The adoption of mobile parking and parking utilisation

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Executive summary

Parking has increasingly gained importance in the last two decades, due to a growing number of cars and increased car use (Mingardo et al., 2015), explaining the need for increased implementation of parking policies and supporting technologies to enable efficient use of parking space.

Many municipalities have implemented mobile parking payment systems in their cities, aiming at an improved and time saving parking experience for car parkers, while reducing corruption and maximizing parking revenues (Komo et al., 2016). Following this development, mobile parking payments have been widely adopted by car drivers to pay for a parking space. One on the five car parkers uses mobile payment services to pay for the parking time and space, and this number is only increasing further (Deloitte, 2015).

The continuing adoption of mobile payments is addressed in various studies. For parking purposes specifically, determinants of the adoption of mobile payment services and attitudes towards mobile payment services are mainly utilitarian and instrumentally motivated. The ease of use of mobile payments and the independence of time and place when using a mobile payment service are seen as advantageous factors (Pederson, 2003; Yang et al, 2008; Mallat, 2007).

However, the effect of the on-going adoption of mobile payments on behaviour, such as parking behaviour, is an unaddressed subject in the literature (Dahlberg et al, 2008), yet of great importance for current and future implementation of parking policies. There is an increased use of mobile parking payment services and its exploitations and applications will only expand in the future.

This thesis analyses the effect of the on-going adoption of mobile parking services on on-street parking space utilization in urban areas. A dataset about parking utilization in the city of 's Hertogenbosch has been used to analyse on-street parking utilization behaviour for both mobile and non-mobile parking payment methods. The influence of the adoption of mobile parking payments on on-street parking utilization is examined based on the analysis of three parking utilization concepts, namely the parking location, the parking moment and the parking duration. The number of parking transactions, distinguishing a mobile and a meter payment method, was analysed over time. Furthermore, the average parking duration was analysed for both payment methods and for different points in time. Furthermore, it was examined which lengths of parking durations contribute most towards the average parking

duration. Lastly, the parking occupancy was analysed for three different areas in the city of ‘s Hertogenbosch, namely the city centre, the edge of the city centre and the residential area. The number of occupied places using the two given payment methods was determined and analysed for different days of the week.

The main findings of the research were that the average parking duration is higher when using a mobile payment method, than when using a meter payment method. Furthermore, different parking preferences in terms of parking location and parking moment were found as well. Occupied parking spaces for which a mobile parking payment was used are located more often in the city centre than in areas moving outwards the city centre. Additionally, differences in parking durations and differences in parking occupancy per day of the week were found.

This thesis highlights several important trends for parking in urban areas. The increased used of mobile parking payments occurs at the expense of traditional meter payments. Meter payments will decreasingly act as a revenue system for cities. Parking utilization behaviour in terms of parking location, parking moment and parking duration has been thoroughly described, which is important when trying to address the needs of motorist and trying to influence parking behaviour with parking policies (Lambe, 1996). Targeted marketing practices can be developed by linking readily demographic and geolocation data to parking transaction data, allowing for parking policies targeting specific groups, providing user-relevant information and adding user relevant additional services.

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1. Introduction

In the last two decades parking has increasingly gained importance in urban planning mainly because car ownership and use keep growing, while urban spaces become scarcer (Mingardo et al., 2015, p.268). In the Netherlands alone, there are over eight million registered cars (CBS, 2016). This number increases yearly, which explains the need for increased implementation of parking policies and supporting technologies to optimize parking utilization.

Cities were longing for an efficient parking and payment system that would reduce corruption and at the same time would maximize its revenues. Drivers, by contrast, prefer an accessible, affordable and time saving parking service (Komo et al., 2016) Therefore, many municipalities have implemented mobile parking payment systems in their cities. Examples of cities that use mobile parking payment technologies are Montreal, New York, San Francisco, Geneva and Berlin (Komo et al. 2016). Montréal launched a mobile parking payment application, aiming at an improved customer experience by allowing the city inhabitants to used their mobile device for parking (Murphy, 2013). Berlin implemented a mobile parking payment system aiming at a demand based pricing scheme in the future (Kinyanjui and Kahonge, 2013).

Following this technological development, mobile payment services have been widely adopted by car drivers to pay for parking at the selected parking sites. Mobile payment refers to a payment for goods, services and bills, using a mobile device using wireless and other communication technologies (Yang et al., 2011). For parking purposes, such services are typically used by initiating the parking time in a mobile application when the driver has parked the car on a parking site, and ending the parking time when the driver is leaving the parking site (Pederson, 2003). One on the five car parkers uses mobile payment services to pay for the parking time and this percentage is growing steadily (Deloitte, 2015). The adoption of mobile payment services causes a shift from a pre-parking payment to a post-parking payment, which might influence parking behaviour. Firstly, people are no longer obliged to make a time estimation of the planned activity when making a payment for their parking space. Moreover, parkers are no longer bounded or limited by their on beforehand chosen parking time when performing their activity.

Currently, little is known about the effects of the on-going adoption of mobile parking systems and the increased use of mobile parking payments on parking behaviour and parking space utilization. This thesis will address this matter.

The effects of the adoption of mobile payment services on parking utilization will be investigated, by analysing and comparing past and current on-street parking utilization patterns. Parking utilization describes the usage of a parking spot (Stevenson, 2010, p1959.). Patterns of both mobile and non-mobile parking payment actions will be analysed and compared. Addressing and investigating the past and current effects of the adoption of mobile parking for on-street parking allows for knowledgeable contributions for academic and managerial practices.

First the research objective and the research questions will be discussed. Secondly, an overview of the relevant literature will be presented, including the formulated hypotheses for this research. The section will be concluded with an overview of the conceptual framework and a description of the managerial and the academic relevance of the research. Subsequently, the data, the data preparation process and the research method will be defined. Thereafter the results of the conducted analyses will be discussed and the research will be concluded and discussed.

2. Objective and Research question

This thesis analyses the effect of the on-going adoption of mobile parking services on on-street parking space utilization in urban areas. Patterns on the utilization of on-street parking spaces using both mobile and non-mobile parking payment methods will be examined and parking utilization behaviour will be identified for different days, times and on-street parking locations within the city of 's-Hertogenbosch. The objective of this research is to identify relevant trends in parking utilization behaviour influenced by the adoption of mobile parking payment services and identify future trends enabled by the on-going adoption of parking payment services. Based on these findings, useful recommendations will be developed for important stakeholders such as parking policy makers, mobile parking service providers and city municipalities. The main research question is defined as follows:

What are the main effects of the adoption of mobile parking payment services on parking space utilization in urban areas?

The continuing adoption of mobile payments is addressed in various studies. Dahlberg et al. (2008) discussed mobile payments in general based on a literature review. Prior literature on mobile payments was organized under a proposed framework comprising four contingency and five competitive force factors. The defined competitive force factors of the mobile payment services market are: consumer power, merchant power, traditional payment service, new e-payment services and competition between mobile payment service providers. The defined contingency factors are changes in the social, technological, legal and commerce environment. Dahlberg et al. (2008) state that technical security and consumer perspective are topics that are frequently discussed when investigating mobile payments. Unaddressed subjects are the influence of social factors on mobile payments and comparisons between mobile payment services and traditional payment services. Dahlberg et al. (2008) propose the investigation of situations in which mobile and traditional payment methods are used in order to increase knowledge about mobile payment behaviour.

The influence of consumer factors, such as preferences and attitude, on the adoption of mobile payments services in general have been widely discussed (Pederson, 2003; Dahlberg et al., 2008). For parking specifically, determinants of the adoption of mobile payment services and attitudes towards mobile payment services are mainly utilitarian and instrumentally motivated, such as the ease of use of mobile payments and the independence of time and place when using a mobile payment (Pederson, 2003, Pederson, 2002; Yang et al, 2008; Anzek and Uzelac, 2004; Komo, 2016).

Furthermore, the application of mobile parking payment systems for future parking policies has been examined. The city of San Francisco implemented a mobile application called *Spark* that allows motorists to see whether a parking place is occupied or not, however safety experts argue that a motorist might focus too much on its mobile device instead of on the road (Chen, 2014). Pierce and Shoup, 2013). The same application was used to investigate a demand based pricing scheme. Pierce and Shoup (2013) found an influence of changes in price for extremely over occupied and under occupied on-street parking blocks.

However, the effect of the on-going adoption of mobile payments on behaviour, such as mobile parking payments on parking utilization behaviour, is an unaddressed subject (Dahlberg et al., 2008), yet of great importance for current and future implementation of parking policies. There is an increased use of mobile parking payment services and its exploitation and applications will only expand in the future. With an increased use of mobile parking payments, there exists a shift from pre-parking payment to post-parking payment. Moreover, people are not limited by a predetermined parking time when performing their activity. Little is known about the effect of this trend on parking behaviour and parking space utilization, while this might offer valuable insights for managerial decision-making. Different parking utilization behaviour when using a mobile payment method can for example require adjustments in parking policies in order to stimulate efficient use of on-street parking space.

2.2. Academic relevance

Analysing the effect of the adoption of mobile parking services and mobile parking payments on parking utilisation will contribute to the literature on parking utilization (Gillen, 1978; Hunt, 1988; Kanafani, 1983; Axhausen and Polak, 1991; Hunt and Teply, 1993; e 1996; Thompson and Richardson, 1998; Dell'Orco et al, 2003; Bonsall and Palmer, 2004; Ruisong et al., 2009; van der Waerden, 2012; Chaniotakis and Pel, 2015) and on the literature on the adoption of mobile parking payments (Mallat, 2007; Yang et al., 2012; Dahlberg et al, 2008, Pedersen et al., 2003; Pedersen, 2005) There is limited research that combines the two topics and a lack of research that investigates the difference between mobile payment methods and traditional payment methods (Dahlberg et al., 2008). Dahlberg et al. (2008) propose the investigation of situations in which mobile and traditional payment methods are used in order to increase knowledge about mobile payment behaviour. This research will address this proposal by analysing parking utilization for both mobile and non-mobile payments, delivering new insights for the literature and future research on mobile payments and parking utilization behaviour.

2.3. Managerial relevance

The effect of the adoption of mobile parking services and mobile parking payments on parking utilisation may be an underexposed topic in the academic literature, however of great importance for municipalities, mobile payment parking service providers and parking policy makers. Understanding the behaviour of motorist when making parking choices and utilizing parking spaces is important when addressing the needs of motorist or trying to influence parking behaviour (Lambe, 1996).

A pattern analysis addressing the influence of the adoption of mobile services on parking utilization will therefore disclose valuable knowledge for managerial and policy practices. It will enable to accurately define trends, problem areas and/or policies requiring change for recommendations to cities. The choice for the right parking policy depends on the goals and the ambitions of the city and can vary significantly per case (Martens, 2010). Influencing factors are for example economic growth, climate change, health and security, but also city marketing and satisfying inhabitants and visitors (Palmer and Ferris, 2010). Analysing the influence of a mobile parking payment method on parking utilization patterns will provide city planners and local governments with insights on patterns they were unable to visualize before, improving their arguments for decision-making and implementing the right parking policy. The growing number of parkers using a mobile payment might for example need to be approached through different channels or might require different points of restriction or stimulation in order to fulfil the goals of the city.

Furthermore, considering the future of mobile commerce, it is important to gain a deep understanding of the current influence of adoption of mobile services on parking behaviour. This, in order to successfully facilitate the development and implementation of new business models and new parking solutions in the future that build on this concept (Mallat, 2007)

3. Theoretical background

In the following section theoretical concepts are discussed that are relevant to the concept of mobile parking payments and on-street parking behaviour in urban areas. First the factors influencing the adoption of mobile payments and mobile parking payments will be discussed, in order to explain the on-going adoption of mobile parking payments. Thereafter relevant the concepts of parking behaviour will be discussed, focusing specifically on parking utilization. The formulated hypotheses will be proposed and supported by the relevant theoretical concepts. Lastly, the proposed conceptual framework will be presented.

3.1. Adoption of mobile payments

When parking a car in public urban areas, the parking location possibilities presented to a car driver are on-street parking places and off-street parking places. At these two parking sites, three ways can be distinguished to legally pay for the parking time. Firstly, a driver can park the car in an off-street parking location where the driver typically pays at the end of the parking activity and uses the payment as means to leave the off-street parking location. Alternatively, a driver can pay the parking fee for the use of the on-street parking space through the traditional parking meters, by inserting coins or by card. The driver specifies its intended parking time at the beginning of the parking activity and hereby makes an estimation of the time needed for his activity. The estimation of the parking time can be typically made in units of time (e.g. per 5 or 10 minutes).

Secondly, a driver can park the car in an off-street parking location where the driver typically pays at the end of the parking activity and uses the payment as means to leave the off-street parking location.

Thirdly, instead of a parking meter, an identifying number of the on-street parking space might be present, such as a zone number. A driver can manually enter the zone number into a mobile parking application, such as the application Parkmobile, Park-line or Yellowbrick (Parkeerdata, 2017), or the mobile device locates the user and the corresponding zone number automatically through GPS information. A driver can manually start its parking time at the beginning of a parking activity and end the parking time manually at the end of a parking activity. Based on the parking duration the parking fee is deducted from a pre-specified linked bank account. Such payments made using a mobile device using wireless and other communication technologies are referred to as mobile payments (Chen, 2008; Mallat, 2007; Yang et al., 2012; Dahlberg et al, 2008). This thesis will focus on the two available payment methods for on-street parking.

The use of mobile payments for parking purposes has been widely adopted in the recent years. One on the five car parkers uses mobile payment services to pay for their on-street parking space and time and this percentage is growing steadily (Deloitte, 2015).

Moreover, research on the adoption of mobile payment services in everyday life context has gained increased attention in every-day life and literature. While most literature address the adoption of mobile payments in general (Mallat, 2007; Yang et al, 2012; Dahlberg et al., 2008; Schierz et al. 2009), some research discusses the adoption of mobile payments for parking purposes specifically (Pederson, 2003; Pederson, 2005).

Mallat (2007) conducted a qualitative study on the determinants of the adoption of mobile payments. Contributing factors, both negative and positive, were addressed and discussed. The main contributing factors to the successful adoption of mobile payments can be characterized as utilitarian and instrumental factors. Independence of time and place is depicted as an important determinant. Mobile payments allow a person to pay whenever he wants and wherever he wants, without the need to go to a point of sale or to a cash point. Additionally, the avoidance of the possibility of queuing is found to be an important determinant (Mallat, 2007). These advantages and influential factor of the perceived convenience of the use of mobile payments on the adoption of mobile payments has been addressed more frequently in literature (Carsson et al., 2006; Dahlberg et al, 2008; Chen, 2008).

Furthermore, the size of the purchase plays an important role. Mobile payments are said to be more compatible with smaller value payments, such as for example train tickets or parking fees (Mallat, 2007). The barriers to the successful adoption of mobile payments that were identified were the complexity and the costs of mobile payments. Actions as registering an account and separate billing arrangements are perceived as the drawbacks of mobile payments, as well as the premium pricing that is connected to some mobile payments (Mallat, 2007). Other explanatory variables explaining the unsuccessful adoption of mobile payments are the lack trust and risk issues related to the use of mobile payments (Srivastava et al., 2010; Siau & Shen, 2003).

