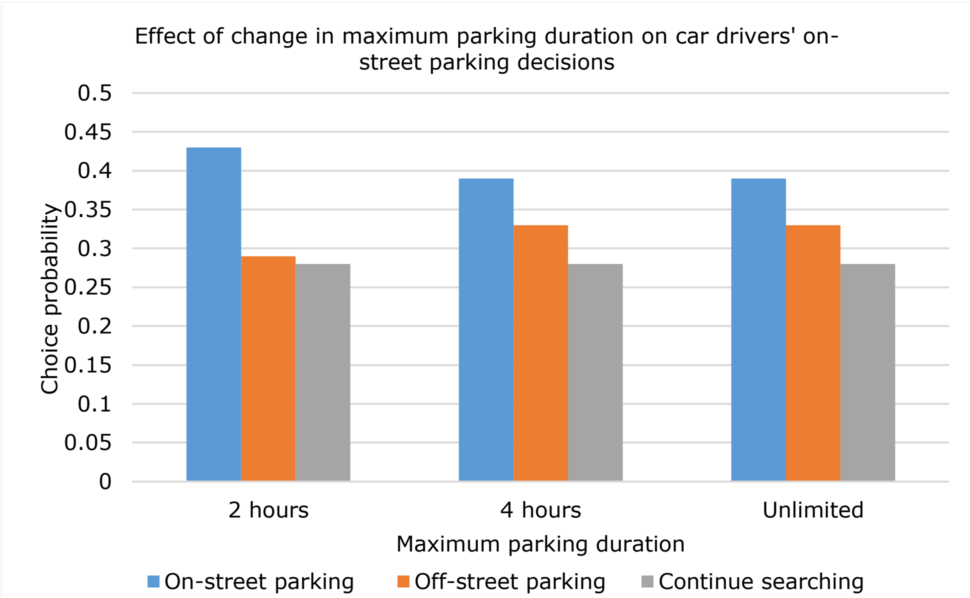

Figure 5.6. Car drivers' parking decisions with respect to change in maximum allowed parking duration

Figure 5.6 shows if allowed parking duration is less car drivers prefer to park on-street, while duration restriction does not impact cruising. Both these figures indicate that car drivers' parking choices are significantly affected by the duration of trip. It can be inferred from these results that short term trips to city center induce more search traffic than long term trips such as work trips.

(d) Speed limit

The simulation results indicate that speed limit affect car divers' parking decisions (shown in Figure 5.7). Both these measures can be adjusted to achieve the required parking condition in the street thus changing car drivers' parking behavior. Roads having low speed limit induce relatively less search traffic as compared to higher speed limits and car drivers' prefer to park on-street on roads where allowed speed limit is 20 km/hour.

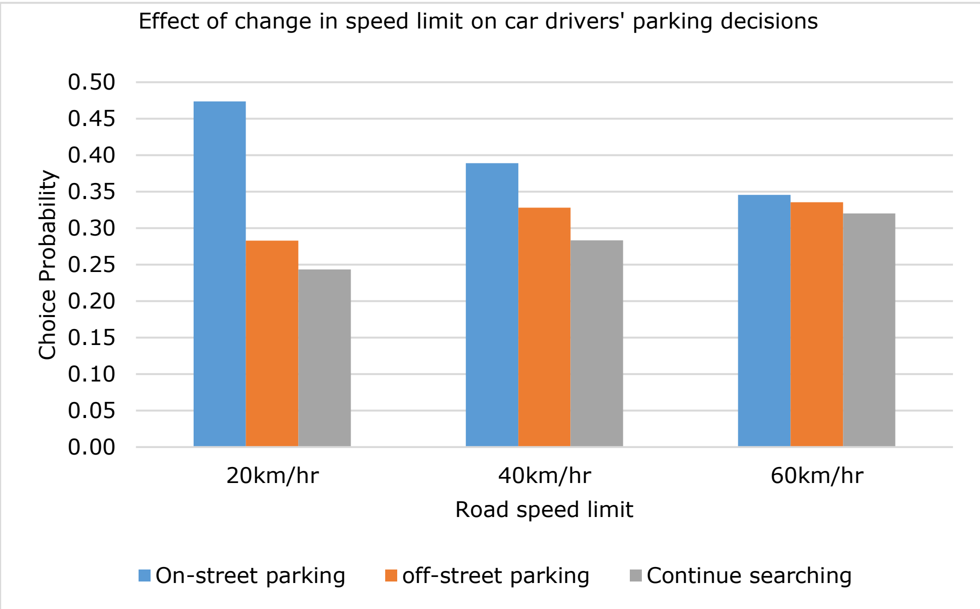

Figure 5.7. Car drivers' parking decisions with respect to different speed limit

(e) Number of streets visited

The number of streets visited by driver has a minor impact on car divers' parking decisions (shown in Figure 5.8). It can be noticed that the number of streets visited do not have a significant effect on car drivers' parking choices. However, cruising is a bit higher if only one street is visited.

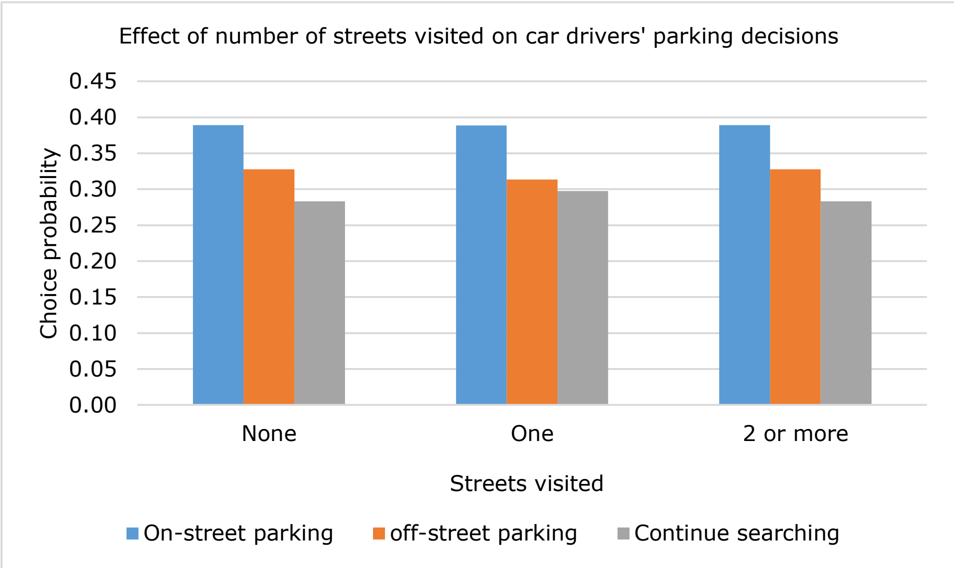

Figure 5.8. Car drivers' parking decisions with respect to number of streets visited

(f) Level of parking and road convenience

The simulation results indicate that parking and road convenience levels also effect car drivers’ parking decisions (shown in Figure 5.9 and Figure 5.10). It can be noticed that car drivers’ tend to park on-street in almost all of parking and road convenience levels but at a high level of parking convenience people tend to park on-street more compared, to other convenience levels. As high level of parking convenience means that there are more spaces available on street and the parking cost is low therefore the probability for parking off-street and searching is low. It can be noticed that the effect of parking convenience level affects car drivers parking decisions more significantly than the road convenience level.

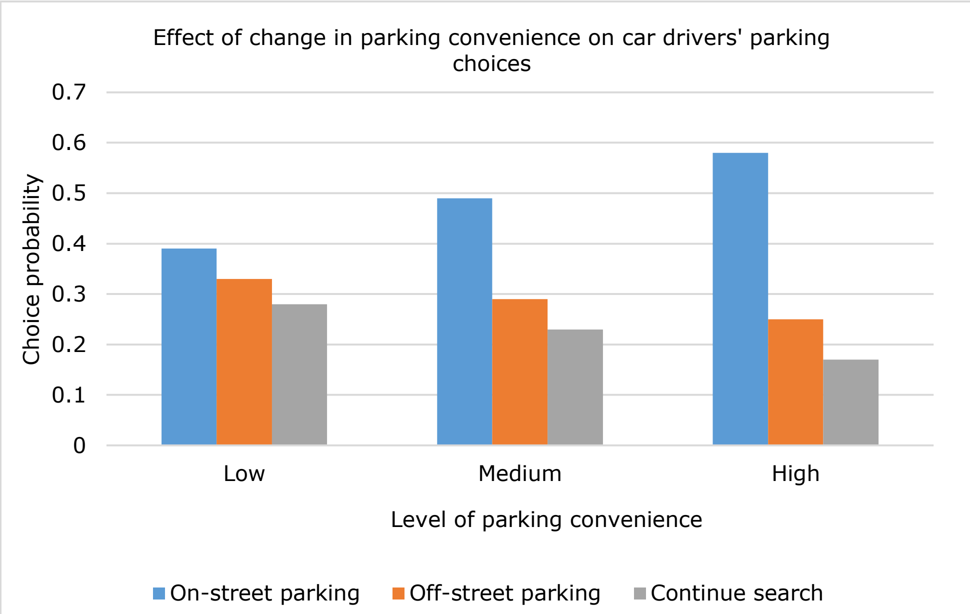

Figure 5.9. Car drivers' parking decisions with respect to level of parking convenience