Moreover, research suggests that social influences and personal traits have an influence on the adoption of mobile payment services however do diverge across different stages of adoption (Yang et al, 2011). Most of the research address the adoption of mobile payments after a mobile payment system was implemented and taken into use (Chen, 2008; Schierz et al, 2010), whereas other make a distinction between a pre-adoption phase and a post-adoption

phase (Yang et al, 2011). This takes the fact that motives for the initial adoption of mobile payment and the continued usage of mobile payments can differ for adopters of different stages into account. It is found for example that social influences are no longer of substantial influence on the intention to use mobile payments after initial adoption of mobile payments, while personal traits remain an important factor (Yang et al., 2011)

Pederson (2005) and Pederson et al. (2003) have addressed the adoption of mobile payments to pay for the space and time of parking specifically. Data of 459 users who used mobile parking payment services was used to investigate and propose a model on the adoption of mobile parking payment services. The main findings were that easiness and usefulness, thus utilitarian motivations, play a significant role in the adoption of mobile parking services. Additionally, both self-expressiveness and the attitude towards the use of mobile parking payment services are explanatory variables for the adoption of mobile parking payments. Furthermore, amusement or enjoyment of the service has no significant influence on the adoption of mobile parking payments (Pedersen et al., 2003; Pedersen, 2005).

In addition, mobile payment services in a mobility context have been investigated (Mallat et al., 2008). 362 surveys were collected from inhabitants of Helsinki in Finland, were mobile payment services have been taken into use for public transportation. Again, utilitarian motivations, such as the ease of use, compatibility and relative advantage appear to be important determinants in the adoption of mobile payment services. Moreover, social influence, attitude towards mobile payments, trust and risks were identified as influential factors as well. The variable cost had no significant impact on the choice of using mobile payment services, which is explained by the fact that purchasing a ticket with cash appears to be more expensive than when purchasing the ticket by using a mobile device. Interestingly, contextual factors were identified, which are also applicable to a parking context. The absence of readily available cash to perform the payment, the unexpected need to perform a payment and lack of time or hurry were of noteworthy influence on the future use of mobile payments for public transportation (Mallat et al., 2008).

3.2. Parking utilization

This thesis focuses on the effect of the adoption of mobile parking payments on parking utilization, therefore focusing on a set of attributes of parking. Parking utilization describes the usage of a parking spot (Stevenson, 2010, p1959). It thus concerns the specific location of the parking space, the moment in time the parking space is used and the duration the parking space is deployed by a car.

3.2.1 Parking location choice

Parking choice models have been developed to simulate the parking choice behaviour (Richardson, 1982; Thompson and Richardson;1998, Martens et al, 2008). The aim of modeling parking choice behaviour is to identify the fundamental factors that influence a car driver's decision-making for a specific parking spot and thus addresses the parking location.

A perspective on (parking) choice modeling is its focus on available choice alternatives. The choice set refers to the set of all choice alternatives an individual has when making a decision. Bovy and Stern (1990) have developed a hierarchical choice process where the decision maker reduces its alternatives, describing that the amount of alternatives are decreasing once the point of decision making approaches.

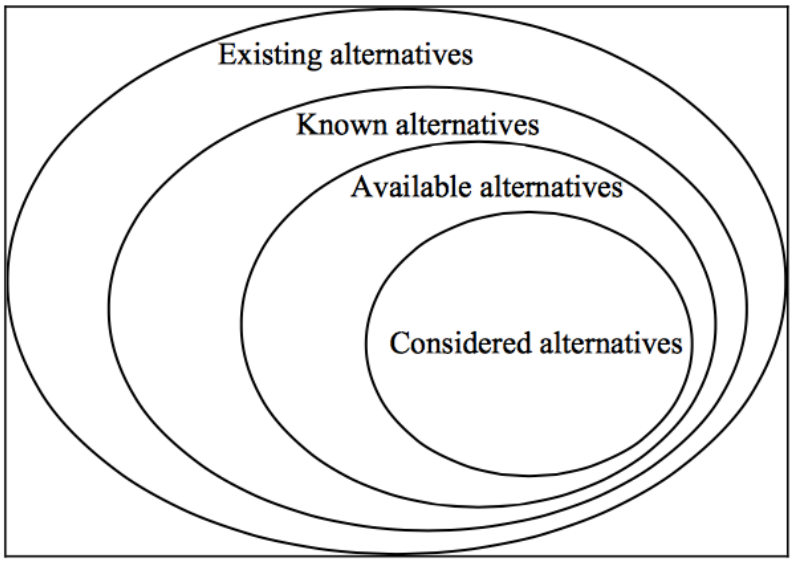

Figure 1: Hierarchical series of choice sets of a given choice situation (Bovy and Stern, 1990)

Authors have presented overviews of different kind of parking models that have been developed since the 1980's (Martens et al., 2008; Young et al., 2008). The first generation has mostly developed spatially implicit parking models, based on a driver's stated preferences of characteristics of the parking location (e.g. Axhausen and Polak, 1991). The models are static in nature and logit regression is used to predict and explain the parking choice of a driver. Additionally, spatially implicit, but dynamic, models have been developed to empirically examine the influence of parking conditions and parking policies. Arnott (2006) for example has studied parking policies, from the perspective of economic theory, in urban areas focusing on parking garages as a key feature. Private parking garage operators are given market power, since a driver is willing to pay a premium price to park at a location that is close to its

destination of interest, and thus reduces walking time. Raising price for on-street parking would decrease cruising, meaning to drive around searching for a vacant parking location and traffic congestion. A second type of parking models, which have been developed since the 1990's, are spatially explicit parking models trying to simulate car drivers search and parking behaviour and assess a wide variety of policy practices in a real-world scenario (Martens and Benenson, 2008).

Over the years, several attributes that influence the parking location choice have been identified. Chaniotakis and Pel (2015) present an overview of the parking choice model attributes that have been studied in literature. Factors that have been identified as influencing on the parking location choice are: the parking costs, the walking distance to the point of destination, the access time of the parking location, the search time for a vacant parking spot, the duration of the parking action, the parking type in terms of a off-street and on-street parking location, the age of the parker, the possibility of an illegal fine, the action to be performed during parking, the usage of parking guidance and information systems, the occupancy level of the parking location and lastly, the probability to find a vacant parking spot (Gillen, 1978; Hunt, 1988; Kanafani, 1983; Axhausen and Polak, 1991; Hunt and Teply, 1993; Lambe 1996; Thompson and Richardson, 1998; Dell'Orco et al, 2003; Bonsall and Palmer, 2004; Ruisong et al., 2009; van der Waerden, 2012; Chaniotakis and Pel, 2015, p232).

Table 1: Parking choice model attributes reported in literature (Chaniotakis and Pel, 2015, p232)

Study	Park Cost	Walk Dist.	Access Time	Search Time	Duration	Type[a]	Age	Illegal fine	Purpose	Inc.	PGI[b]	Occupancy[c]	Prob.[d]
1	✓	✓	✓	✓			✓			✓			
2	✓	✓	✓	✓		✓							
3	✓				✓								
4	✓	✓	✓	✓				✓					
5	✓	✓	✓	✓		✓							
6	✓	✓	✓										
7	✓	✓	✓	✓	✓			✓					
8	✓	✓	✓	✓					✓				
9	✓	✓	✓								✓		
10	✓	✓				✓	✓					✓	
11	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓

The city centre in European countries is often the desired destination for parkers, since most of the city centres are home to shopping areas, public services and work places. Moving outwards from the city centre, the probability of vacant parking spaces increases (Ferilli, 2008). As discussed previously, parkers consider the advantages and disadvantages of a parking spot when making a choice for a specific parking place, referring to the above discussed attributes. Parking close to the city centre thus offers the parker the advantages of a short walking distance to the point of destination. However, the parking cost increase as one parks closer to the city centre, as does the probability of an occupied spot (Ferilli, 2008).

When a person chooses a parking spot close to the city centre, it is fair to assume that one values a short walking distance to the point of destination thus higher than the incurred costs of searching time and the parking.

As discussed in the theoretical concepts related to mobile payments, the adoption of mobile parking payments can among others be explained by utilitarian motivations (Dahlberg et al. 2008; Mallet et al, 2008; Pedersen et al, 2003; Chen, 2008; Carlsson, 2006). Parking and using a mobile payment method is less time consuming than using a meter payment method. Car parkers in the Netherlands spend on average six minutes to walk to an on-street parking meter and make a payment for their parking spot. When using mobile services, this amount is decreased to two minutes (Parkline, 2010). Furthermore, using a mobile payment method decreases the probability of queuing for a parking meter in busy areas and moreover eliminates the probability of having to visit an ATM to acquire cash for a meter payment.

In short, using a mobile parking payment method is less time consuming than using a meter payment method and increases the probability to arrive timelier at the point of destination. The same applies to parking near the city centre. When a person chooses a parking spot close to the city centre, its probability of arriving timelier at the point of destination is increased as well, due to a short walking distance. Parkers that park near the city centre value a time efficient parking location as do parkers that use a mobile payment method to pay for their parking time.

H1: The number of parking transactions using a mobile parking payment method will increase as the distance of the parking location to the city centre decreases.

3.2.2. Parking duration

Two available payment methods exist to legally pay for your on-street parking space and time. The first method is a traditional meter payment, where the parker typically pays at the beginning of the parking activity and hereby makes and estimation of the time needed for his activity. The second payment method is a mobile payment method where the parker automatically pays for its parking space and time and the end of its parking activity. With an increased use of mobile payments for parking purposes, there exists a shift from a pre-parking payment to a post-parking payment, eliminating a time estimation of the planned activity.

No single sense organ or perceptual system mediates psychological time. This is especially puzzling regarding durations in the range of miliseconds, seconds and minutes (Zakay and

Block, 1996, p1). A car driver needs to estimate the time necessary for performing its planned activity when parking a car and making a pre-parking payment, however this estimation is influenced by experiences and both event- and time based experiences.

Zakay and Block (1996) argue that time is subjective, where the subjective time may advance faster or slower than the actual objective time in certain contexts. This explains the concept of retrospective and prospective duration judgment processes. Retrospective duration processes are denoted to as remembered duration, whereas prospective duration processes are referred to as experienced duration (Block, 1989). A motorist for example parks his car 500 meters away from a supermarket to do his weekly grocery shopping, which takes on average 20 minutes. When the motorists has a busy day and needs to perform another activity afterwards, the duration of twenty minutes will for example be experience as 12 minutes from a prospective point of view.

Literature mainly describes two types of prospective remembering: event-based and time-based. Time based prospective remembering is defined as more self-initiated, whereas event-based remembering is environmentally influenced, such as by activities. The remembrance of weekly parking action of the motorist to do grocery shopping is thus referred to as event-based prospective remembering (Block, 1989).

The adoption of mobile parking eliminates this time estimation process of the yet to be performed activity at the beginning of an on-street parking action, as is necessary when paying via a traditional on-street parking meter. Additionally, the parking meter often demands a fixed parking rate per time frame (e.g. an amount per 10 minutes), which might be inconvenient for the car driver when the activity only requires five minutes. In the Netherlands, 10% of the car drivers always pay too much for their parking time, while 32% of the car drivers experience this on a regular basis. On average, car drivers pay a premium amount of €2, - for unused parking time and space. Activities in which persons often overestimate the duration of the parking activity are shopping, restaurants, business meetings and doctor appointments (Parkline, 2010). Furthermore, using a meter payment method to pay for parking space and time takes on average four minutes longer than using a mobile payment method (Parkline, 2010)

H2: The average parking time duration for on-street parking is lower for parking actions using a mobile payment method than for parking actions using a meter payment method.

3.2.2. Parking moment

Related to the above-described theoretical concepts is the principle of the parking start time or the moment of parking. It is assumed that people are on average busier during weekdays than on weekend days and therefore value time savage and the utilitarian advantages the usage of mobile payments offers more.

H3: The number of parking transactions using a mobile payment method will be higher on weekdays than on weekend days.

3.3. Conceptual framework

The conceptual framework, summarizing the relevant concepts and proposed hypotheses, is presented in figure 3. Parking utilisation describes the usage of a parking spot (Stevenson, 2010, p1959.), and is addressed by three concepts, namely the parking location, the parking moment and the parking duration. It is assumed that a relation exists between the number of parking transactions using a mobile payment method and the distance to the city centre. Parkers who use a mobile payment method to pay for their parking time value a time efficient payment method and a timelier arrival at the point of destination. Parkers who choose a parking location near the city centre also value a timelier arrival at the point of destination, which is achieved due to a short walking distance to the city centre. It is thus assumed that the number of transactions using a mobile payment method increases as the distance of the parking location to the city centre decreases.

Additionally, it is assumed that the average parking time duration for on-street parking is lower for parking actions using a mobile payment method than for parking actions using a meter payment method. Using a mobile parking method to pay for the parking space and time eliminates the process of the yet to be performed activity at the beginning of an on-street parking action, as is necessary when paying via a traditional on-street parking meter. Furthermore, using a meter payment method is more time consuming than using a mobile payment method to pay for your parking.

Lastly, related to the principle of time savage that is achieved when using a mobile parking payment method, it is assumed that people are busier during weekdays than on weekend days. The number of parking transactions using a mobile payment method will thus be higher on weekdays than on weekend days.

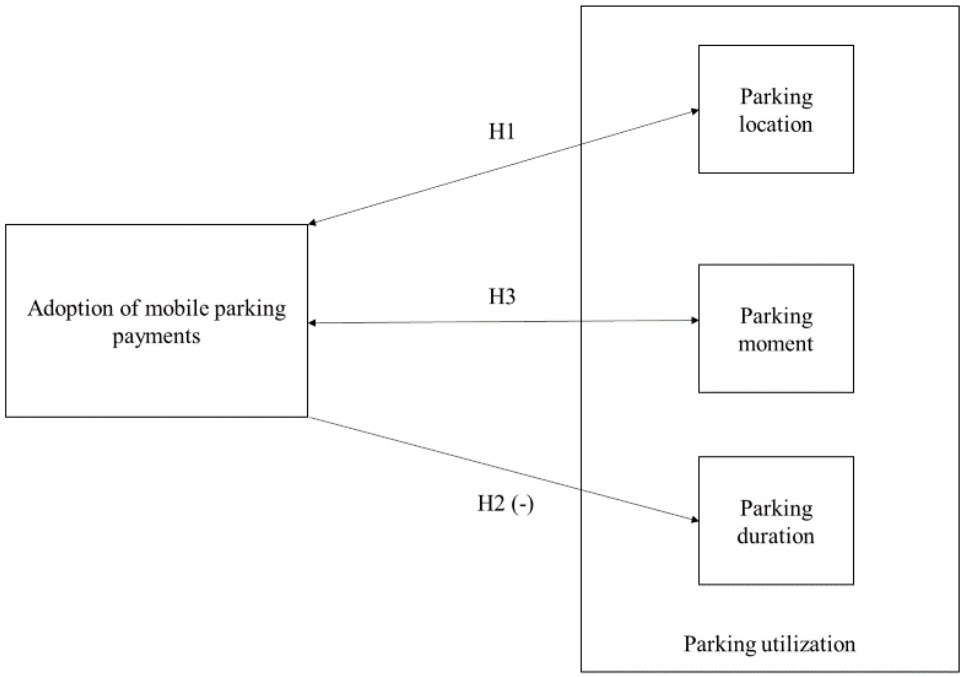

Figure 2: Conceptual framework

4. Data and Method

In the following section the data and the used methods will be described. Firstly, the data used for this research will be described. Thereafter a description of the parking situation in the city of 's-Hertogenbosch will be given in order to get a broad understanding of the environment the data was collected from. Lastly, the methodology will be described including the data preparation process to conduct the proposed analysis.

4.1. Data

For this study a dataset about the utilization of parking spaces in the city of 's-Hertogenbosch in the Netherlands will be used. Through the department of Urban, Port and Transport Economics of the Erasmus School of Economics, Spark Parkeren and the city of 's-Hertogenbosch, access to the data of the utilization of parking spaces in the city of 's-Hertogenbosch is provided, as well as relevant information.

The data set gives a brought understanding of the exploitation of on-street parking spaces and off-street parking spaces in the city. The data set contains parking transactions for the period of 1 January 2014 to 28 February 2017. The total data set consists of three subsets, namely off-street non-mobile parking data, on-street mobile parking data and on-street non-mobile parking data. The number of transactions per quarter of the year is presented in table 2. The total number of transactions is presented, as well as the number of transactions for each subgroup. Additionally, the subgroups are given as a percentage of the total number of observations. In the first quarter of 2014 for example, a total number of 814.857 parking transactions were conducted. 5% of these transactions were on-street parking transactions for which a mobile payment was used, 37% of these transactions were on-street parking transactions for which a non-mobile payment was used and 58% of these transactions were off-street parking transactions for which a non-mobile payment was used. Thus in Q1 2014, 44.062 on-street parking transactions using a mobile payment, 301.562 on-street parking transactions using a non-mobile payment and 469.233 off-street parking transactions using a non-mobile payment were conducted.

Table 2: Number of on-street and off-street parking transactions.

Date	Total	On-street mobile payment	% of Total	On-street non-mobile payment	% of Total	Off-street non-mobile payment	% of Total
31-03-2014	814.857	44.062	5%	301.562	37%	469.233	58%
30-06-2014	823.937	48.764	6%	291.836	35%	483.337	59%
30-09-2014	805.479	49.566	6%	283.906	35%	472.007	59%
31-12-2014	888.919	63.311	7%	299.261	34%	526.347	59%
31-03-2015	810.440	68.020	8%	268.604	33%	473.816	58%
30-06-2015	808.177	70.763	9%	264.433	33%	472.981	59%
30-09-2015	791.374	67.844	9%	245.613	31%	477.917	60%
31-12-2015	913.452	82.428	9%	263.157	29%	567.867	62%
31-03-2016	871.116	88.677	10%	258.433	30%	524.006	60%
30-06-2016	892.940	91.646	10%	254.886	29%	546.408	61%
30-09-2016	783.831	88.969	11%	243.454	31%	451.408	58%
31-12-2016	907.518	110.785	12%	264.296	29%	532.437	59%
31-02-2017	535.076	73.465	14%	161.447	30%	300.164	56%

4.2. Parking in the city of ‘s-Hertogenbosch

The city of ‘s-Hertogenbosch provides several off-street and on-street parking options. The city provides eight off-street parking facilities: Josephstraat, Keizerstraat, Museumkwartier, Paleiskwartier, P+R de Vliert, P+R Pettelaar, P+R Vlijmenseweg, Stationsplein, St. Jan, Visstraat and Wolvenhoek. Three of the eight parking facilities are only available for users with a subscription to that parking garage. The locations of the off-street parking facilities are presented in figure 3, represented by a *P*. Users pay a fixed monthly or yearly fee for the utilization of the particular parking facility they are subscribed to. The other five parking garages are publicly available and located near the city centre of ‘s-Hertogenbosch (Spark, 2017).

The hourly tariff for on-street parking in the city centres of ‘s-Hertogenbosch varies between €1.50 and €2.50, and the hourly tariff for off-street parking garages varies between €1.00 and €2.20. The prices tend to reach the higher boundary on shopping day and nights, public holidays and weekends (‘s-Hertogenbosch, 2017). The average on-street parking fee near centres in the Netherlands is €1.55 per hour for on-street parking and €1.52 per hour for off-street parking. Hourly parking fees in larger cities tend to be higher, typically between €3.00 or €5.00 (van Ommeren, 2012)

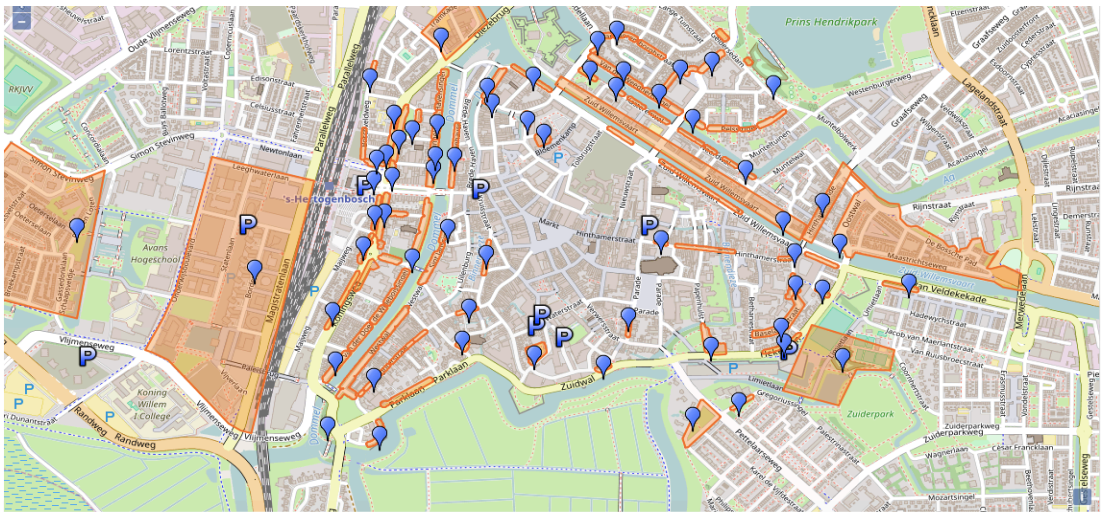

Figure 3: Parking in the city of ‘s-Hertogenbosch (Parkeerdata, 2016)

The timeframes at which a car parker needs to pay for its on-street parking space and time and the corresponding tariff are presented at the parking meters on the street. Often, an overview is also presented by mobile payment service providers in the mobile application a car driver uses for its payment. All parking meters are provided with a zone number for the purpose of a mobile parking payment (‘s-Hertogenbosch, 2017).

The city is divided into three subareas for which different parking tariffs and timeframes count: the city centre, the edge of the city centre and the residential area. In the city centre, the timeframe for which one needs to pay for parking is from Monday until Saturday 9:00 – 24:00. On Sundays and national holidays a parker needs to pay from 14:00 to 24:00. Exceptional days are the national holidays Kingsday and Ascension Day, on which a parker pays from 9:00 to 24:00. For parking utilization at the edge of the city centre, the timeframe for which a parker needs to pay is 9:00 – 18:00 from Monday to Saturday. On Sunday and national holidays, one needs to pay from 9:00 to 21:00. On Kingsday and Ascension Day the paid timeframe is 9:00 – 17:00. In the residential area the paid timeframes are 9:00 – 18:00 from Monday to Saturday. On Sunday and national holidays parking is free in this area (‘s-Hertogenbosch, 2017).

Furthermore, the city of ‘s-Hertogenbosch offers three so called *transferia* locations outside the city centre. One can park his car for a daily amount of €4.00,- and take a free bus or bike to the city centre. The city also provides information about the current occupancy rates in the off-street parking facilities on the routes to the city centre. Both initiatives are implemented to decrease congestion and cruising, meaning to search for a vacant parking spot, in the city centre (‘s-Hertogenbosch, 2017).

4.3. Method

For this research, the on-street parking data of the city of 's-Hertogenbosch is analysed using descriptive statistics, which are data analysis techniques enabling meaningful data descriptions with numerical indices and in graphical form (Fraenkel et al., 1993, p. 3). Patterns on the exploitation of parking spaces are analysed and compared for mobile- and meter payment methods in order to determine the effect of the parking payment method on on-street parking utilization. Furthermore, statistical techniques will be used to examine and interpret relations in the data (Kothari, 2004). For the analyses, the open source programming language and software environment for statistical computing and graphics R is used (R development core team, 2008).

The analyses consist of three parts. Firstly, the amount of parking actions over time is analysed, distinguishing a mobile payment method and a meter payment method. This in order to get a clear understanding of the data and the extent to which mobile parking has been adopted in the city of 's Hertogenbosch. Trends are graphically visualized and described.

Thereafter, the on-street parking duration is analysed, distinguishing the usage of a mobile payment method or a meter payment method. The parking duration is analysed and visualized for different points in time. Subsequently, the parking occupancy will be analysed. The parking occupancy rate is determined for different areas in the city, while making a distinction between mobile- and meter parking payments. Furthermore, the occupancy rate per day of the week is determined and presented. Lastly, a logistic regression model will be created in order to describe the relationship of different variables on the probability of a mobile payment method.

4.4. Data preparation

For the purpose of this research the two subsets containing on-street parking data will be used, thus the subset on-street mobile parking and on-street non-mobile parking data. The variables per subset differ. An overview of the variables per data category is presented in tables 3 and 4.

Table 3: Description variables on-street mobile parking data

Variable	Description
Zone_code	Zone number
Gsm_provider_id	The ID number of the gsm parking provider respresenting: unknown, other, Stadspasparkeren, Yellowbrick, Parkmobile, SMS Parking, Myorder BV, MKB brandstof, Multi Tank Card, Park-line
Transaction_id	Transaction number
Start_parking_dt	Date and time at the start of the parking action
End_parking_dt	Date and time at the end of the parking action
Amount	Transaction amount presented in eurocents

Table 4: Description variables on-street non-mobile parking data

Variable	Description
Meter_code	ID number of parking meter
Payment_type_id	The ID number of the payment method used at the parking meter representing: cash, chipcard, debitcard, other, GSM, payOne parking, payOne reloader, unknown, creditcard
Start_parking_dt	Date and time at the start of the parking action
End_parking_dt	Date and time at the end of the parking action
Paid_duration_sec	Duration of payment presented in seconds
Total_duration_sec	Paid duration of parking action
Amount_paid_cents	Transaction amount paid presented in eurocents

In order to properly analyse and compare the data, the data was pre-processed and carefully selected. All meter codes were replaced by the corresponding zone codes provided by the mobile parking data. Multiple meters may be present in a mobile zone. Furthermore, the mobile parking data of 2014 contained several old zone codes. These are replaced by the new zone codes as well.

The total parking duration in seconds was calculated for each observation in the mobile parking dataset by calculating the time difference between the variables *start_parking_dt* and *end_parking_dt*. Thereafter, an additional categorical variable was added to the datasets, indicating the parking payment method. A mobile payment method is represented by the number 1 and a traditional meter payment method is represented by the number 2. The variable *id* was added to the dataset in order to be able to correctly identify an observation, as well as the variable *day* representing the day of the week corresponding to the start parking date of that observation.

The parking start time and parking end time variables are converted to a time interval of five minutes, in order to limit the amount of data for the analyses. A day consists of 288 time intervals of five minutes, resulting in 288 possible time data points for each date. The parking start time and parking end time are rounded to the nearest data point for each observation. For example, a parking start time of 11:00AM is thus presented by the time interval value 132.

The datasets were merged and inspected for invalid observations. The data contained circa 30.000 meter payment transactions with a transaction amount equal to zero and four negative transaction amounts. An on-street parking action paid by a parking meter can only be initiated with a transaction amount above zero. An explanation for these observations might be that a parker may have changed his mind during the parking payment action resulting in cancellation of the parking payment. Furthermore, the data contained four observations with a zone code of -1, which are non-existent and thus invalid zone codes. These observations, accounting for circa 0.7% of the original data, were removed from the data.

Moreover, the dataset contains a large amount of observations of which the date of the starting time and the date of the end time differ, meaning the parking action persisted for two days. For the majority of these observations, a meter payment was used and the parking end time was close to the beginning of the paid timeframe for that subsequent area. These observations can be explained by the following example situation: a person, arriving at 23:00PM, wants to park his car in the city centre of 's-Hertogenbosch on a Saturday night. The timeframe for which a person needs to pay for his parking space in the city centre is 9:00 - 12:00 on a Saturday and 14:00-24:00 on a Sunday ('s-Hertogenbosch, 2017). The car parker is planning to leave at 01:00 in the night and wants to pay by meter for his parking action. The car parker uses coins for his payment and inserts €3.00 in the parking meter. Since the parker is only required to pay for his parking time until midnight, the parking meter will automatically switch to 14:00 PM on Sunday. For these observations we cannot validate whether the car parker has actually ended his parking action at the beginning of the paid timeframe of that zone, or whether he has left before like the car parker in the example above. Therefore, these observations were removed from the data. This resulted in removal of circa 12.2% of the original data.

As previously described, the city of 's-Hertogenbosch can be divided into three parking areas: the city centre, the edge of the city centre and the residential area. Each subsequent area has different timeframes for which a car parker needs to pay for its on-street parking space and time ('s-Hertogenbosch, 2017) Each observation was assigned to one of these three areas and

corrected based on the paid parking times of that area. An overview of zone codes assigned to each area is given in table 5. All observations of which the parking end time is later than the end time paid parking of the corresponding area were removed. Additionally, the observations of which the parking end time is earlier than the start time paid parking of the corresponding area were removed. Different paid parking times per day of the week and on national holidays has been taken into account. This results in observations of which the parking start time and parking end time is on the same day only.

However, the majority of the above described invalid observations used a meter payment method to pay for its parking action, there were some mobile payment transactions present. The practices for automatically or manually ending a parking action differ per mobile parking provider and cannot be determined based on the data. Therefore the same processing has been applied to the mobile parking data.

Table 5: Zones per area

Area	Assigned zones
City centre	73001, 73008, 73011, 73016, 73018, 73020, 73021, 73024, 73025, 73027, 73028, 73052, 73053, 73054, 73055, 73056, 73058, 73060, 73064, 73072, 73073, 73075, 73087, 73095, 73102, 73107, 73108, 73109
Edge of the city centre	73009, 73010, 73012, 73030, 73031, 7332, 73033, 73034, 73035, 73051, 73089, 73090, 73100, 73110, 73115, 73122, 73135
Residential area	73036, 73037, 73038, 73043, 73048, 73066, 73070, 73074, 73076, 73077, 73078, 73079, 73080, 73081, 73082, 73093, 73096, 73099

However, the majority of the above described invalid observations used a meter payment method to pay for its parking action, there were some mobile payment transactions present. The practices for automatically or manually ending a parking action differ per mobile parking provider and cannot be determined based on the data. Therefore the same processing has been applied to the mobile parking data.

The final dataset consists of 3.943.682 observations, of which 3.064.244 (78%) observations have used a meter payment method and 879.438 (22%) observations have used a mobile payment method. An overview of the structure of the dataset is presented in Table 6.