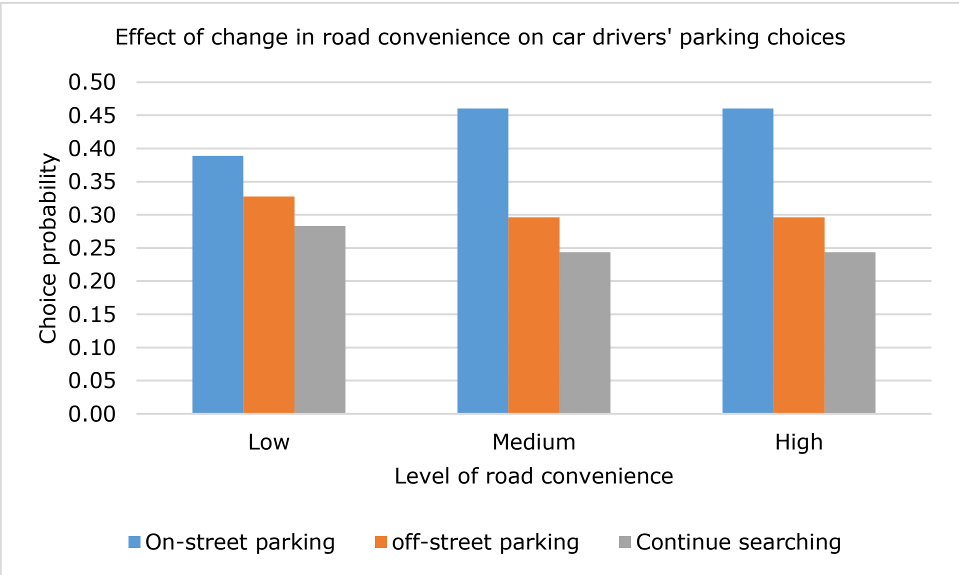

Figure 5.10. Car drivers' parking decisions with respect to level of road convenience

(g) Distance to Destination

Distance to destination of both on-street and off-street parking also affect car drivers' parking decisions (shown in Figure 5.11). Both these measures can be adjusted to achieve the required parking condition in the street thus changing car drivers' parking behavior. The results of simulations indicate that people tend to park on-street more at a distance of 100m while people tend to park off-street at 200m of destination compared to 100m and 300m also cruising is lowest in both these cases.

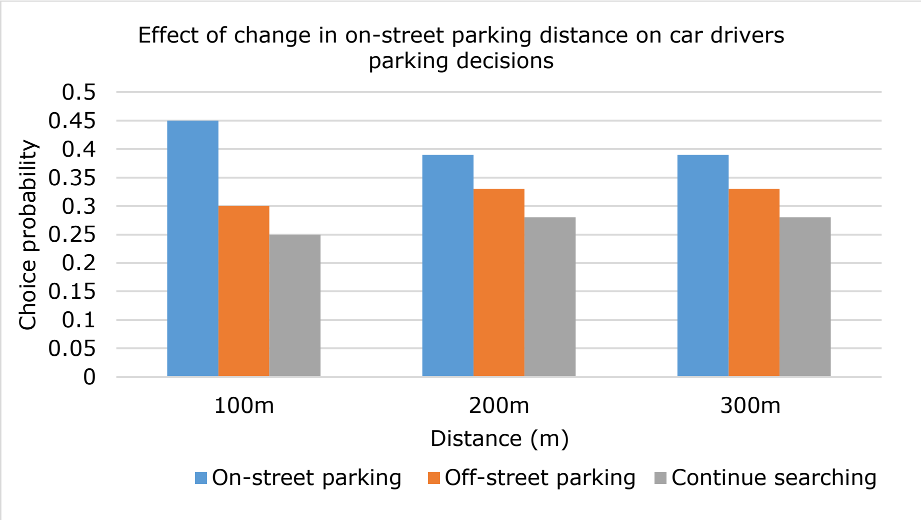

Figure 5.11. Car drivers' parking decisions with respect to change in distance of both off-street and off-street parking

Keeping in view all these model predictions it can be deduced that the effect of change of significant attributes such as parking cost, surrounding activities, speed limit and parking duration show more influence on car drivers parking decisions and are more realistic compared to the insignificant attributes which only show limited influence on car drivers parking decisions.

5.8. Conclusions

The study described in this chapter aims at providing more insights into simulation of car drivers' on-street parking decisions regarding trips to inner city. A set of hypothetical street conditions are presented to the respondents and their parking choices are recorded. The model analyses show that characteristics of parking and road conditions significantly influence car drivers' parking decisions. The most influential characteristic is parking costs; speed limit and surrounding activities. It can be deduced from the simulations that attributes having significant mean and standard deviation are showing useful results (more fluctuations in probabilities). In future, the influence of personal characteristics along with parking and road conditions should be investigated. Interestingly, the identified parking preferences are generic and not time dependent. Nevertheless, it seems useful to repeat the study in other areas with different parking conditions and with different levels of parking problems. For planners the results of this study are useful when setting up measures to decrease parking problems in city centers.

For example, to increase the utilization of off-street parking garages in the city center, the introduction of paid parking can be accompanied by the introduction of guarding at the parking. These insights can be incorporated in an agent-based simulation model to investigate effect of cruising in more detail. To show the working of the model, several simulations using the estimated model with main effects only, were carried out. For planners the results of this study are useful when setting up measures to decrease parking problems in city centers. The 'best' application of such models can be done using multi-agent systems to find out other policy relevant parameters such as effect of parking congestion on travel time and travel distance.

5.9. Discussion

The results presented in Table 5.1 are useful because these determine individual taste differences among respondents regarding parking and road conditions. The model estimates show that speed limit, on-street and off-street parking costs, level of parking convenience and parking duration highly affect car drivers parking decisions so these factors can be controlled in order to change car drivers parking decisions. The results from the simulations clearly indicate the significance of all the highlighted factors on car drivers' parking choices. The model is not able to simulate the actual effect of these factors related to parking and road on daily travel schedules of people such as delay in travel time or travel behavior, but the model is well able to highlight effect of change in these parking and road related factors on car drivers parking choices that is necessary for policy making. With the use of Monte Carlo simulations we can determine the parking decisions of a car driver that is useful and easily understandable for policy makers. It does not require extra time or effort to identify how a change in one factor can affect car drivers' parking decisions. If this model is integrated with a traffic simulator, it can predict choices of car drivers in a network quite comprehensive. The unique thing about this model is that it identifies car drivers' parking decision making process while they are driving. Therefore, different policies can be easily tested by using this model. However, effect of personal characteristics along with parking and road characteristics can also be investigated in future research.

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6. Conclusions and Future research direction

Parking is an important and complex policy instrument for urban planners and policymakers. In this thesis an attempt is made to shed more light on factors that effect on-street parking choices of car drivers in order to identify which of the parking and road related factors induce search traffic. Some of the outlines of research are given below:

- Car drivers' on-street parking decisions have been investigated using Hierarchical information integration approach.
- A general framework to demonstrate car drivers' on-street parking decisions is provided.
- On-street parking decisions of car drivers' have been investigated using discrete choice models (Standard Multinomial logit model and Mixed logit models).
- The results of model estimation for parking measure evaluation have been demonstrated using Monte-Carlo simulations.

The main research question was to explore parking and road related factors that affect car drivers' on-street parking choices. The answer to this question has been explored by employing several strategies mentioned step by step in each chapter below.
Chapter 2 describes a review of several parking choice studies conducted to analyze the parking choice behavior of car drivers. In this review, studies that highlight factors affecting parking choice have been determined. The main research question addressed in this chapter is: "Which factors related to parking choices of car drivers have been identified in the literature?. The aim of the chapter is twofold: first to highlight factors affecting parking choices and identify which factors have been overlooked. Secondly, several categories of parking choice simulation models have been listed. This sort of review is useful for researchers to identify future research direction.

This chapter also highlights various approaches that have been used for collecting car drivers' preferences regarding parking. Moreover, factors affecting on-street and off-street parking have been mentioned separately. In a nutshell, it can be observed that on-street parking choice of car drivers need significant attention, because people find it convenient to park on-street rather parking off-street. There is a need to design on-street parking policy that helps meet local needs keeping in view the mobility goals of the city. Understanding how people make parking decisions is crucial for urban parking policy applications with associated environmental and economic benefits. It is suggested that future research should focus more on on-street parking to devise smart solutions for better parking management.