Table 6: Overview of the structure and the content of the parking data

ID	Zone code	Payment method	Parking date	Parking start time	Parking end time	Parking duration (sec)	Weekday
496583	73135	2	11-12-2015	190	203	4080	Thursday
1842531	73030	2	03-26-2016	151	163	3600	Saturday
2466996	73099	2	10-20-2015	183	186	1080	Tuesday
1154402	73110	2	02-26-2016	116	125	2880	Friday
4320783	73122	2	02-06-2016	117	153	10800	Saturday
2558770	73025	2	03-20-2015	198	210	3840	Friday
1228009	73110	2	05-11-2016	124	130	1920	Wednesday
3910697	73027	2	07-07-2016	225	227	720	Thursday
247585	73056	2	04-13-2015	168	179	3420	Monday
1551381	73076	1	06-03-2016	108	164	16813	Friday
286474	73102	2	02-04-2015	194	210	4800	Wednesday
3161623	73001	1	01-21-2015	189	271	24808	Wednesday
4120366	73025	1	08-24-2015	186	208	6844	Monday
227471	73072	2	07-19-2014	231	237	1800	Saturday
3022291	73109	2	10-18-2015	170	190	6000	Sunday

5. Analyses and results

In this section the results of the analyses of the historical on-street parking data will be discussed, focusing on the effect of mobile parking payments compared to traditional meter parking payments. First, the analysis of the number of parking transactions will be discussed. Thereafter, the results of the parking duration analysis and the results of the parking occupancy analysis will be thoroughly described.

5.1. Number of parking transactions

The total daily number of on-street parking transactions has been calculated and analysed from 01-01-2014 until 28-02-2017, distinguishing a mobile parking payment method and a meter parking payment method. The mean daily number of transactions per payment method and the total on-street parking transactions are presented in table 7.

The total quantity of daily on-street parking transactions is visualized in figure 4. Additionally, the average number of both meter and mobile payments has been calculated, using a seven point moving average. The moving average is centered between three days in the past and three days ahead. This means that the sum of seven days of parking transactions has been taken and divided by a period of a week. Furthermore, the division of the number of transactions for which a meter payment has been used and the number of transactions for which a meter payment has been used is visualized in figure 5. The average number of parking transactions per payment method are presented as a percentage of the total number of parking transactions overtime. The y-axis shows the division of the different average number of parking transactions per payment method in percentages, given that 100% is the total number of parking transactions for the given period. The x-axis represents the point in time.

As presented in table 7 and visualized in figures 4 and 5, the daily sum of parking transactions using a meter payment method shows a downward trend. The number decreased from an average of 2780 daily transactions in 2014 to an average of 2534 transactions a day in 2017. The daily number of parking transaction using a mobile payment method is subjected to an upward trend, having increased from an average of 521 payments a day in 2014 to an average of 1160 daily transactions in 2017.

The use of mobile parking payments is growing at the expense of the use of traditional meter payments. In 2014 the percentage mobile and meter payment transactions of the total number of on-street parking transactions were 16% and 84% respectively, while in 2017 these

percentages have changed to 31% and 69% respectively. This trend can also be seen in figure 5, in which the mobile payment parking transactions and meter payment parking transactions are presented as a percentage of the total number of transactions. While the average number of parking transactions using a meter payment method is still significantly larger than the average number of transactions using a mobile payment method, the decreasing contribution of meter payment parking transactions to the total number of parking actions is clearly shown.

Furthermore, as can be seen in figure 4, large daily variations are noticeable for parking actions using a meter payment method, while less variation is present in the number of parking actions using a mobile payment method.

Moreover, seasonal trends can be observed in figure 4. A low point in the total number of transactions is reached every year around Christmas, followed by a peak at the beginning of the year. The number of parking transactions is low again in the summer, while the period of October and November shows the highest yearly number of transactions is reached.

Table 7: Daily number of on-street parking transactions

Year	Mean total transactions	Mean mobile payment	% of total	St. Dev. mobile payment	Mean meter payment	% of total	St. Dev. meter payment
2014	3,301	521	16%	187.7	2,780	84%	895.3
2015	3,348	734	22%	246.6	2,614	78%	793.5
2016	3,530	965	27%	318.6	2,565	73%	748.9
2017	3,694	1,160	31%	406.2	2,534	69%	798.7

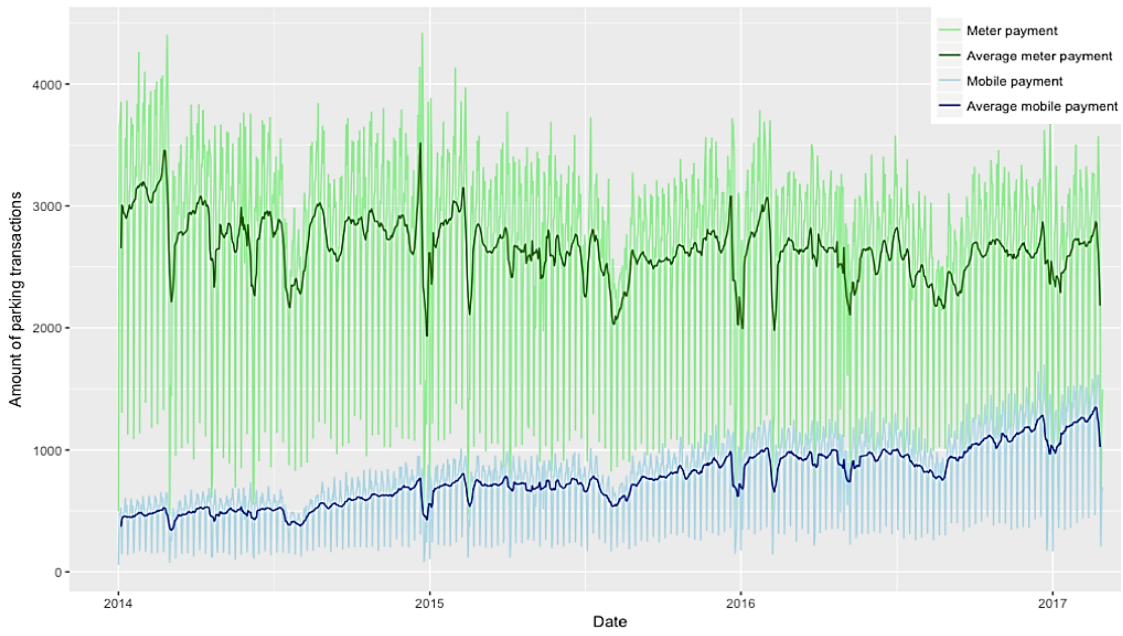

Figure 4: Time series daily number of on-street parking transactions

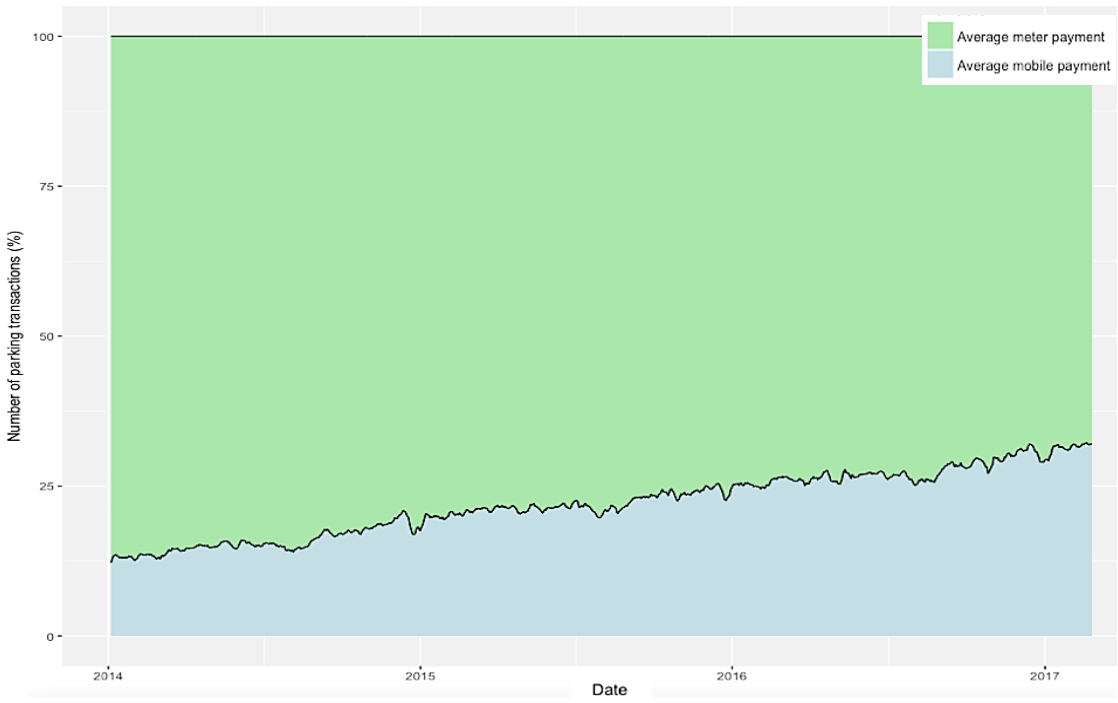

Figure 5: Division of daily number of on-street parking transactions

5.2. Parking duration analysis

The parking duration of all parking transactions from 01-01-2014 to 28-02-2017 were analysed, given the parking duration is the time difference between the starting time and the ending time of a parking transactions.

The daily average parking duration was calculated by dividing the total parking duration per day by the number of parking transactions on that day, while making a distinction between a mobile payment method and a meter payment method. The period from 01-01-2014 to 28-02-2017 consists of 1155 days in total, giving 1155 average parking durations per payment method. In figures 6 and 7, a division of the average parking duration is presented for the whole period. It is noticeable that the average daily parking duration using a meter payment method is lower than the average daily parking duration using a mobile payment method. The average daily on-street parking duration is most frequently between 90 and 100 minutes when using a meter payment method, while this average using a mobile payment methods varies most frequently between 110 and 130 minutes. The average parking duration is thus longer when using a mobile payment method than when using a meter payment method.

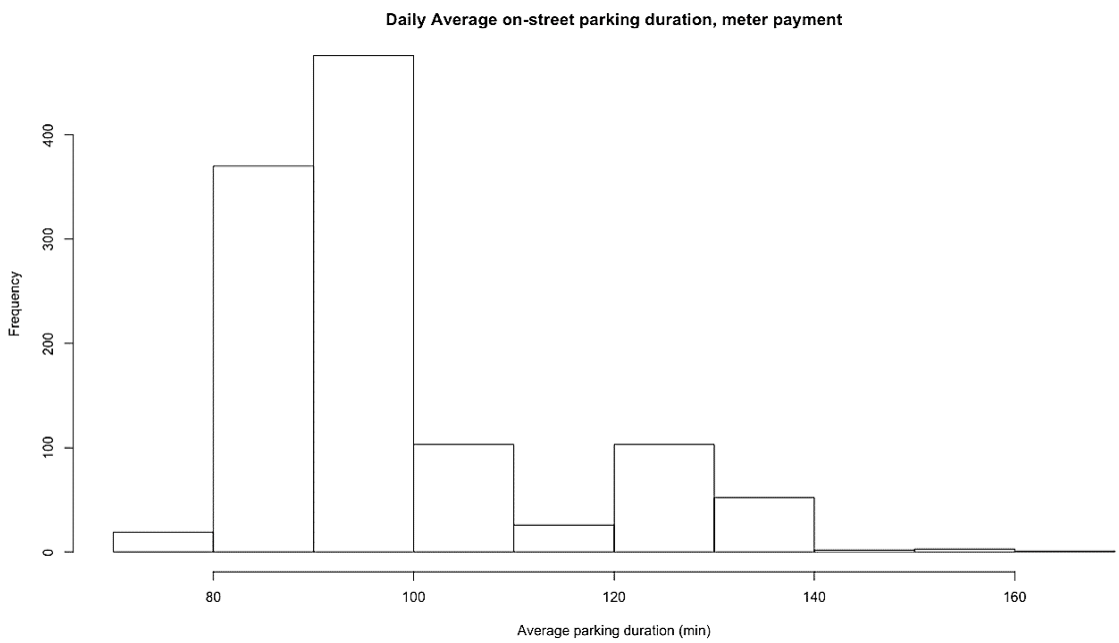

Figure 6: Histogram of the average daily on-street parking duration using meter payment method

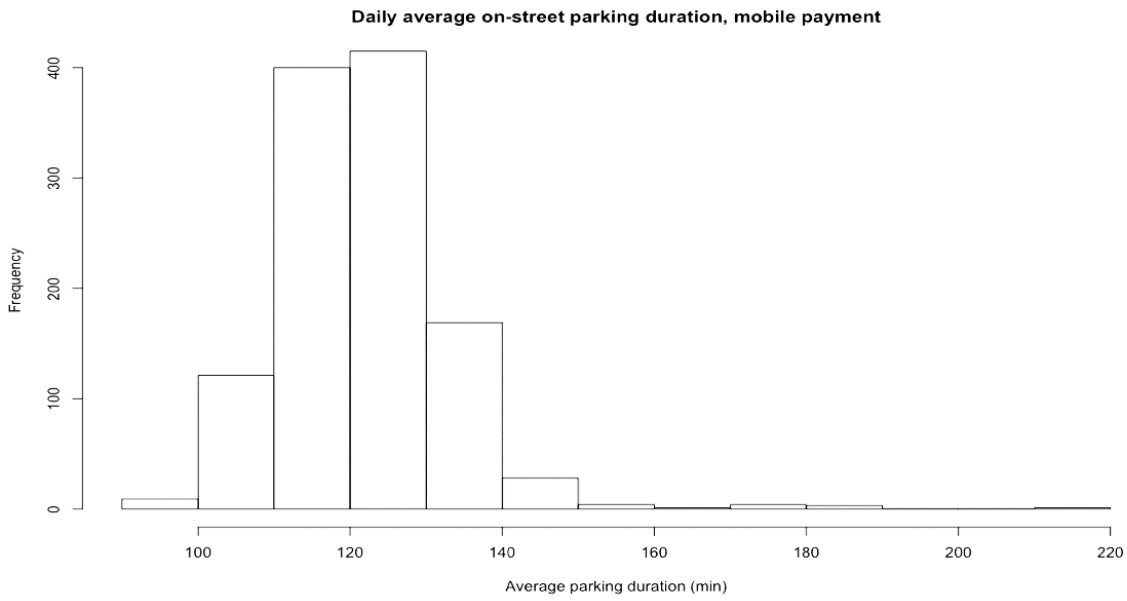

Figure 7: Histogram of the average daily on-street parking duration using mobile payment method

In figure 8 the average daily parking duration is visualized over time. Again, it is noticeable that the average parking duration using a mobile payment method is significantly higher than the average parking duration using a meter payment method. However, a slightly upward trend can be observed for the average parking duration using a meter payment. The parking duration using a mobile payment method remains stable over the period. This is confirmed by the presented values in table 8, where the mean parking duration of the average daily parking duration is shown per year, making a distinction between the two available payment methods. The mean average parking duration using a traditional payment method has increased from circa 93 minutes in 2014 to 100 minutes in 2017, while the mean parking duration using a mobile payment method has decreased minimally with one minute from circa 123 minutes in 2014 to circa 122 minutes in 2017. The increase in the parking duration using a meter payment also causes the decrease in the mean difference between the average parking durations of the two payment groups. The mean difference has decreased from 30.830 minutes in 2017 to 18.568 minutes in 2015, where after it increased to 22.337 minutes in 2017.

Additionally, the difference between the calculated means is presented in table 8, as well as the results of the two sample t-test that was conducted to compare the mean values of the average daily parking durations per year for both payment methods. An alpha of 0,05 was used as significance level. Results all give a p-value below 0.05, meaning that there is a significant difference between the means values of the average daily parking duration of the two given payment methods.

Furthermore, the parking duration using a meter payment shows larger variations between days than the parking duration using a mobile payment method. The standard deviations shown in table 8 are also significantly larger for the average parking duration using a meter payment method. Noteworthy are the high peaks visible at the beginning of the year. These peaks are observable for the parking duration of both payment methods, however to a larger extent for the parking duration of parking actions using a mobile payment method. These peaks can be explained by the Dutch spring festival *Carnaval*. This of origin Catholic festivity is celebrated in the days prior to Ash Wednesday (Burke, 2009). The relevant historic dates of Carnaval are 02-03-2014, 15-02-2015, 07-02-2016 and 26-02-2017. It can be observed that the average parking duration correspond with these given dates.

Table 8: Average daily on-street parking duration given in minutes

Year	Mean mobile payment	St. Dev. Mobile payment	Mean meter payment	St. Dev. Meter payment	Mean difference	Welch two sample T-test
2014	123.863	11.082	93.033	14.463	30.830	t = 31.408 df = 667.28 p-value < 2.2e-16
2015	121.613	10.340	97.926	13.268	23.687	t = 25.454 df = 659.02 p-value < 2.2e-16
2016	119.748	10.129	101.180	13.386	18.568	t = 21.28 df = 682.57 p-value < 2.2e-16
2017	122.693	14.336	100.356	15.129	22.337	t = 8.7475 df = 115.46 p-value = 2.07e-14

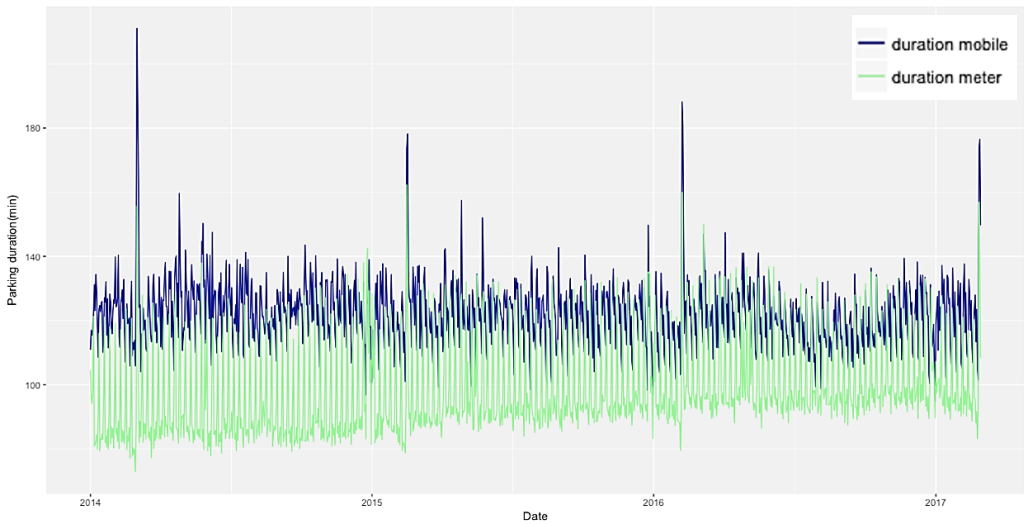

Figure 8: Time series average daily on-street parking duration

As determined from the results of the average daily parking duration analysis shown in figure 8, variations in parking durations exist between days. Therefore, the parking duration of all parking transactions was analysed per day of the week, making a distinction between the available payment methods. The results are presented in figure 9 and table 9. The mean parking duration using a meter payment method varies per day of the week. On Monday to Friday the parking duration values around an average of 90 minutes, however on Saturday and Sunday this number increases to 99.960 minutes and 126.647 minutes respectively. The average parking duration using a mobile payment method is different per day of the week as well, however a different pattern can be distinguished. On Monday the highest average parking duration of 129.167 minutes is observed. Tuesday, Thursday and Sunday show high parking duration values as well, giving average parking duration values of 125.494 minutes, 124.818 minutes and 126.435 minutes respectively.

Table 9: Average on-street parking duration per day of the week given in minutes

Day of the week	Mean mobile payment	St. Dev. Mobile payment	Mean meter payment	St. Dev. Meter payment	Mean difference	Welch two sample T-test
Monday	129.167	139.677	91.000	84.053	38.167	t = -86.815 df = 135930 p-value < 2.2e-16
Tuesday	125.494	134.924	91.297	83.419	34.197	t = -89.51 df = 171390 p-value < 2.2e-16
Wednesday	117.786	139.677	89.406	79.677	28.380	t = -79.646 df = 175730 p-value < 2.2e-16
Thursday	124.818	130.857	92.432	81.229	32.386	t = -93.68 df = 196830 p-value < 2.07e-14
Friday	112.766	120.855	87.857	78.240	24.909	t = -74.258 df = 190710 p-value < 2.2e-16
Saturday	111.121	106.178	99.960	94.970	11.161	t = -36.388 df = 61473 p-value < 2.2e-16
Sunday	126.435	96.832	126.647	88.310	0.212	t = 0.41151 df = 61473 p-value = 0.6807

As shown in table 9, on weekdays a significant difference in average parking duration can be depicted for the two parking payment methods, while on weekend days the average parking duration is more similar. The mean difference between the average parking durations for the two given payment groups is decreasing towards the weekend, giving the highest mean difference of 38.167 minutes on Monday and the lowest mean difference of 0.212 minutes on Sunday. An independent samples t-test was conducted for each day of the week to interpret the difference between the presented mean parking durations of both payment methods. An alpha of 0.05 was used as significance level. For all days of the week, except for Sunday, the given p-value is lower than 2.2e-16. This means that the mean parking duration using a meter payment method and the mean parking duration using a mobile payment method significantly differ from each other on the days from Monday to Saturday. However, the results for Sunday give a p-value of 0.6807, meaning that the average parking durations for both payment methods do not significantly differ from each other.

The individual parking durations vary significantly. This is shown by the high values of the presented standard deviation in table 9 and by the presented boxplots in figure 9. Therefore, an analysis of variance, also called ANOVA was conducted in order to determine if a significant difference exists between the mean parking durations for different days of the week per payment method, or that the mean parking durations for different weekdays is caused by high variability on the different days of the week. The analysis showed a significant difference at a $p < 0.05$ significance level in the parking duration using a mobile payment method for the different days of the week: F (6, 879431) = 407.2 , p < 2e-16. A statistic significant difference was also determined in the parking duration using a meter payment method for the different days of the week: F (6, 3064237) = 5870 , p < 2e-16.

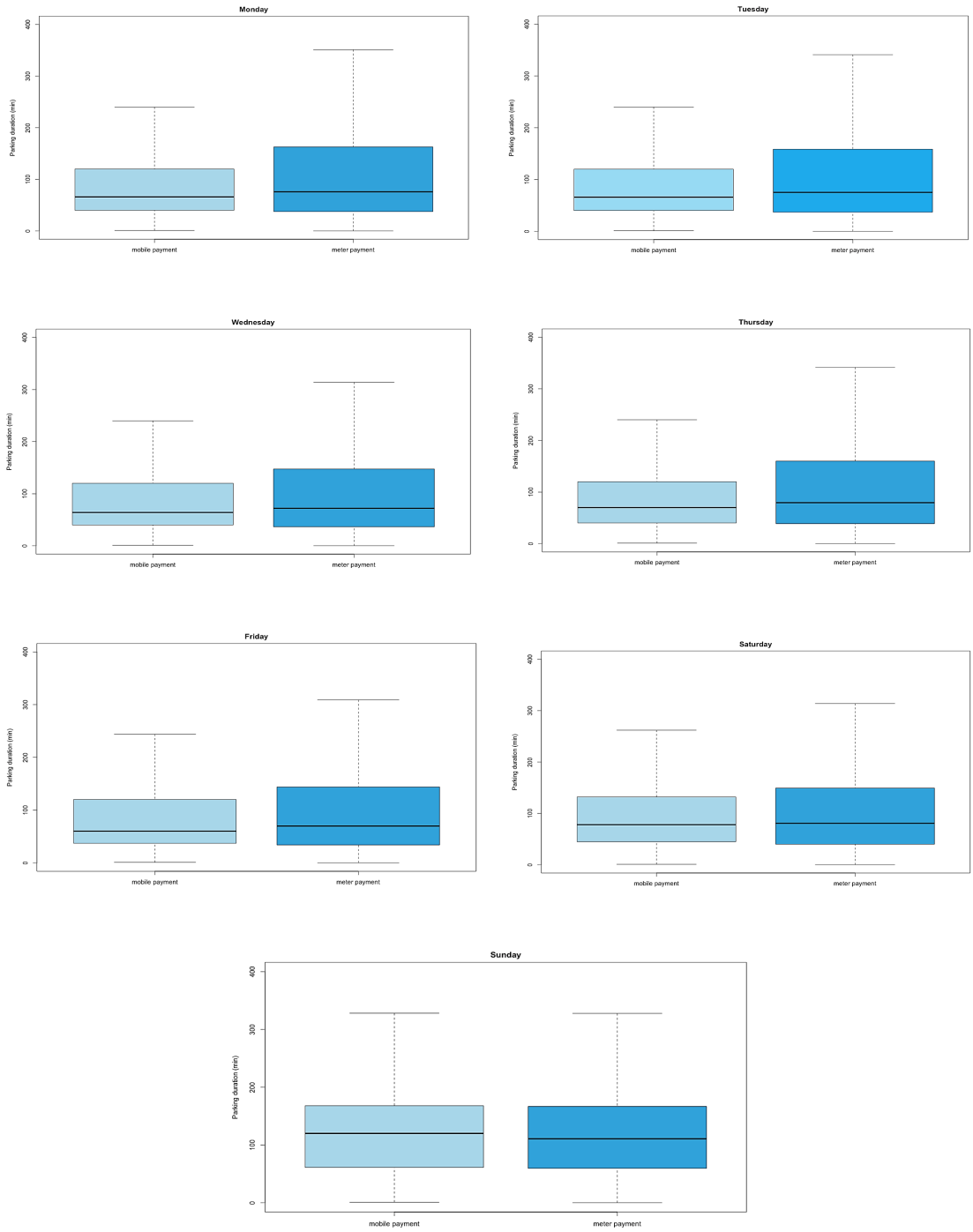

Figure 9: Boxplot average daily on-street parking duration per day of the week

In figure 10 the division of the on-street parking duration of all parking transactions over the given period are shown, distinguishing a mobile parking payment method and a traditional meter parking payment method. The on-street parking transactions were assigned to one of the eight categories based on their parking duration, enabling to analyse and visualize which categories of different parking durations contribute most towards prior discussed average daily parking duration. The eight categories for differentiating parking duration are: 0 – 15 min, 15 – 30 min, 30 – 45 min, 45 – 60 min, 60 – 90 min, 90 – 120 min, 120 – 240 min, >240 min. The y-axis shows the division of the different parking duration categories in percentages, given that 1.00 is the total amount of parking transactions for the given period. The x-axis represents the point in time. All parking start dates of the corresponding parking transactions are limited to the month of parking, giving a total of 38 time points in the period of 01-01-2014 to 28-02-2017. This because of the predetermined large variations in parking durations per day of the week.

As presented in table 10, more than 65% of the total parking actions using a mobile payment method, has a parking duration that values below 120 minutes. The parking duration categories below this value are said to be equally divided, with a slightly larger contribution of the parking duration category 60-90 minutes, which accounts for 13,7% of the total number of transactions using a mobile payment method. The largest parking duration category is 120-240 minutes. 21.7% of the parkers using a mobile parking payment method has a parking duration between 120 and 240 minutes.

Circa 70% of the total parking actions using a meter payment method has a parking duration that ranges below the value of 120 minutes. Most parking actions using a meter payment method have a parking duration that ranges between 60 – 90 minutes and 120 – 240 minutes, respectively 22.2% and 23.7% of the total number of parking transactions. However, as can be seen in figure 10, the category 45 – 60 minutes is increasing since June 2016 as well.

Noteworthy are the differencing categories for the two available payment methods. The parking duration category 0 – 15 minutes is significantly larger for parking transactions using a mobile payment method. Furthermore, the category 60 – 90 minutes is a considerably more contributing category for parking actions using a meter payment method than parking actions using a mobile payment method, whereas the category >240 minutes is larger for parking actions using a mobile payment. These observations are in accordance with the prior determined average daily parking durations. A greater amount longer parking durations contribute to a higher average parking duration of mobile parking payments.

Table 10: Division of on-street parking duration

Parking duration class	Number of mobile payments	% of total mobile payments	Cumulative percentage mobile payments	Number of meter payments	% of total meter payments	Cumulative percentage meter payments
0-15 min.	87064	9.9%	9.9%	143078	4.7%	4.7%
15-30 min.	88632	10.1%	20.0%	354619	11.6%	16.2%
30-45 min.	81064	9.2%	29.2%	329317	10.7%	27.4%
45-60 min.	107671	12.2%	41.4%	346525	11.3%	38.2%
60-90 min.	120432	13.7%	55.1%	679671	22.2%	60.5%
90-120 min.	89665	10.2%	65.3%	313462	10.2%	70.7%
120-240 min	190910	21.7%	87.0%	725194	23.7%	94.4%
>240 min	114010	13.0%	100.0%	172378	5.6%	100.0%

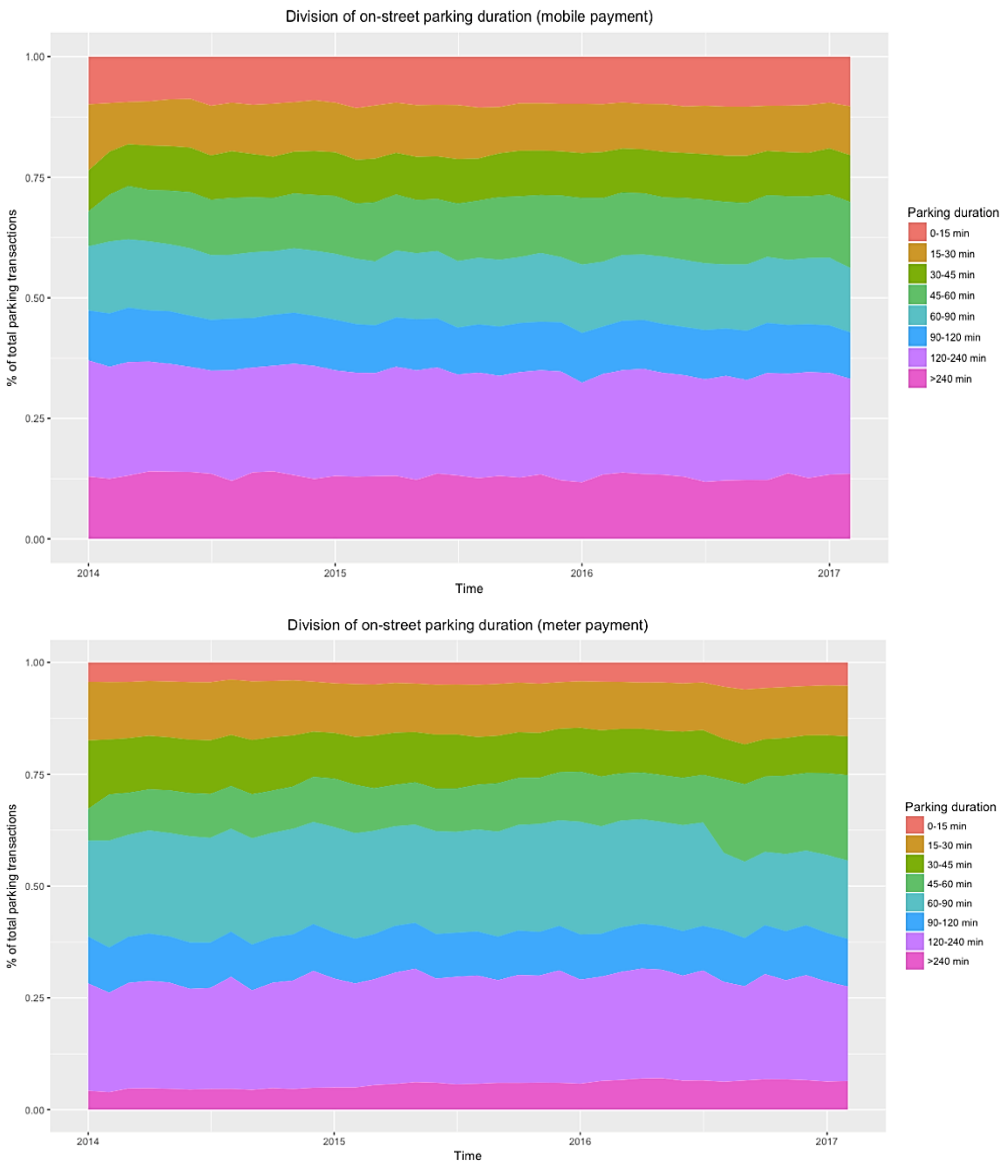

Figure 10: Time series division of on-street parking duration

5.3. Parking occupancy analysis

In this subsection the results of the parking occupancy analysis will be discussed. An analysis was performed for three areas in the city of 's-Hertogenbosch, namely the city centre, the edge of the city centre and the residential area. All zones were assigned to one of the three subsequent areas based on their zone code.