Chapter 3 describes the investigation of car drivers' parking decisions using a stated choice experiment, based on the method of integrated hierarchical information integration. According to this approach, a large set of parking and road related attributes and attribute levels are grouped into two higher order decision constructs, which are presented as hypothetical street segments. The respondents were asked if they would park their car in the street segment with the listed attributes. The collected data is used to estimate the parameters of a standard multinomial logit model. The sample size for two constructs was calculated using the number of attribute levels and the number of choice tasks presented. In total, 548 respondents completed the questionnaire which was in line with the sample size. Keeping in view the literature, only a limited number of studies focused on car drivers' on-street parking choice decisions. The basic aim of this research is to identify factors affecting on-street parking preferences of car drivers by presenting a large set of street parking related attributes. Major benefit of this approach is to reduce respondents' biasness as a large set of attributes divides respondents' attention to several parking related attributes. This study differs from previous studies as a large range of attributes is examined, including the both parking and road conditions in a street segment along with some features of off-street parking facilities present in the vicinity of the street segment. The results indicate that the contextual variables such as 'walking distance to destination' and 'parking cost' are key attributes that the car drivers consider while making on-street parking decisions, while road attributes such as 'occupancy', 'security' and 'surrounding activities' seem to have only a minor impact. The study concludes with an outlook of how these insights into car drivers' parking choice process can be used by local authorities to reduce cruising in urban areas.

Moreover, this approach highlights preferable on-street parking conditions that can help planners to reduce cruising for parking. A large set of parking and road related attributes broaden the range of possible parking policies, as parking choice has wide implications for parking and traffic policy. Nowadays, municipalities are employing parking policies that restrict streets for on-street parking and direct car drivers to other streets or off-street parking facilities. Such policies are inducing search traffic as more time is required by car drivers to find an optimal parking place and also more time is required to walk from selected parking space to final destination. Therefore, this approach can identify which other measures cities can take to reduce such issues.

Chapter 4 describes a model proposed to investigate cars drivers' on-street parking decisions considering parking and road attributes. The model is designed to evaluate parking decisions of car drivers' to the city center by considering time pressure and parking pressure. Existing literature focuses on models explaining mainly off-street parking choices of car drivers, but none of the studies aid in identifying car drivers' parking decisions keeping in view the actual conditions of roads. The model is capable of investigating car drivers' reactions who are facing certain parking and road conditions set by various attributes. The basic aim is to identify car drivers' parking preferences with respect to certain parking and road conditions and explore preferable parking and road conditions that induce search traffic which can later be avoided using relevant parking measures. This means considering on-street parking as a tool to achieve convenience and accessibility in the city center. Until now, the existing literature highlights only a limited set of attributes thus parking decisions of car drivers in response to changes in parking policy cannot be predicted. A comparison between MNL model estimates and MMNL estimates show that MMNL model fits the data better.

Chapter 5 describes the application of the extensive behavioral model developed in the previous chapter, for predicting on-street parking choices of car drivers in response to changes of road or parking conditions due to parking measures. This model predicts car drivers' parking choices based on the principle of utility maximization. The model included 13 trip, parking, and road related attributes. The data for the estimation of the parameters is collected through a stated preference experiment and focuses on car drivers' decision to park their car on-street in the visited street segment, to park the car in the nearest off-street parking facility, or to continue searching for a more suitable parking location. The choices of car drivers are evaluated using a Mixed Multinomial Logit Model. The following attributes significantly contribute to the utility of on-street parking decision: the number of streets visited before entering the street, the expected parking duration, the distance between road segment and final destination, the costs of on-street parking, the costs of off-street parking, the level of parking convenience, the level of road convenience, parking spaces availability and the maximum speed at a road. The choice of off-street parking is significantly influenced by the distance between road segment and nearest off-street parking, the costs of off-street parking, the expected parking duration, and the type of activity along the road. With the results of the model estimation a simulation is setup to illustrate the working of the model when investigating the effects of certain parking measures. With the simulation, the effects of (a) surrounding activities (b) speed limit (c) parking duration (d) the introduction of paid parking or an increase of the on-street parking cost from 1.00 euro to 2.00 euro are evaluated. The simulation shows clearly the changes in probabilities of on-street parking, off-street parking, and continue to search due to the parking cost changes. Similarly, effects of other parking and road conditions such as parking duration, speed limit and surrounding activities are also determined. Simulation results show that cruising is highest for short term trips such as performing recreation or shopping activities and at a high on-street parking tariff.

6.1. Limitations

This research has identified some of the factors related to parking and road (such as speed reduction or changing parking tariff) that can be controlled by the municipalities or local authorities to reduce cruising for parking. This in turn reduces traffic congestion and other issues related to traffic flow. Each chapter of this thesis presents some limitations. These limitations consist of missing information from literature because several parking studies are published that investigated parking issues using different methodologies such as GPS traces, video analysis etc. These are not under the scope of current research (investigating car drivers' parking choices under hypothetical road conditions) therefore not included in literature.

A major consideration that can be paid in the current research is that a more detailed analysis of data is required such as developing separate models based on socio-demographic factors such as separate choice model for males and females and their comparisons could be performed. Another consideration about the sample can be that it consists of respondents mainly from Belgium. Therefore, the results of the study indicate the preferences of Belgian community. These may not remain true for other countries. The study does not focus on traffic simulation where the interactions of agents and the effect of their parking decisions on other agents can be identified for a more realistic representation of parking issues in combination with travel behavior. Although, the data has been checked for ambiguities (such as the amount of time taken by the respondent to fill out the questionnaire), but the fact that if the selection of the alternative by the respondent was logical and either the respondents actually read and understood the task cannot be identified. Less number of significant attributes can also be considered a limitation that can be reduced in future by increasing the number of observations (more choice tasks per respondents).

Moreover, limited attention is paid towards the contextual attributes such as weather conditions, time of the day or travel group characteristics, these can be incorporated in the design of choice tasks. This information can be used to investigate car drivers preferences for different travel purposes, under different weather and temporal conditions and travel group characteristics. Time pressure is not explicitly represented in the choice task making choices situation based rather time based. Another consideration is that the external validation of the model could not be performed in the current phase of research this can be considered as a future research direction. Moreover, the effect of personal attributes (socio-demographic factors) on car drivers' parking choices along with parking and road conditions has not been investigated in the current research, this can be considered another limitation. All these limitation can be explored in future research.

6.2. Recommendations for practice

Understanding and modeling parking behavior is essential for urban planning and parking management. It is necessary to identify, quantify and model all the relevant factors influencing individual parking behavior and decision-making processes. In order to plan sustainable future urban mobility systems, a set of forecasting tools is needed to help make well-informed and consistent assessments of future conditions under various scenarios. This research is unique in such a way that it provides policy makers, urban planners and decision makers with a complete picture of different parking and road related attributes that affect car drivers' parking decisions and how these characteristics can be used in policy making to design parking management and overall travel demand management goals. As policy makers are extremely interested in knowing, before implementing a given policy, what the most likely reactions will be in terms of achievement of the desired objectives.

The analyses from model results highlight the attributes that significantly affect car drivers' parking decisions while driving. It can be noticed that only a few attributes are significant. This shows that respondents only consider a limited set of attributes (the significant ones) while making parking decisions. The insignificant attributes are also important because they have part worth utilities that describe the effect of attribute levels on parking decisions of car drivers. For example, payment options are insignificant but it indicates which type of payment mode is preferred (cash and bank card from multinomial logit model (MNL) estimates). Similarly, mixed logit model provides individual taste differences that shows the impact of parking and road conditions at individual level. This means that at individual preference level (assuming all individuals are different keeping in view their emotions and feelings) which of the attributes contribute to parking choices such as number of streets visited, maximum parking duration and level of parking convenience. This shows that at an individual level car drivers do consider these attributes while making parking decisions. This information is useful for analysts and travel demand modelers to develop realistic models for depicting actual parking choice behavior of car drivers. Such detailed investigation provides firm guidelines while devising policy measures to decrease parking problems in city centers and investigating the reactions of car drivers' with respect to the devised policies (such as investigating reaction of car drivers with change in parking tariff, speed reduction, change in payment methods or security measures). This research is also useful for depicting parking issues from car drivers' perspective e.g. which payment mode is preferred by the drivers; either they prefer to have CCTV cameras or guards for security, so they can decide where to park. Such information also makes parking policies more acceptable by the users.

6.3. Recommendations for future research

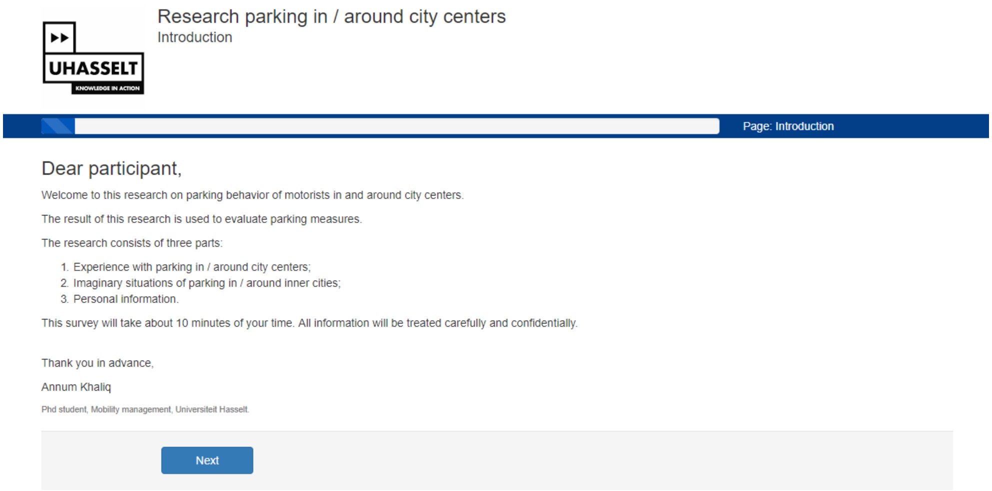
This research has provided scientific contribution by using Integrated Hierarchical Information Integration approach in the context of investigating car drivers' parking choices. The attributes such as occupancy rate (high occupancy show peak hours) and maximum parking duration indicate time pressure, thus the model do consider that the driver has to make decision keeping in view time pressure and parking pressure on the road. The model also assumes that the driver possesses advance knowledge of the area and has experience with on-street parking attributes such as available payment options. It should be noticed that the identified parking preferences are generic and not time dependent. Moreover, the effect of personal attributes (socio-demographic factors) and travel group composition on car drivers' parking choices along with parking and road conditions can also be investigated in the future research. Other behavioral approaches such as theory of planned behavior can also be considered for investigating car drivers' parking decisions (there is evidence in the literature about the use of this theory for mode choice but its application in parking still needs to be explored).