Each day in the subsequent period of 01-01-2014 to 28-02-2017 is divided into time intervals of five minutes, giving 288 points of time in a day. The starting time and the ending time of each parking transaction was rounded to the nearest interval. A parking space in a specific zone is said to be occupied at the start time of the parking action, the end time of a parking action and all time intervals between the start and the end time of the parking action. For example, if a parking action in zone 73001 (corresponding to city centre area) starts at time interval 108 (corresponds to 9:00AM) and ends at time interval 111 (corresponds to 9:15AM), a parking space in zone 73001 is said to be occupied at time intervals 108, 109, 110 and 111.

For each parking transaction it was specified at which time intervals, in which zone and at which date it occupies a parking space. For each date and zone, the amount of occupied parking spaces was calculated per time frame. The assumption was made that all zones have been fully occupied at least once in the period from 01-01-2014 to 28-02-2017, giving the maximum occupation rate per subsequent zone. The sum of the maximum occupation rates for all zones assigned to one of the three areas, gives the maximum occupation rate for the area.

Based on the maximum occupancy rate per area, the occupied percentage of parking spaces in the area was calculated for the 288 points of time per day. Thereafter the average occupation rate for each area was calculated for the time period of 01-01-2014 to 28-02-2017. In figure 11 and table 11 the results are presented.

The black line shows the average parking occupancy per time interval. The dark blue area shows a 98% confidence interval of the computed average occupancy rate, meaning that 98% of the days the occupied percentage of parking spaces are within this boundaries. The blue and light blue coloured areas show a 90% and an 80% confidence interval respectively.

As shown in table 11 and figure 11, the occupancy is the highest in the city centre of 's-Hertogenbosch, giving an average of 12.258% occupied parking spaces. The mean occupancy of parking places in the edge of the city centre is 7.888%, whereas the mean occupancy of

parking spaces in the residential area is 4.887%. All parking areas show a peak around 14:00PM – 15:00PM, however the occupancy during this time frame differs more from the occupancy during the rest of the day in the city centre and in the edge of the city centre, than in the residential area.

While the confidence intervals of 98% and 90% of the areas city centre and edge of the city centre are shaped similarly, the lower boundary of the 80% lies significantly lower for the edge of the city centre and almost reaches an occupancy of 0%. For the residential area, the 98% confidence interval already covers a large surface of the graph, meaning that the occupancy within this area is highly fluctuating.

Table 11: Average occupancy (%) per on-street parking area

Area	Mean total	St. Dev. total	Mean mobile payment	% of total	St. Dev. mobile payment	Mean meter payment	% of total	St. Dev. Meter payment	Mean difference
City centre	12.258	11.277	3.638	29.7%	3.293	8.619	70.3%	7.994	4.981
Edge of city centre	7.888	10.200	1.489	18.9%	1.855	6.398	81.1%	8.352	4.909
Residential area	4.887	6.371	1.286	26.3%	1.617	3.601	73.7%	4.771	2.315

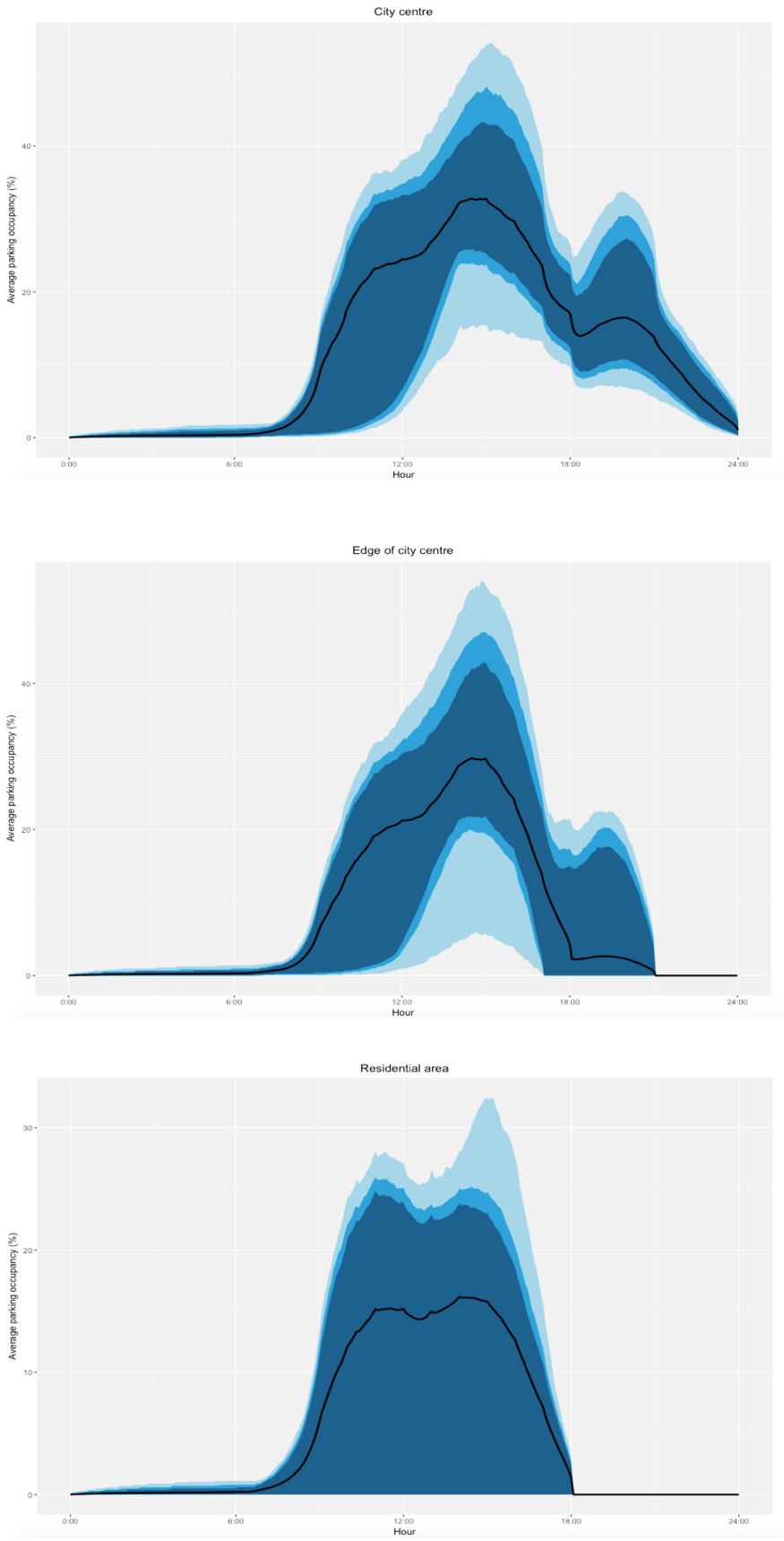

Figure 11: Graph average on-street occupancy with confidence intervals per area

Hereafter, the average occupancy rate per area was computed, making a distinction between a mobile parking payment method and a traditional parking payment method. Results are shown in table 11 and figure 12. The upper boundary of the stacked graph shows the average parking occupancy per time of the day as computed in the prior analysis. However, now the parking occupancy is divided in the average percentage of parking spaces occupied by parkers using a mobile payment method and the percentage of parking spaces occupied by parkers using a meter payment method.

The largest share of occupied parking places is occupied by parkers using a meter payment method, however this percentage is significantly larger in the edge of the city centre than in the other two areas. In the city centre, on average 3.638% of all parking places is occupied by parkers using a mobile payment method, whereas 8.619% of all parking places is occupied by parkers using a meter payment method. The sum of these percentages gives the previous discussed average occupation rate of 12.258%, of which 29.7% has used a mobile payment method and 70.3% has used a meter payment method.

In both the city centre and the residential area, more than 25% of the occupied parking spaces is on average occupied by car parkers parking by a mobile payment method. In the edge of the city centre less than 20% of the occupied parking spaces is on average paid with a mobile payment method. However, the amount of cars paying with a mobile payment method is still significantly lower in the residential area, due to the lower average occupancy rate in this area. Overall, the highest amount of parking spaces occupied by car parkers using a mobile payment are located in the city centre of ‘s Hertogenbosch.

Moreover, an analysis of variance was conducted in order to determine if a significant difference exists between the mean occupancy rates of the three given areas, or that the previous described difference is subjected to large variability in the three areas. The analysis showed a significant difference at a $p<0.05$ significance level in the amount of parking spaces occupied by parkers using a mobile payment method in the three different areas: $F(2, 861) = 86.88$, $p < 2.2e\text{-}16$. A significant difference was also given in the amount of parking spaces occupied by parkers using a meter payment method: $F(2,961) = 34.93$, $p < 2.2e\text{-}16$.

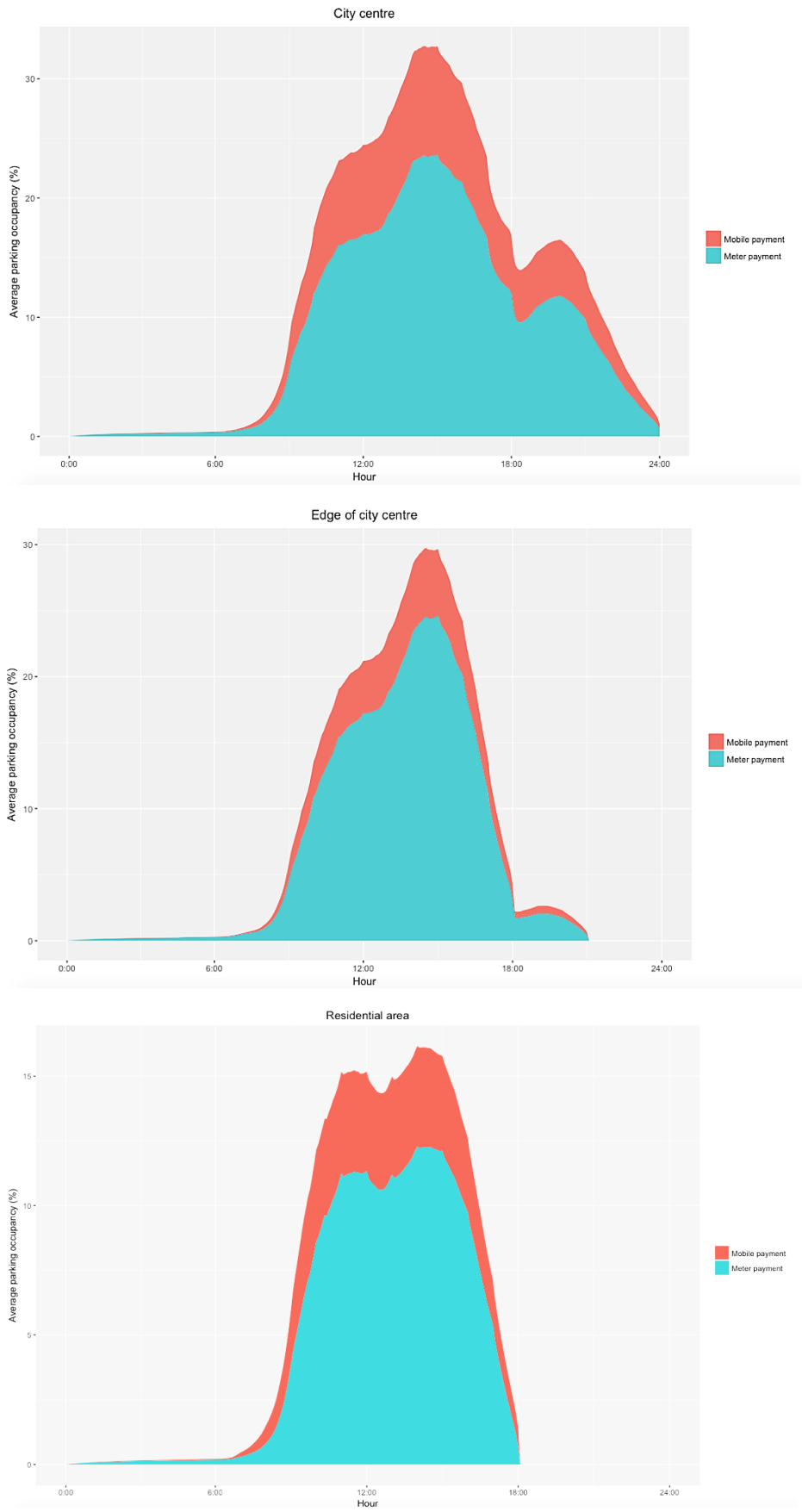

Figure 12: Graph average on-street parking occupancy distinguishing payment methods

Furthermore, the average parking occupancy was computed per day of the week per area. Both the total average parking occupancy was analysed, as well as the average parking occupancy distinguishing the two given payment methods. Results of the city centre are given in table 12 and figures 13 and 14. Results for the edge of the city centre are given in table 12 and figures 15 and 16, whereas results of the residential area are presented in table 13 and figures 17 and 18.

The black line in figure 13 shows the average percentage of occupied parking places per time of the week, whereas the grey area shows the standard deviation of the determined mean occupancy rate. The standard deviation shows the extent of variation in the mean average occupancy. The lower boundary of the grey area shows the mean minus the corresponding standard deviation and the upper boundary shows the mean plus the standard deviation.