In order to investigate a detailed effect of parking measures on traffic flow, the results from this research can be used to develop multi-agent systems or traffic simulation models. Such models can identify in detail the effect of change in parking measures on travel time and travel distance. In addition, the interactions of agents and the effect of their parking decisions on other agents can be identified. In order to conduct a more detailed stated choice investigation driver simulation can also be used in future research. This can offer a better view of parking and road conditions to respondents than mere text and assumptions. The choice tasks presented to each respondent can also be extended for more detailed investigation of parking choices with respect to target groups so that latent class models can be used for analyses of data. The results from the current research can also be used for autonomous vehicles. As these vehicles are very much in debate nowadays but they still need to be parked somewhere. Therefore, the parking decision has to be made even in case of autonomous vehicles (which requires car driver preferences to follow the suggestion). Moreover, this research can also be conducted in other countries where car drivers' parking preferences need to be investigated with respect to parking and road conditions, however, attribute levels need to be adjusted with the local condition of the study area to provide more realistic results.

Based on the current research some other main suggestions for further research can be drawn. Even though in the last decades more academics have studied parking related topics and more professionals have come across some academic studies on parking, the gap between academics and parking professionals (urban planners, policy makers, advisers…) is still considerable and the interaction among them is still poor. There is a mismatch between the knowledge needed by professionals and the knowledge produced by academics, often because academics are driven by different goals than policy makers. Behavioral realism and complexity is one of the major issue faced by the analysts. The challenge is to sufficiently represent a decision process so that valid results are achieved. These results should not only match traveler behavior, but also yields useful information to be used by decision makers. Future academic research on parking should aim to bridge this gap in order to help policy makers produce more evidence based parking policies. Also more quantitative but practically useful research on parking is necessary. The analysis of these empirical data sets can provide very useful information about car parking behavior and the effects of different policy measures for making parking policies. Such policies are more acceptable/successful on ground level rather than mere documentation. Therefore, it is necessary that the scientific community make policy makers better understand parking issues and their possible solutions.

Appendix I

Online Questionnaire



UHASSELT KNOWLEDGE IN ACTION

Research parking in / around city centers

Introduction

Page: Introduction

Dear participant,

Welcome to this research on parking behavior of motorists in and around city centers.

The result of this research is used to evaluate parking measures.

The research consists of three parts:

1. Experience with parking in / around city centers;
2. Imaginary situations of parking in / around inner cities;
3. Personal information.

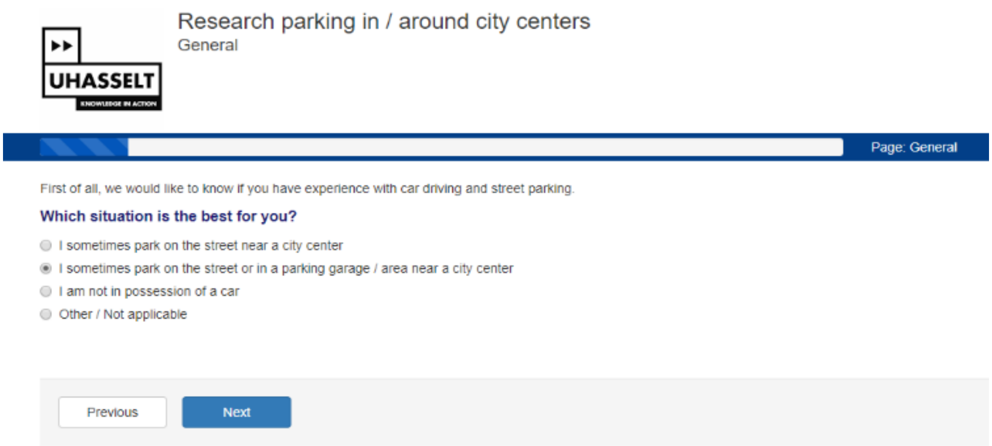
This survey will take about 10 minutes of your time. All information will be treated carefully and confidentially.

Thank you in advance,

Annum Khaliq

Phd student, Mobility management, Universiteit Hasselt

Next



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Research parking in / around city centers

General

Page: General

First of all, we would like to know if you have experience with car driving and street parking.

Which situation is the best for you?

- I sometimes park on the street near a city center
- I sometimes park on the street or in a parking garage / area near a city center
- I am not in possession of a car
- Other / Not applicable

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UHASSELT

Research parking in / around city centers

Parking experiences

Page: Parking Experiences 1

First of all, we would like to know if you have experience with car driving and street parking.

Which of the following types of cities do you sometimes visit by car?

	Never	Rarely	Regularly	Often
Big city	○	○	○	●
Medium city	○	●	○	○
Small city	○	●	○	○
Other city	○	●	○	○

For what reason (s) do you usually park in the street near a city center? (multiple answers possible)

- [ ] Living
- [ ] Shop
- [ ] Work / study
- [ ] Leisure

Otherwise, namely:

How often do you park on the street?

- ○ Every weekday
- ● 2-3 times a week
- ○ Once a week
- ○ Once every 2-3 weeks
- ○ Once per month
- ○ 2-3 times per half year
- ○ Once every six months or less

How many minutes do you usually have to walk between your parking location and final destination?

- ○ Less than 3 minutes
- ● 3-5 minutes
- ○ 6-8 minutes
- ○ 9-11 minutes
- ○ More than 11 minutes

How much time does it usually take to find an available parking space on the street (for leisure / work / shopping)?

- [ ] Immediately after arrival

Record time in minutes: 12

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Research parking in / around city centers

Parking experiences

Page: Parking Experiences 3

Where do you prefer to park the following weather conditions?

	On the street	On a parking lot	In a parking garage
High temperature (more than 25 degrees)	○	◉	○
Average temperature (between 15 and 25 degrees)	◉	○	○
Low temperature (less than 15 degrees)	○	◉	○

Where do you prefer to park the following weather conditions?

	On the street	On a parking lot	In a parking garage
Heavy rainfall	○	◉	○
Drizzle	○	◉	○
Dry weather	○	◉	○

Where do you prefer to park the following composition of your travel group?

	On the street	On a parking lot	In a parking garage
Traveling with others	○	◉	○
Traveling alone	○	◉	○

Where do you prefer to park the following travel motifs?

	On the street	On a parking lot	In a parking garage
Work movement	○	◉	○
Shop move	○	◉	○
Leisure movement	○	◉	○

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Research parking in / around city centers
Parking experiences

Page: Parking Experiences 2

How do you receive your information about available parking spaces on the street? (multiple answers possible)

- ☐ I do not use any information.
- ☐ Mobile app
- ☐ Parking signage

Otherwise, namely:

How does your parking use in the street compare with parking in parking garages and grounds?

	100% on the street	75% on the street / 25% parking garages and terrains	50% on the streets / 50% parking garages and terrains	25% on the street / 75% parking garages and terrains	100% parking garages / and grounds	
On the street	◉	○	○	○	○	Parking garages and grounds

Which of the following problems do you encounter when parking on the street? (Multiple answers possible)

- ☐ Unknown with the environment
- ☑ Lack of information about free parking spaces
- ☐ Disrupted by nearby land use (playground, school, restaurant, shop)
- ☐ Difficult parking by design parking spaces (insufficient width / length)
- ☐ Confusing parking rules (rules and costs related to certain times)
- ☐ Insufficient street lighting
- ☐ Awkward payment options

Otherwise, namely:

On which of the following streets can you park the most difficult, considering your parking experience? (multiple answers possible)

- ☑ Residential street
- ☐ Shopping district

Different street type, namely:

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UHASSELT
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Research parking in / around city centers
Choice experiment, introduction

Page: Introduction_situations

Explanation

This part of the research shows you imaginary streets you drive through during your journey from your home to a random city center. The conditions in a street are described with the help of multiple parking and street characteristics. These characteristics can take different values. We ask you to make a choice if you enter the street and are looking for a suitable parking space. You can choose from the following options: Street **parking** (in the described street), **Divert to parking garage or parking area** or **Continue search** .

The basic **travel and parking features** for street parking are shown below. These characteristics describe your (imaginary) movement and the parking situation on the street.