As presented in table 12, the average amount of occupied parking places in the city centre is at its lowest point during Mondays and Sundays, respectively a mean of 10.213% and 7.785%. The parking occupancy reaches a peak on Saturday, namely 15.018%. However, Thursday also occurs to be a busy parking day, which shows an occupancy rate of on average 14.515%. This can be explained by the late opening hours of the shops on Thursday evenings. In the graph this peak in the amount of occupied parking spaces in the evening is also visible. Furthermore, all days show a peak around 14:00PM – 15:00PM and a smaller peak in the evening, with the exception of Thursdays.

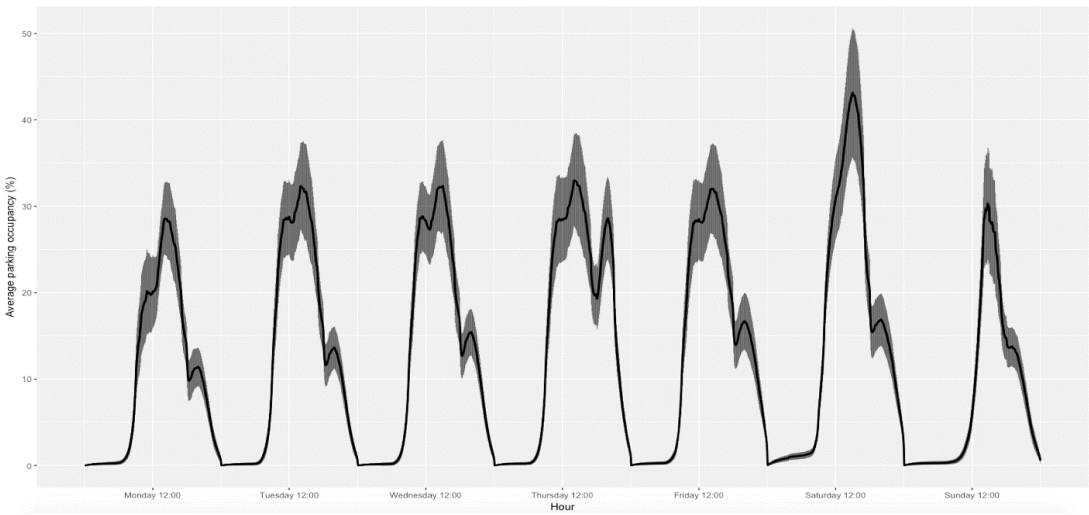

Figure 13: Graph average parking occupancy per day of the week in the city centre

Table 12: Average parking occupancy (%) per day of the week in the city centre

Day of the week	Mean total	St. Dev. total	Mean mobile payment	% of total	St. Dev. mobile payment	Mean meter payment	% of total	St. Dev. meter payment
Monday	10.213	9.719	3.222	31.6%	3.7929	6.990	68.4%	6.706
Tuesday	12.340	11.825	3.927	31.8%	3.729	8.413	68.2%	8.104
Wednesday	12.646	11.807	3.928	31.1%	3.612	8.717	68.9%	8.202
Thursday	14.515	12.675	4.524	31.2%	3.886	9.992	68.8%	8.813
Friday	13.286	11.719	4.069	30.6%	3.585	9.217	69.4%	8.139
Saturday	15.018	14.366	4.087	27.2%	3.908	10.931	728%	10.467
Sunday	7.785	9.372	1.709	22.0%	2.074	6.076	78%	7.353

The percentage of occupied parking places in the city centre for which a mobile payment method is used is higher during weekdays than on weekend days. On weekdays this percentage values above 30%, whereas this percentage decreases to 27.2% on Saturday and 22.0% on Sundays. This is division is visualized in figure 14. The upper boundary of the stacked graph shows the average parking occupancy per time of the week as computed in the prior analysis. The parking occupancy is now however divided in the average percentage of parking spaces occupied by parkers using a mobile payment method and the percentage of parking spaces occupied by parkers using a meter payment method.

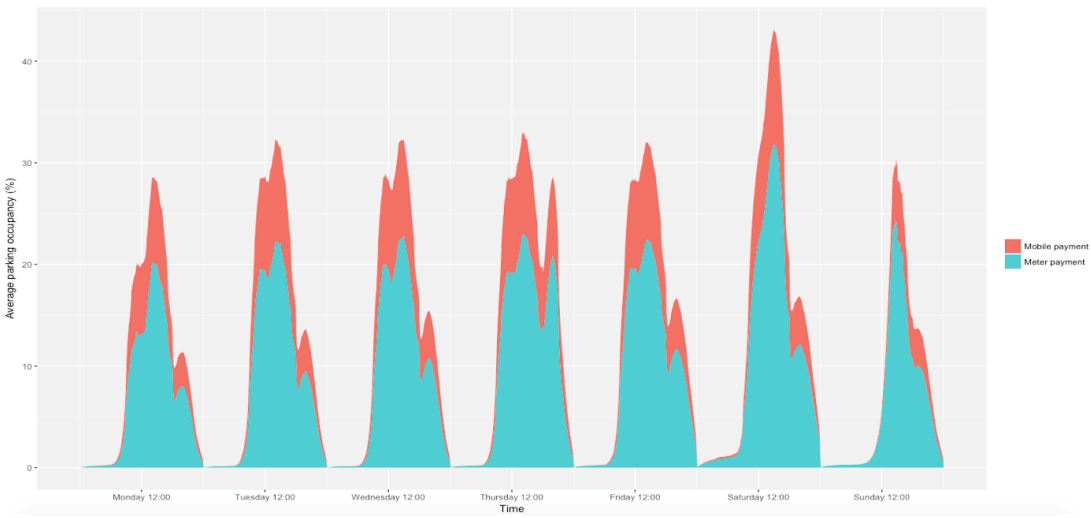

Figure 14: Graph average parking occupancy per day of the week in the city centre, distinguishing a mobile and a meter payment method

In the edge of the city centre, a similar weekly pattern can be noticed. As shown in table 13 and figure 15, the average parking occupancy is the highest on Thursdays and Saturdays, having a mean of 10.710% and 10.241% respectively. The lowest parking occupancy is given at Sundays, given a mean occupied parking places of 3.931%. A large peak can be depicted on Saturdays, reaching an occupancy rate of over 40%.

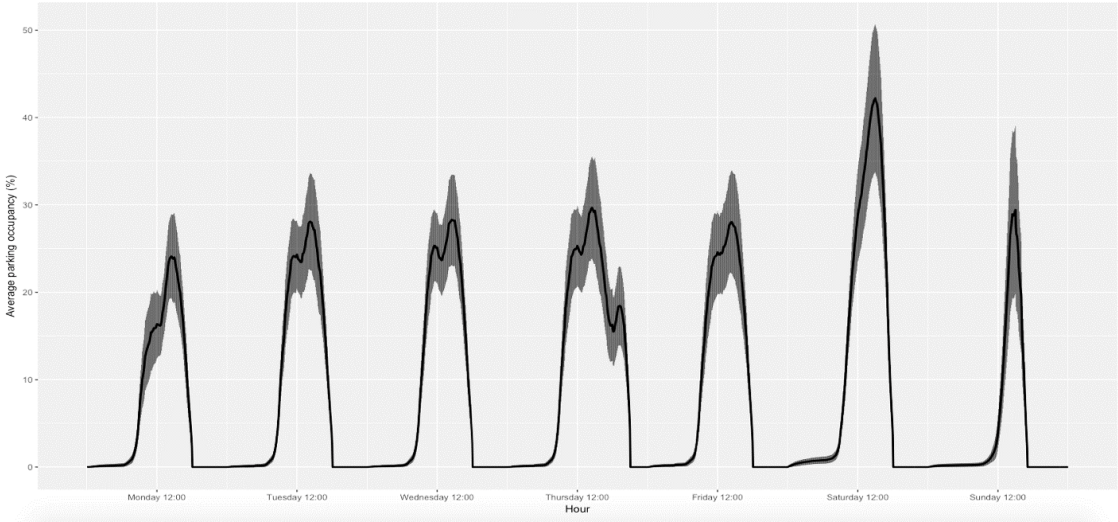

Figure 15: Graph average parking occupancy per day of the week in the edge of the city centre

As presented in table 13 and figure 16, the percentage of occupied parking places for which a mobile payment method is used is the highest on Mondays, Tuesdays and Thursdays. On average more than 20% of the occupied parking places is paid with a mobile payment method. On Wednesday, Friday and Saturday, this percentage decreases to 18.7%, 18.7% and 17.5% respectively. However, the lowest amount of occupied places for which a mobile payment method is used can be observed on Sundays, where a percentage of 13.0% is presented.

Table 13: Average parking occupancy (%) per day of the week in the edge of the city centre

Day of the week	Mean total	St. Dev. total	Mean mobile payment	% of total	St. Dev. mobile payment	Mean meter payment	% of total	St. Dev. Meter payment
Monday	6.272	8.379	1.258	20.1%	1.628	5.013	79.9%	6.771
Tuesday	7.940	10.594	1.595	20.1%	2.096	6.345	79.9%	8.509
Wednesday	8.075	10.822	1.513	18.7%	1.976	6.562	81.3%	8.852
Thursday	10.710	11.070	2.244	21.1%	2.254	8.466	78.9%	8.830
Friday	8.046	10.675	1.508	18.7%	1.978	6.538	81.3%	8.701
Saturday	10.241	14.616	1.793	17.5%	2.547	8.447	82.5%	12.072
Sunday	3.931	8.113	0.514	13%	1.109	3.417	83.0%	7.005

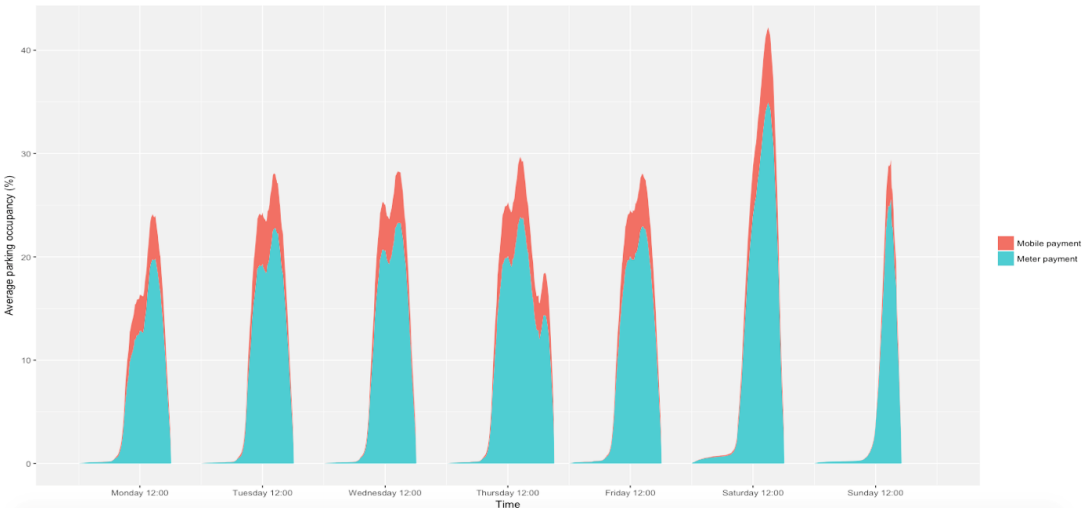

Figure 16: Graph average parking occupancy per day of the week in the edge of the city centre, distinguishing a mobile and a meter payment method

As presented in table 14 and figure 17, the average parking occupancy in the residential area reaches its highest point on Tuesdays, namely a mean parking occupancy of 6.494%. No parking places are said to be occupied on Sundays, because there is no paid parking time on Sundays. This means there are no parking transactions on this day of the week. Two daily peaks can be distinguished in this area during weekdays: one before midday and one after midday. In contrast to the other two areas, the parking spaces in this area show the lowest average occupancy on Saturdays, given a mean occupancy of 5.035%.

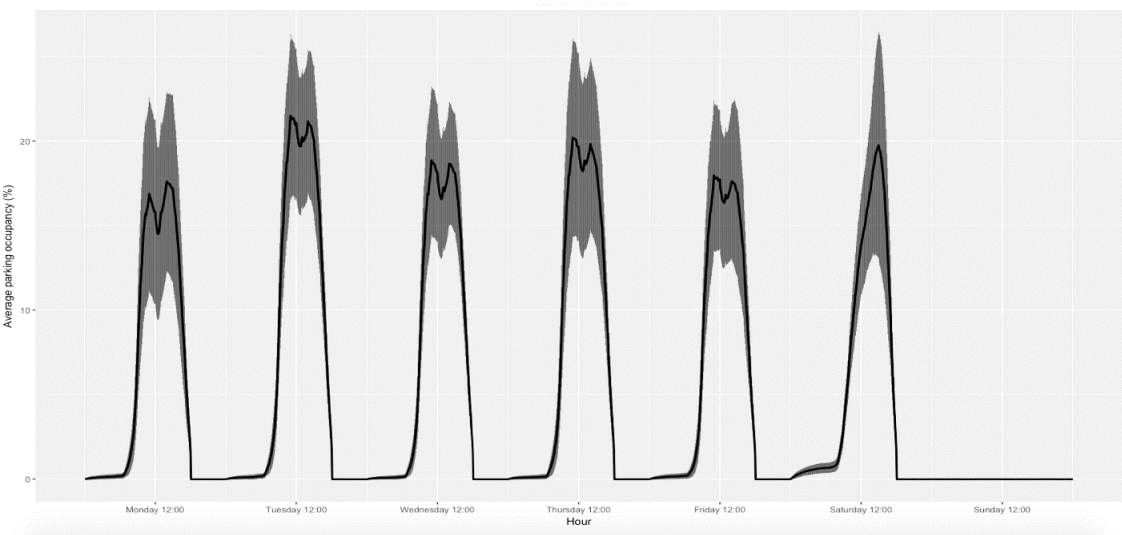

Figure 17: Graph average parking occupancy per day of the week in the residential area

Table 14: Average parking occupancy (%) per day of the week in the residential area

Day of the week	Mean total	St. Dev. total	Mean mobile payment	% of total	St. Dev. mobile payment	Mean meter payment	% of total	St. Dev. Meter payment
Monday	5.335	6.924	1.618	30.3%	2.021	3.717	67.7%	4.917
Tuesday	6.494	8.549	1.871	28.8%	2.369	4.623	71.2%	6.196
Wednesday	5.767	7.547	1.621	28.1%	2.064	4.145	71.9%	5.503
Thursday	6.101	8.017	1.779	29.2%	2.253	4.322	70.8%	5.781
Friday	5.481	7.171	1.354	24.7%	1.712	4.127	75.3%	5.483
Saturday	5.035	6.793	0.757	15.0%	0.963	4.278	85.0%	5.839
Sunday	0.000	0.000	0.000	0.00%	0.000	0.000	0.00%	0.000

As presented in table 14 and figure 18, the percentage of occupied parking places for which a mobile payment method is used values the highest on Mondays and decreases towards the weekend. A percentage of 30.3% is given on Mondays, whereas on Saturdays this percentage is 15%.