- **Expected parking time:** *Less than 60 minutes, Between 60-120 minutes, More than 120 minutes*
- **Number of streets already visited:** *No streets, 1 street, 2 or more streets*
- **Distance to destination:** *100 meters, 200 meters, 300 meters*
- **Payment options:** *Smartphone app* , *Card* , *Cash*
- **Parking costs:** *Free, 1.00 Euro / hour, 2.00 Euro / hour*

In addition, parking features are included for the nearest **parking garage / site** :

- **Distance to nearest parking garage / site:** *100 meters, 200 meters, 300 meters*
- **Parking fee for parking garage and parking area:** *0.50 Euro / hour, 1.50 Euro / hour, 2.50 Euro / hour*

For your convenience, we have also divided various parking and street features into categories. These categories are explained further on the next page.

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Research parking in / around city centers
Choice experiment, explanation

Page: Explanation

Explanation

We want to familiarize you with the choice situations of this research with a sample question. You will always see a table with three parking options (Street **parking** , **Dodge to parking garage / site** or **Continue search**).

We distinguish **two categories** with regard to the street. These categories are important when choosing a parking space on the street and contain:

1. **Parking situation**
2. **road situation**

Each category includes **three characteristics** . These characteristics vary at different values. The category **'Parking situation'** contains the following three characteristics with associated values:

a. **Maximum parking duration:** Unlimited, 2 hours, 4 hours
b. **Occupancy rate:** High, 100%; Average, 75%; Low, 50%
c. **Security present: Security guards** , CCTV camera, None

Each table shows **one category** in detail, as mentioned above. The other category is indicated by the following **three values** . These values represent the service quality of the category:

- (High service level)
- (Average service level)
- (Low service level)

For example, if the category **'Parking situation' is** described with *'High service level'* (indicated by :) , then there is a good service level for parking with *a low occupancy rate and multiple payment options. A 'Limited service level'* ( ) *means that the street offers a lower service level with limited parking duration and a high occupancy rate.*

You will see several tables. One category is discussed in detail in each table. On the next page you will first find a sample question.

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Research parking in / around city centers

Choice experiment, example task

Page: ExampleQuestion

The table below shows an example of a choice situation where one situation is defined. View the situation carefully and indicate whether you will park in this street or not. You can make your choice known at the bottom of the table.

Imagine yourself entering a street and looking for a suitable parking space. Below you see the details of your trip and a situation sketch of that street. The question is' Are you going to park your car here *on the street* , go to the nearest *parking garage / site* , or are you *looking* for another parking space on the street?

Characteristics	Situation
Parking on the street	
Estimated parking duration	*Less than 60 minutes*
Number of streets already visited	*2 or more streets*
Payment options	
Distance to destination	*200 meter*
Parking costs	*2.00 euros / hour*
Parking garage / site	
Distance to parking garage / site	*200 meter*
Parking fee parking garage / grounds	*2.50 Euro / hour*
Detailed parking situation	
Maximum parking time	*4 hours*
Occupancy rate	*Average, 75%*
Available security	
Global road situation	
Convenience level	
What would you choose in this situation?	Parking on the street Dodge to parking garage / site Search further

This was an example question. We hope that you can assess the **following 2 comparable situations** based on the explanation given.

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Research parking in / around city centers

Page: ParkingSituation

Parking situation

The following table is about the **parking situation** . You will see a situation where the characteristics related to parking on the street are highlighted. We ask you to choose one of the following parking options: Street **parking** , **Divert to parking garage / site** , or **Continue search** . The **parking situation** category contains the following three characteristics with corresponding values:

a. **Maximum parking duration:** *Unlimited, 2 hours, 4 hours*

b. **Occupancy rate:** *High, 100%; Average, 75%; Low, 50%*

c. **Available Security:** *Security guards*  , *CCTV cameras*  , *None* 

On the next page you will see a table in which you are asked to make a choice based on a detailed description of the parking situation.

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Research parking in / around city centers

Parking situation

Page: CategoryParking

Detailed parking situation

Imagine yourself entering a street and looking for a suitable parking space. Below you see the details of your trip and a situation sketch of that street. The question is' Are you going to *park* your car here *on the street* , to the nearest *parking garage / site* , or are you *looking* for another parking space on the street?

Characteristics	Situation
Parking on the street	
Estimated parking duration	*More than 120 minutes*
Number of streets already visited	*1 street*
Payment options	
Distance to destination	*100 meter*
Parking costs	*Free*
Nearest parking garage / site	
Distance to parking garage / site	*100 meter*
Parking fee parking garage / grounds	*2.50 euros / hour*
Detailed parking situation	
Maximum parking time	*4 hours*
Occupancy rate	*Low, 50%*
Available security	
Global road situation	
Convenience level	
What would you choose in this situation?	Parking on the street Dodge to parking garage / site Search further

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Research parking in / around city centers

Parking situation

Page: CategoryParking

Detailed parking situation

Imagine yourself entering a street and looking for a suitable parking space. Below you see the details of your trip and a situation sketch of that street. The question is' Are you going to *park* your car here *on the street* , to the nearest *parking garage / site* , or are you *looking* for another parking space on the street?

Characteristics	Situation
Parking on the street	
Estimated parking duration	*Between 60-120 minutes*
Number of streets already visited	*1 street*
Payment options	
Distance to destination	*300 meter*
Parking costs	*2.00 euros / hour*
Nearest parking garage / site	
Distance to parking garage / site	*100 meter*
Parking fee parking garage / grounds	*2.50 euros / hour*
Detailed parking situation	
Maximum parking time	*4 hours*
Occupancy rate	*High, 100%*
Available security	
Global road situation	
Convenience level	
What would you choose in this situation?	Parking on the street Dodge to parking garage / site Search further

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UHASSELT KNOWLEDGE IN ACTION

Research parking in / around city centers

Page: RoadConditions

road situation

The following table is about the **Situation of the road** . This category concerns the situation of the road where parking on the street is permitted. You will see a situation where the characteristics related to the road situation have been highlighted. You can choose from one of the following parking options **Parking on the street** , **Diverting to parking garage / parking area** , or **Search further**).

The category **'Situation of the road'** contains the following three characteristics with associated values:

a. **Average number of available parking spaces per 100 meters:** *10 places / 100 meters, 15 places / 100 meters, 20 places / 100 meters*

b. **Surrounding activities:** *Playground / school, Shops, Homes*

c. **Permissible maximum speed:** *20 km / h, 40 km / h, 60 km / h*

On the next page you will see a table in which you are asked to make a choice based on a detailed description of the road situation.

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Research parking in / around city centers

road situation

Page: CategoryRoad

Detailed road situation

Imagine yourself entering a street and looking for a suitable parking space. Below you see the details of your trip and a situation sketch of that street. The question is' Are you going to *park* your car here *on the street* , to the nearest *parking garage / site* , or are you *looking* for another parking space on the street?

Characteristics	Situation
On-street parking	
Estimated parking duration	*More than 120 minutes*
Number of streets already visited	*1 street*
Payment options	
Distance to destination	*100 meter*
Parking costs	*Free*
Nearest parking garage / site	
Distance to parking garage / site	*100 meter*
Parking garage / parking space fee	*2.50 euros / hour*
Detailed road situation	
Available parking places per 100 meters	*20 courses / 100 meters*
Surrounding activities	*Houses*
Permissible maximum speed	*20 km / hour*
Global parking situation	
Convenience level	
What would you choose in this situation?	Parking on the street Dodge to parking garage / site Search further

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TU/e Technische Universiteit Eindhoven University of Technology

Research parking in / around city centers
road situation

Page: CategoryRoad

Detailed road situation

Imagine yourself entering a street and looking for a suitable parking space. Below you see the details of your trip and a situation sketch of that street. The question is' Are you going to *park* your car here *on the street* , to the nearest *parking garage / site* , or are you *looking* for another parking space on the street?

Characteristics	Situation
On-street parking	
Estimated parking duration	*Less than 60 minutes*
Number of streets already visited	*1 street*
Payment options	
Distance to destination	*100 meter*
Parking costs	*1.00 euros / hour*
Nearest parking garage / site	
Distance to parking garage / site	*200 meter*
Parking garage / parking space fee	*0.50 euros / hour*
Detailed road situation	
Available parking places per 100 meters	*10 courses / 100 meters*
Surrounding activities	*Houses*
Permissible maximum speed	*60 km / hour*
Global parking situation	
Convenience level	
What would you choose in this situation?	○ Parking on the street ○ Dodge to parking garage / site ○ Search further

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Research parking in / around city centers

Page: Personal

Some information about you.

What is your gender?

- Man
- Woman

What is your year of birth?

make a choice

What is your highest education?

- Primary education / Primary education
- General secondary education (ASO)
- Art secondary education (KSO)
- Technical secondary education (TSO)
- Vocational secondary education (BSO)
- Exceptional secondary education (BUSO)
- Hogeschool (professional bachelor)
- University (academic bachelor and master)

How high is your gross family income?

- Less than 5000 euros per month
- Between 5000-7500 euros per month
- Between 7500-10000 euros per month
- More than 10,000 euros per month
- I prefer not to say

What type of car do you have?

- Small car (5.3 meters)
- Medium car (5.7 meters)
- Large car (6.3 meters)
- Different

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Appendix II

Multinomial Logit Estimates with Dummy coding

```
Start values obtained using MNL model
Dependent variable              Choice
Log likelihood function     -1917.09493
No coefficients -2416.9470  .2750 .2641
Estimation based on N =   2200, K =  62
Inf.Cr.AIC  =   3958.2 AIC/N =    1.799
Model estimated: Feb 16, 2018, 15:59:16
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -2098.1977  .0863 .0726
Response data are given as ind. choices
Number of obs.=  2200, skipped    0 obs
```

KEUZE	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
ICONS1	1.25774***	.35407	3.55	.0004	.56377	1.95171
ICONS2	.41771	.37635	1.11	.2670	-.31993	1.15535
IPO1	.02366	.18868	.13	.9002	-.34615	.39346
IPO2	.14539	.19129	.76	.4472	-.22954	.52032
IDOFF1	.12238	.19098	.64	.5216	-.25194	.49671
IDOFF2	.05363	.18947	.28	.7772	-.31774	.42499
IOTAR1	.08337	.19428	.43	.6678	-.29742	.46416
IOTAR2	-.05097	.17411	-.29	.7697	-.39223	.29028
ISTRV1	.11970	.19327	.62	.5357	-.25911	.49851
ISTRV2	-.06855	.19015	-.36	.7185	-.44123	.30413
IEDUA1	-.19758	.20136	-.98	.3265	-.59224	.19708
IEDUA2	-.41562**	.19506	-2.13	.0331	-.79793	-.03332
IPCOS1	.40467**	.19559	2.07	.0386	.02132	.78803
IPCOS2	-.64003***	.18975	-3.37	.0007	-1.01193	-.26813
IDISD1	.25938	.19610	1.32	.1859	-.12497	.64373
IDISD2	.12826	.18498	.69	.4881	-.23429	.49081
IPSIT1	-.33659	.23835	-1.41	.1579	-.80375	.13057
IPSIT2	.29478	.25921	1.14	.2554	-.21326	.80281
IMDUA1	.34956	.25759	1.36	.1748	-.15530	.85443
IMDUA2	-.09371	.24118	-.39	.6976	-.56641	.37900
ISECU1	.36896	.25230	1.46	.1436	-.12554	.86346
ISECU2	.00194	.24427	.01	.9937	-.47682	.48070
IORAT1	.40801	.24950	1.64	.1020	-.08101	.89702
IORAT2	-.11820	.24179	-.49	.6249	-.59209	.35569
IRCOND1	-.27093	.24281	-1.12	.2645	-.74684	.20497
IRCOND2	.14271	.27403	.52	.6025	-.39438	.67981
IACT1	-.04263	.25125	-.17	.8653	-.53507	.44981
IACT2	.36278	.25978	1.40	.1626	-.14638	.87194
ISLIM1	.38250	.24774	1.54	.1226	-.10306	.86806
ISLIM2	.52083**	.25643	2.03	.0422	.01824	1.02343
IPARK1	.00541	.25811	.02	.9833	-.50048	.51130
IPARK2	-.04586	.25359	-.18	.8565	-.54289	.45116
JPO1	.08909	.19259	.46	.6436	-.28837	.46656
JPO2	.04754	.19614	.24	.8085	-.33689	.43196
JDOFF1	.18089	.19640	.92	.3570	-.20404	.56582
JDOFF2	.24069	.19268	1.25	.2116	-.13695	.61832
JOTAR1	1.37764***	.19950	6.91	.0000	.98663	1.76865

JOTAR2	.75050***	.18458	4.07	.0000	.38873	1.11227
JSTRV1	.04712	.19841	.24	.8123	-.34176	.43599
JSTRV2	-.12146	.19432	-.63	.5319	-.50232	.25939
JEDUA1	-.29914	.20535	-1.46	.1452	-.70161	.10333
JEDUA2	-.51015***	.19803	-2.58	.0100	-.89827	-.12202
JPCOS1	-.37184*	.20587	-1.81	.0709	-.77534	.03166
JPCOS2	-.01743	.18727	-.09	.9258	-.38447	.34961
JDISD1	.09478	.19867	.48	.6333	-.29460	.48416
JDISD2	-.09159	.18818	-.49	.6265	-.46041	.27723
JPSIT1	-.10139	.24464	-.41	.6785	-.58088	.37809
JPSIT2	.26039	.26713	.97	.3297	-.26317	.78395
JMDUA1	.46269*	.26320	1.76	.0788	-.05317	.97855
JMDUA2	.09453	.24544	.39	.7001	-.38652	.57557
JSECU1	.16219	.25937	.63	.5318	-.34616	.67055
JSECU2	.06418	.24424	.26	.7927	-.41453	.54289
JORAT1	.22067	.25815	.85	.3927	-.28531	.72664
JORAT2	.12338	.24505	.50	.6146	-.35691	.60367
JRCOND1	.09375	.24963	.38	.7073	-.39552	.58301
JRCOND2	.18915	.28486	.66	.5067	-.36917	.74748
JACT1	.44383*	.25764	1.72	.0849	-.06112	.94879
JACT2	.51999*	.26965	1.93	.0538	-.00851	1.04849
JSLIM1	.00291	.25650	.01	.9910	-.49982	.50563
JSLIM2	.16721	.26218	.64	.5236	-.34665	.68107
JPARK1	-.04748	.26306	-.18	.8568	-.56306	.46810
JPARK2	.01089	.26284	.04	.9670	-.50427	.52604

Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

Mixed Multinomial Logit Estimates with dummy codding

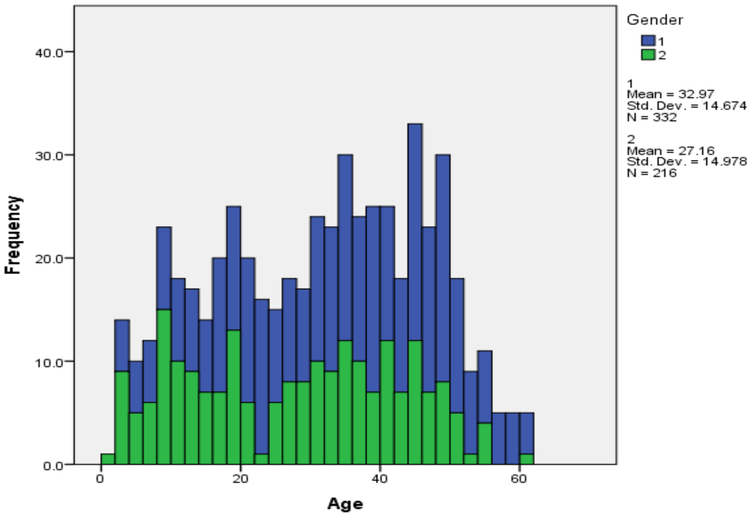
```
Random Parameters Logit Model
Dependent variable                KEUZE
Log likelihood function     -1720.94463
Restricted log likelihood   -2416.94704
Chi squared [  79 d.f.]      1392.00481
Significance level               .00000
McFadden Pseudo R-squared      .2879676
Estimation based on N =   2200, K =  79
Inf.Cr.AIC  =   3599.9 AIC/N =    1.636
Model estimated: Apr 24, 2018, 10:49:45
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
No coefficients -2416.9470  .2880 .2749
Constants only  -2098.1977  .1798 .1648
At start values -1917.0949  .1023 .0859
Response data are given as ind. choices
Replications for simulated probs. =1000
Used Halton sequences in simulations.
RPL model with panel has     550 groups
Fixed number of obsrvs./group=       4
Number of obs.=  2200, skipped    0 obs
```

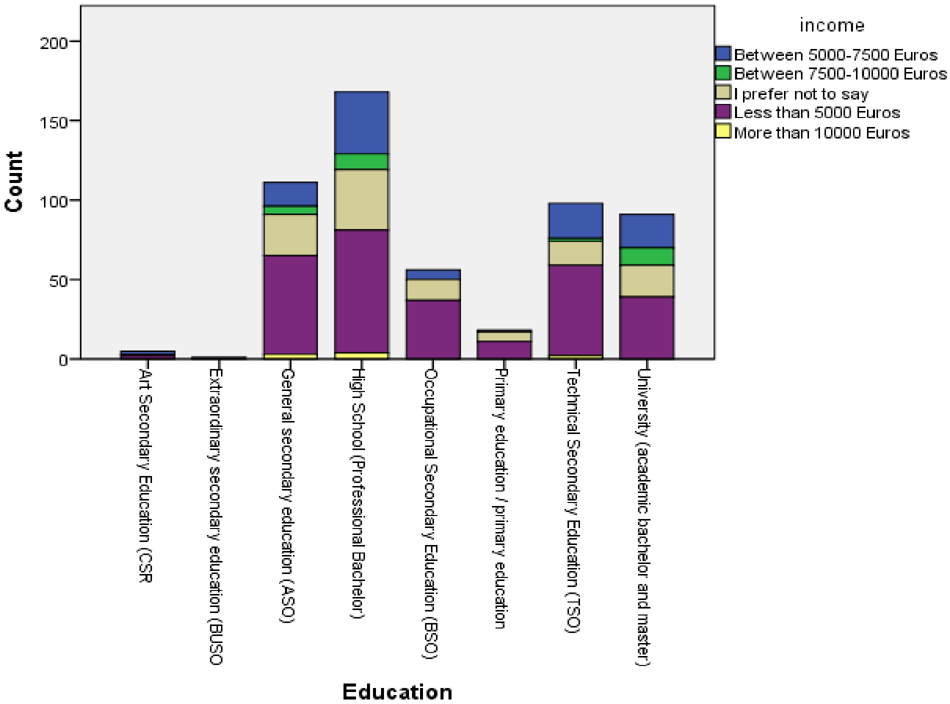
KEUZE	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
	Random parameters in utility functions					
ICONS1	1.51764**	.70958	2.14	.0325	.12689	2.90838
ICONS2	-.22313	.66461	-.34	.7371	-1.52575	1.07949
IDISD1	.75996*	.44375	1.71	.0868	-.10977	1.62969
ISTRV1	.74766	.46923	1.59	.1111	-.17200	1.66733
IDOFF1	-.03251	.41318	-.08	.9373	-.84234	.77732
IPARK1	.60119	.56689	1.06	.2889	-.50989	1.71227
IPARK2	-.07951	.54068	-.15	.8831	-1.13923	.98021
ISLIM2	.79421	.58473	1.36	.1744	-.35184	1.94025
ISLIM1	1.28421**	.59922	2.14	.0321	.10975	2.45866
IMDUA1	.58075	.58369	.99	.3198	-.56327	1.72477
IPSIT2	-1.00758*	.56628	-1.78	.0752	-2.11747	.10231
IPSIT1	1.05705*	.57136	1.85	.0643	-.06280	2.17690
JDOFF1	.53693	.36321	1.48	.1393	-.17494	1.24881
JOTAR1	3.61470***	.69105	5.23	.0000	2.26027	4.96913
JACT1	1.13079**	.49548	2.28	.0225	.15966	2.10191
JACT2	.62342	.48893	1.28	.2023	-.33486	1.58170
JSLIM1	-.23016	.45848	-.50	.6157	-1.12876	.66843
	Nonrandom parameters in utility functions					
IPO1	.12559	.39538	.32	.7508	-.64934	.90053
IPO2	.64870	.43183	1.50	.1330	-.19767	1.49507
IDOFF2	-.02463	.41592	-.06	.9528	-.83982	.79056
IOTAR1	.12092	.49888	.24	.8085	-.85686	1.09870
IOTAR2	-.77931*	.44217	-1.76	.0780	-1.64595	.08733
ISTRV2	.17329	.39010	.44	.6569	-.59128	.93787
IEDUA1	.05497	.44417	.12	.9015	-.81559	.92554
IEDUA2	-.24841	.41559	-.60	.5500	-1.06296	.56613
IPCOS1	1.63454***	.52446	3.12	.0018	.60662	2.66247
IPCOS2	-1.96981***	.58670	-3.36	.0008	-3.11971	-.81990
IDISD2	.60356	.39187	1.54	.1235	-.16449	1.37162
IMDUA2	-.33876	.50391	-.67	.5014	-1.32641	.64890
ISECU1	.46772	.52749	.89	.3752	-.56614	1.50158
ISECU2	.17504	.52331	.33	.7380	-.85063	1.20072
IORAT1	.84232	.53853	1.56	.1178	-.21318	1.89782

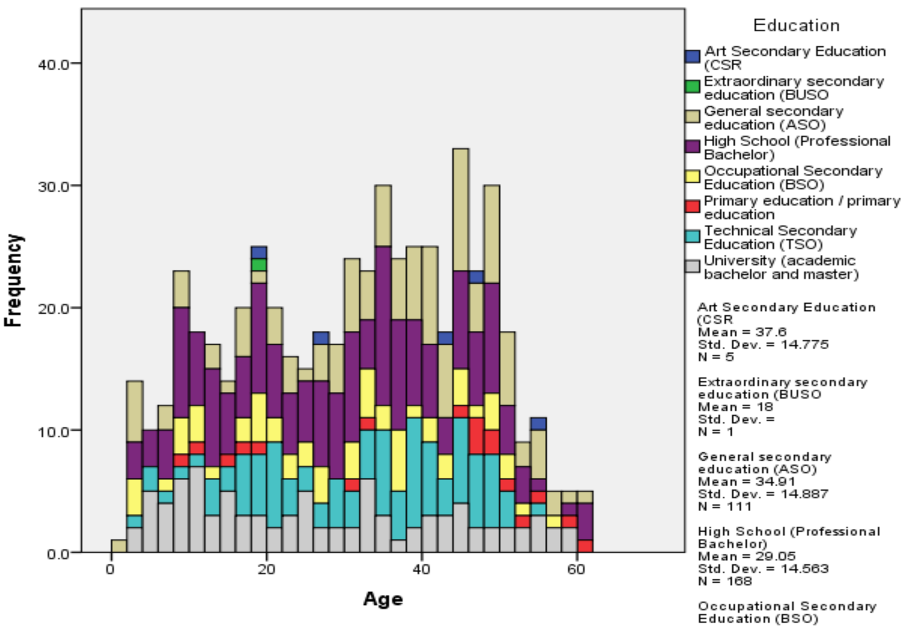
```
  IORAT2|   -.02245        .52053     -.04  .9656     -1.04267    .99777
  IRCND1|   -.94919*       .52311    -1.81  .0696     -1.97447    .07609
  IRCND2|    .64836        .59091     1.10  .2725      -.50981   1.80652
   IACT1|   -.28634        .55157     -.52  .6037     -1.36740    .79472
   IACT2|    .79491        .54927     1.45  .1478      -.28164   1.87146
    JPO1|    .45452        .35095     1.30  .1953      -.23334   1.14237
    JPO2|    .09344        .35370      .26  .7916      -.59980    .78669
  JDOFF2|    .66980*       .35723     1.87  .0608      -.03036   1.36995
  JOTAR2|   1.28250***     .32725     3.92  .0001       .64109   1.92390
  JSTRV1|    .00781        .36618      .02  .9830      -.70989    .72551
  JSTRV2|   -.34328        .34963     -.98  .3262     -1.02854    .34199
  JEDUA1|   -.36588        .36581    -1.00  .3172     -1.08285    .35110
  JEDUA2|   -.76138**      .36615    -2.08  .0376     -1.47903   -.04373
  JPCOS1|   -.82552**      .38555    -2.14  .0323     -1.58118   -.06986
  JPCOS2|    .27130        .34510      .79  .4318      -.40509    .94768
  JDISD1|    .38221        .35738     1.07  .2848      -.31823   1.08266
  JDISD2|   -.05694        .34291     -.17  .8681      -.72903    .61515
  JPSIT1|   -.02202        .41853     -.05  .9580      -.84232    .79829
  JPSIT2|    .75461        .47249     1.60  .1102      -.17146   1.68067
  JMDUA1|    .52159        .45975     1.13  .2566      -.37950   1.42268
  JMDUA2|    .16779        .43526      .39  .6999      -.68530   1.02088
  JSECU1|    .17468        .44197      .40  .6927      -.69158   1.04093
  JSECU2|    .46923        .43220     1.09  .2776      -.37785   1.31632
  JORAT1|    .27479        .44660      .62  .5384      -.60052   1.15010
  JORAT2|    .47165        .43022     1.10  .2729      -.37156   1.31487
  JRCND1|    .32815        .43619      .75  .4519      -.52677   1.18308
  JRCND2|    .55486        .52131     1.06  .2872      -.46689   1.57661
  JSLIM2|    .35962        .47990      .75  .4536      -.58096   1.30021
  JPARK1|   -.12022        .48286     -.25  .8034     -1.06661    .82617
  JPARK2|    .06703        .47165      .14  .8870      -.85738    .99145
        |Distns. of RPs. Std.Devs or limits of triangular
NsICONS1|   3.46409***     .64556     5.37  .0000      2.19883   4.72936
NsICONS2|   2.65258***     .40366     6.57  .0000      1.86141   3.44375
NsIDISD1|   2.31284**      .93727     2.47  .0136       .47582   4.14987
NsISTRV1|   2.79048***     .94173     2.96  .0030       .94473   4.63623
NsIDOFF1|   1.04424        .74976     1.39  .1637      -.42527   2.51375
NsIPARK1|   1.75256       1.22895     1.43  .1538      -.65613   4.16125
NsIPARK2|    .16044       1.46467      .11  .9128     -2.71026   3.03113
NsISLIM2|   2.49953*      1.32804     1.88  .0598      -.10337   5.10244
NsISLIM1|   2.52381**     1.08734     2.32  .0203       .39266   4.65496
NsIMDUA1|   3.79800***    1.25314     3.03  .0024      1.34188   6.25411
NsIPSIT2|   2.64518**     1.30613     2.03  .0428       .08522   5.20514
NsIPSIT1|   1.67492       1.35248     1.24  .2156      -.97589   4.32572
NsJDOFF1|    .04476        .54931      .08  .9351     -1.03187   1.12138
NsJOTAR1|   3.80507***     .89284     4.26  .0000      2.05513   5.55502
 NsJACT1|   1.59807*       .93858     1.70  .0886      -.24152   3.43767
 NsJACT2|   1.64908**      .79024     2.09  .0369       .10023   3.19792
NsJSLIM1|    .36186       3.70213      .10  .9221     -6.89418   7.61790
----+-----------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
----------------------------------------------------------------------
```

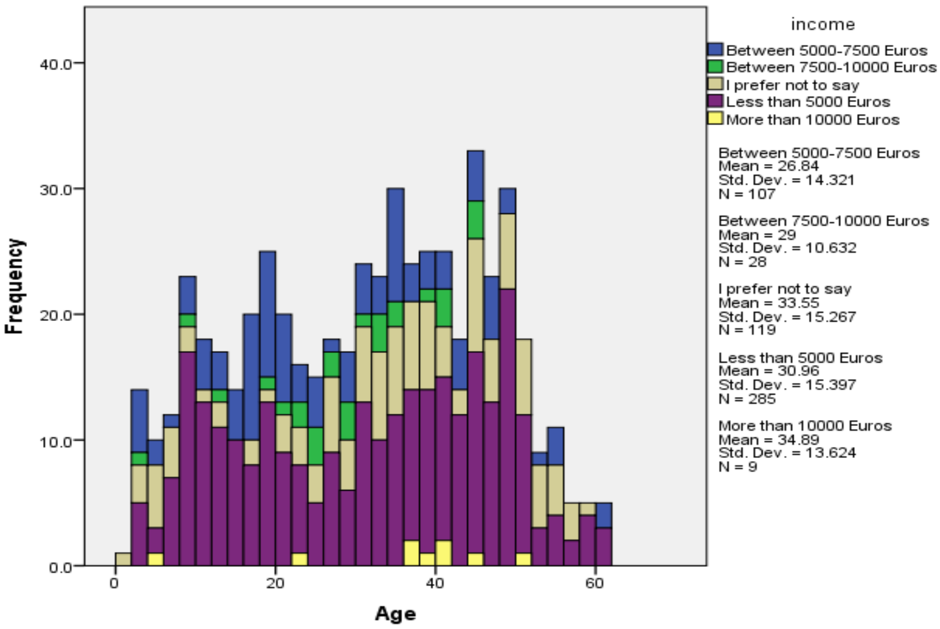
Appendix III

Descriptive Analysis of Data






Education
Art Secondary Education (CSR
Extraordinary secondary education (BUSO
General secondary education (ASO)
High School (Professional Bachelor)
Occupational Secondary Education (BSO)
Primary education / primary education
Technical Secondary Education (TSO)
University (academic bachelor and master)
Art Secondary Education (CSR
Mean = 37.6
Std. Dev. = 14.775
N = 5
Extraordinary secondary education (BUSO
Mean = 18
Std. Dev. =
N = 1
General secondary education (ASO)
Mean = 34.91
Std. Dev. = 14.887
N = 111
High School (Professional Bachelor)
Mean = 29.05
Std. Dev. = 14.563
N = 168
Occupational Secondary Education (BSO)
Frequency
Age
0.0
10.0
20.0
30.0
40.0
0
20
40
60


income
Between 5000-7500 Euros
Between 7500-10000 Euros
I prefer not to say
Less than 5000 Euros
More than 10000 Euros
Between 5000-7500 Euros
Mean = 26.84
Std. Dev. = 14.321
N = 107
Between 7500-10000 Euros
Mean = 29
Std. Dev. = 10.632
N = 28
I prefer not to say
Mean = 33.55
Std. Dev. = 15.267
N = 119
Less than 5000 Euros
Mean = 30.96
Std. Dev. = 15.397
N = 285
More than 10000 Euros
Mean = 34.89
Std. Dev. = 13.624
N = 9
Frequency
Age
0.0
10.0
20.0
30.0
40.0
0
20
40
60

Curriculum Vitae

ANNUM KHALIQ

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Personal details

Place of birth:	Lahore, Pakistan
Date of birth:	20/08/1989
Marital status:	Married
Nationality:	Pakistani
Language:	Urdu (National Language), English (Fluent).

Educational Background

2003 - 2005	*Matriculation (Science)* *Aligarh Public School (Lahore), Pakistan*
2005 - 2007	*Intermediate FSc. (pre-Engg)* *Punjab Collage (Lahore), Pakistan*
2007 – 2011	*Bachelors of Science City and Regional Planning* University of Engineering and Technology (Lahore), Pakistan
2013 – 2015	*Masters of Transportation Sciences (Mobility Management)* Hasselt University, Belgium
2015 – 2018	Doctorate in Transportation Sciences (*Mobility Management)* *Transportation Research Institute, IMOB (Belgium)* *Transportation Behavior*

Work Experience

10/2015 – NOW	TRANSPORTATION RESEARCH INSTITUTE, IMOB HASSELT UNIVERSITY (DIEPENBEEK) PHD. STUDENT SUPERVISOR: DR. ING. PETER VAN DER WAERDEN PROMOTOR: PROF. DR. DAVY JANSSENS
06/2013 – 09/2013	LOCAL GOVERNMENT AND COMMUNITY DEVELOPMENT DEPARTMENT (PUNJAB, PAKISTAN) TOWN OFFICER PLANNING AND CO-ORDINATION (TOPANDC), MIAN CHANNU.

06/2012 – THE URBAN UNIT (PAKISTAN)
06/2013 RESEARCH ASSISTANT

01/2012 - OSMANI AND COMPANY (PAKISTAN)
06/2012 JR. TOWN PLANNER

09/2011 - MAC CONSULTANTS (PAKISTAN)
12/2011 JR. TOWN PLANNER

Internships

06/2010-08/2010 THE URBAN UNIT (PAKISTAN)

06/2009-07/2009 LAHORE DEVELOPMENT AUTHORITY, LDA (PAKISTAN)
03/2014-06/2014 TOURISM LIMBURG (BELGIUM)
04/2018-08/2018 UITP-INTERNATIONAL ASSOCIATION OF PUBLIC TRANSPORT (BELGIUM)

Competencies

TECHNICAL SKILLS

- CONCEPTUAL THINKING: DEVELOPING NEW RESEARCH TOPICS, SOLVING ACUTE PROBLEMS
- PLANNING AND ORGANIZING: DEVELOPING AND EXECUTING RESEARCH, COLLECTING DATA
- DATA ANALYSIS: ANALYZING SPECIFIC DATA INTO USEFUL INFORMATION (FOR INSTANCE POLICY RECOMMENDATIONS)

COMMUNICATION

- WRITING SKILLS: WRITING OF REPORTS AND JOURNAL ARTICLES
- PRESENTING SCIENTIFIC WORK
- MEETING WITH TEAM AND EXPERTS
- EVALUATING: REVIEWING OF REPORTS, EVALUATION OF THESES

OTHER SKILLS

- KNOWLEDGE OF LANGUAGES: URDU (NATIVE LANGUAGE), ENGLISH (READING, WRITING, SPEAKING).
- COMPUTER SKILLS: WORD, EXCEL, POWER POINT, ACCESS, ARCGIS, VISIO, SPSS, R, AUTOCAD, SAS, PARAMICS DISCOVERY, VISSIM.
- MENTOR WORK IN THE EDUCATION PROGRAM OF TRANSPORTATION SCIENCES AT HASSELT UNIVERSITY

Publications

MODELLING CAR DRIVERS' ON-STREET PARKING DECISIONS USING THE INTEGRATED HIERARCHICAL INFORMATION INTEGRATION APPROACH **JOURNAL OF TRANSPORTATION RESEARCH BOARD-TRANSPORTATION RESEARCH RECORD 2018.**

A Conceptual Framework for Forecasting Car Drivers On-Street Parking Decisions. **Transportation Research Procedia 2018.**

Conferences

EUROPEON CONFERENCE ON MOBILITY MANAGEMENT (ECOMM 2016) 1-3 June 2016 Faculty Award Winner Abstract Presentation

WORLD PARKING SYMPOSIUM (WPS) 26-29 JUNE 2016 New Concepts of Parking in residential areas (Abstract Presentation)

URBAN TRANSPORT CONFERENCE 5-7 Sept 2017 (Paper Presentation)

Transportation Research Board Annual meeting 7-11 January 2018 (Paper Presentation)

21st EURO Working Group on Transportation Meeting, EWGT 2018. (Paper Presentation)

Other conference material

PARKAGENT: Sensitivity Analysis and Integration with FEATHERS **ECOMM 2016**

New Concepts of Parking in residential areas **World Parking Symposium 2016**

A Discrete choice approach to model individual parking choice in parkagent model **Urban Transport 2017**

Modelling Car Drivers' On-Street Parking Decisions using the Integrated Hierarchical Information Integration Approach **Transportation research Board 2018**

Education activities

Master thesis supervisor: Sensitivity analysis of fundamental parameters of PARKAGENT model 2017.

Master thesis supervisor: Research into payment methods and price setting of Q-park 2017.

Courses

Transportation systems and transportation policy: an introduction