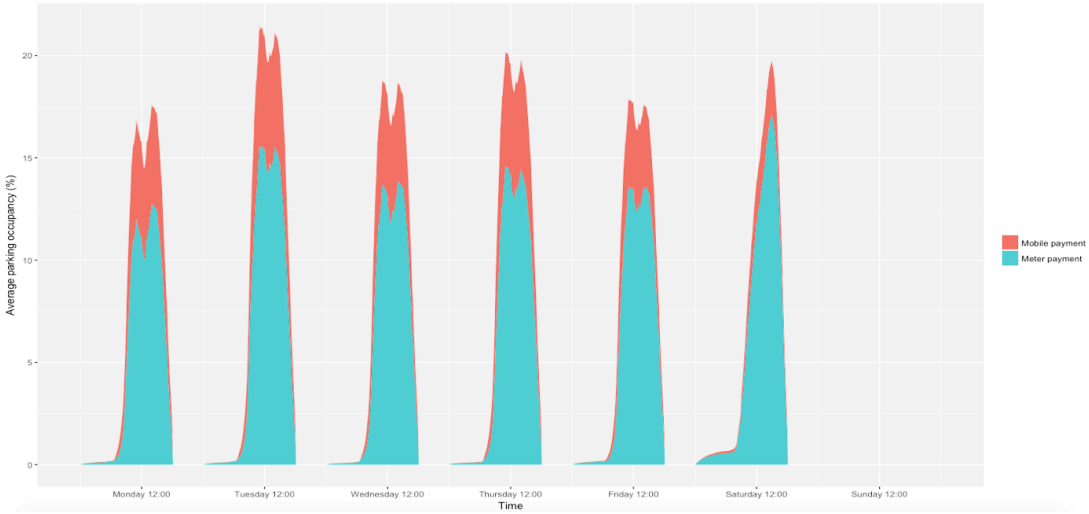

Figure 18: Graph average on-street parking occupancy per day of the week in the residential area, distinguishing a mobile and meter payment method.

Overall, the same division can be observed as in the previous graphs where no distinction per day of the week was made: in the city centre and in the residential area, the part of parking spaces occupied by parkers paying by a mobile payment method is the largest. However, it can be observed that during weekdays, parkers tend to pay more often with a mobile payment method than during days in the weekend, especially on Sundays.

5.4. Logistic regression model

In order to identify which factors influence the occurrence of a mobile payment method to pay for parking, two logistic regression models were created. A logistic regression model enables us to identify the key determinants that influence the probability of a mobile payment method being used for parking. A dichotomous variable was computed to indicate whether a mobile payment method was used (1) or not (0) (Menard, 2002).

The first logistic regression model tests whether the predictors parking start time, parking date, day of the week and month of the year are associated with the probability of a mobile payment method being used. The results of the model are presented in table 15.

The logistic regression estimate gives the change in the log odds of the probability outcome, thus the probability of using a mobile payment, for one unit increase in the predictor variable. We can see that the parking start date influences the probability of a mobile payment being used negatively. When the parking start time increases with one unit, log odds of a mobile payment being used decreases by 1.66e2. The variable Thursday however, has a positive influence on the mobile payment probability. When a parking transaction is performed on the day Thursday, compared to a transaction being performed on Monday, the log odds of a mobile payment being used changes with 1.41e1. The coefficients *Thursday, Tuesday, February* and *Parking date* all show a positive estimate value, meaning one unit increase of these coefficients increase the log odds probability of a mobile payment being used with the given estimate value. All other coefficients show a negative relation, meaning that an increase of one unit of these coefficients decrease the log-odds probability of a mobile payment with the given estimate value. Based on a 0.05 significance level, the coefficient *Parking start time* and *Parking date* are highly significant, giving a p-value of <2e-16. This means that the probability of using a mobile payment is highly dependent on these coefficients. The days Thursday, Monday, Friday, Saturday and Sunday also give a p-value lower than 0.05, meaning that the probability of a mobile payment is highly dependent on these coefficients. The day Tuesday however, gives a p-value of 0.46, meaning that this coefficient has no significant influence on the probability of a mobile payment. All months give a p-value below the significance level of 0.05, except for the months December and March, which give a p-value of 0.36 and 0.57 respectively. This means that these months have no significant influence on the probability of a mobile payment being used.

Furthermore, it was tested how well the developed model fits. The model has a null deviance of 4185649 on 3943681 degrees of freedom and a residual deviance of 4115445 on 3943662 degrees of freedom. The AIC value gives 4115485.

Table 15: Results logistic regression model 1.

Variable	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1,66e+04	6,37e+01	-260.183	< 2e-16
Parking start time	-1,50e+00	3,24e-02	-46.206	< 2e-16
Day - Thursday	1,41e+01	4,23e+00	3.344	0.000825
Day - Monday	-1,45e+01	4,61e+00	-3.150	0.001632 **
Day - Friday	-1,21e+01	4,31e+00	-2.806	0.005023 **
Day - Tuesday	3,20e+00	4,34e+00	0.738	0.460742
Day - Saturday	-8,29e+01	4,33e+00	-19.139	< 2e-16
Day - Sunday	-1,45e+02	6,31e+00	-23.025	< 2e-16
Month - August	-1,27e+02	6,47e+00	-19.612	< 2e-16
Month - December	-5,58e+00	6,07e+00	-0.920	0.357775
Month - February	2,03e+01	5,86e+00	-3.459	0.000543
Month - January	-2,58e+01	5,79e+00	-4.464	8.03e-06
Month - July	-7,59e+01	6,32e+00	-12.006	< 2e-16
Month - June	-3,09e+01	6,28e+00	-4.909	9.14e-07
Month - March	-3,54e+00	6,29e+00	-0.563	0.573744
Month - May	-2,60e+01	6,31e+00	-4.123	3.74e-05
Month - November	-1,60e+01	6,14e+00	-2.611	0.009032
Month - October	-3,46e+01	6,11e+00	-5.659	1.52e-08
Month - September	-3,09e+01	6,26e+00	-4.934	8.07e-07
Parking date	9,36e-01	3,81e-03	245.628	< 2e-16

Hereafter a second logistic regression model was created, adding the coefficient location as a predictor of the probability of a mobile payment. The location is a categorical variable with three possible options, namely the city centre, the edge of the city centre and the residential area. The results of the second logistic regression model are presented in table 15.

The results of the former included coefficients show the same significant or non-significant relation, as well as the same positive or negative influence on the log-odds probability of a mobile payment by the given estimate. However, the coefficient *February* in this model gives a negative relation to the log odds probability of the occurrence of a mobile payment. The

coefficients *Parking start time* and *Parking date* give again give a p-value below 2e-16, indicating a significant association between these coefficients and the probability of a mobile payment. The days Thursday, Monday, Friday, Saturday and Sunday also give a p-value lower than 0.05, meaning that the probability of a mobile payment is highly dependent on these coefficients. The coefficient Tuesday again gives a non-significant p-value of 0.49, meaning that this coefficient has no significant influence on the probability of a mobile payment. All months give a p-value below the significance level of 0.05, except for the months December and March, which give a p-value of 0.39 and 0.70 respectively. This means that these months have no significant influence on the probability of a mobile payment being used. The location categories *Residential area* and *Edge of the city centre* both have a p-value below <2e-16, meaning that they have a significant influence on the probability of a mobile payment. Both coefficients show a negative relation towards the probability, meaning that compared to a transaction performed in the city centre, a parking transaction in the residential area or the edge of the city centre decreases the probability of a mobile payment.

The second model gave a null deviance of 4185649 on 3943681 degrees of freedom and a residual deviance of 4088077 on 3943660 degrees of freedom. The AIC value is 4088121, which is lower than the AIC value of 4115485. This means that the second model is a better model to describe the relation between the coefficients and the probability of a mobile payment method being chosen (Menard, 2010).

A Hosmer-Lemeshow Goodness of fit was conducted on the two logistic regression models, in order to test whether the model depends on the data. The results for the first model valued X^2 = 1248, df = 8, p-value < 2.2e-16. The results for the second model gave X^2 914.91, df = 8, p-value < 2.2e-16. Results for both logistic regression models result in a p-value below 0.05. This means that the models fits the data too well, and thus cannot be used to properly describe the relation between the given coefficients and the probability of using a mobile payment. (Menard, 2010)

Table 16: Results logistic regression model 2.

Variable	Estimate	Std. error	Z value	Pr(>|z|)
(Intercept)	-1,63e+04	6.390e-02	-255.479	< 2e-16
Parking start time	-2,34e+00	3,30e-02	-71.037	< 2e-16
Day - Thursday	2,89e+01	4,24e+00	6.817	9.30e-12
Day - Monday	-1,27e+01	4,63e+00	-2.739	0.00617
Day - Friday	-1,35e+01	4,32e+00	-3.121	0.00180
Day - Tuesday	3,00e+00	4,35e+00	0.689	0.49068
Day - Saturday	-7,96e+01	4,35e+00	-18.301	< 2e-16
Day - Sunday	-1,63e+02	6,35e+00	-25.639	< 2e-16
Month - August	-1,28e+02	6,49e+00	-19.709	< 2e-16
Month - December	-5,23e+00	6,09e+03	-0.858	0.39082
Month - February	-2,49e+01	5,88e+00	-4.225	2.39e-05
Month - January	-2,95e+01	5,81e+00	-5.081	3.75e-07
Month - July	-8,11e+01	6,34e+00	-12.788	< 2e-16
Month - June	-2,90e+01	6,31e+00	-4.599	4.24e-06
Month - March	-2,39e+00	6,32e+00	-0.379	0.70481
Month - May	-2,78e+01	6,33e+00	-4.395	1.11e-05
Month - November	-1,25e+01	6,16e+00	-2.036	0.04178
Month - October	-3,28e+01	6,13e+00	-5.346	9.00e-08
Month - September	-3,13e+01	6.279e-03	-4.984	6.23e-07
Parking date	9,38e-01	3.822e-06	245.373	< 2e-16
Location – Edge city centre	-5,15e+02	3.223e-03	-159.697	< 2e-16
Location – Residential area	-2,14e+02	3,50e+00	-61.180	< 2e-16

6. Conclusion and Discussion

This research has investigated the main effects of the adoption of mobile parking payment services on parking space utilization in urban areas. A dataset about parking utilization in the city of ‘s Hertogenbosch has been used to analyse on-street parking utilization behaviour for the period of 1 January 2014 to 28 February 2017. The effect of the adoption of mobile payments on the parking location, the parking moment and the parking time have been examined. First, the number of parking transactions using a mobile payment have been calculated and compared to the number of parking transactions using a meter payment. Their contributions to the total number of parking transactions have been determined over time. Thereafter the average daily parking duration time was analysed for different points in time, distinguishing a mobile and a meter payment method. Furthermore, it was analysed which categories of different parking durations contribute most towards the average daily parking duration. Subsequently, the parking the occupancy was analysed for three different areas in the city of ‘s-Hertogenbosch, namely the city centre, the edge of the city centre and the residential area. The number of occupied places using the two given payment methods was determined and analysed for different days of the week. Lastly, two logistic regression models were created in order to determine the key determinants of the probability of a mobile payment being used.

The main findings of the research will be described, followed by a discussion of the research according to the formulated hypotheses. Subsequently, the research question will be answered, followed by a discussion of the research. Thereafter, the managerial implications of the research will be thoroughly described as well as the limitations of the study and implications for future research.

6.1. Main findings

First of all, it has been found that the number of mobile parking payments has increased in the past few years at the expense of the traditional meter parking payments. The daily sum of parking transactions using a meter payment method is experiencing a downward trend, with the average number of daily parking transactions decreasing from 2780 in 2014 to 2534 in 2017. The average number of mobile parking transactions has been growing, showing daily transaction numbers of 521 in 2014 and 1160 in 2017. In 2014 the percentage mobile and meter payment transactions of the total number of on-street parking transactions were 16% and 84% respectively, while in 2017 these percentages have changed to 31% and 69% respectively.

Moreover, it was found that most mobile parking transactions were indeed performed in the city centre of ‘s-Hertogenbosch and that this number decreased when moving further away from the city centre. The average percentage of occupied places in the city is 12.258%, whereas the average percentage of occupied places in the residential area is 7.888% and 4.887% respectively. The average percentages of occupied places for which a mobile payment method was used valued 3.638% in the city centre, 1.489% in the edge of the city centre and 1.286% in the residential area. It was determined that the mean differences in occupancy rates for the three given areas significantly differed from each with a conducted analysis of variance: The analysis showed a significant difference at a $p<0.05$ significance level in the amount of parking spaces occupied by parkers using a mobile payment method in the three different areas: $F(2, 861) = 86.88$, $p < 2.2e\text{-}16$. A significant difference was also given in the amount of parking spaces occupied by parkers using a meter payment method: $F(2,961) = 34.93$, $p < 2.2e\text{-}16$.

However, the portion of transactions using a mobile payment method of all transactions does not follow this trend. The share of occupied parking places using a meter payment method is significantly larger in the edge of the city centre, namely 81.1%, than in residential area and the city centre where the percentages were 70.3% and 73.7% respectively. In both the city centre and the residential area more than 25% of the occupied parking spaces is occupied by car parkers parking by a mobile payment method. In area at the edge of the city centre, this portion is lower than 20%.

Furthermore, it was found that the average daily parking duration using a meter payment method was significantly lower than the average parking duration using a meter payment method. The average daily parking duration using a meter payment method valued between the 93 and 100 minutes from 2014 to 2017, whereas the average daily parking duration using a mobile payment method varied minimally from 123 minutes in 2014 to 122 minutes in 2017.

The analysis of the average parking durations for different days of days of the week showed significant differences in parking durations per day of the week. When using a meter payment method, the average parking duration is higher in the weekends than on weekdays. The average parking duration during weekdays values around an average of 90 minutes, however on Saturday and Sunday this number increases to 99.960 minutes and 126.647 minutes respectively. Another pattern can be distinguished for mobile parking actions, where the

average parking duration on Monday, Tuesday, Thursday and Sunday averages above 120 minutes and on Wednesday, Friday and Saturday below 120 minutes. Noteworthy are the similar parking durations for both payment methods on Sundays, for which a parking duration of circa126 minutes was found. This was confirmed by the conducted t-test comparing the mean parking durations of both payment methods. For all days of the week, except for Sundays, the given p-value is lower than 2.2e-16, meaning that the mean parking durations significantly differ from each other. Results for Sunday give a p-value of 0.6087, implying that the average parking duration for both payment methods do not differ from each other. Furthermore, results of the conducted analysis of variance showed a significant difference at a $p<0.05$ significance level in the parking duration using a mobile payment method for the different days of the week.

Moreover, it was found that circa 70% of the total parking actions using a meter payment method has a parking duration that ranges below the value of 120 minutes. The largest share of parkers has a parking duration that ranges between 60 – 90 minutes and 120 – 240 minutes. More than 65% of the total parking actions using a mobile payment has a parking duration below 120 minutes. However the largest share of mobile parkers have a parking duration that value between 120 and 240 minutes, contributing to a higher average parking duration.

Furthermore, two logistic regression models were developed to determine the key determinants of the probability of a mobile payment method. All included coefficients showed a negative relation to the log odds probability of a mobile payment, except for the coefficients *Parking date, Tuesday* and *Thursday*, of which *Parking date* and *Thursday* showed a significant relation with a p-value of <2e-16 and 0.0008 respectively. However, by using the Hosmer-Lemeshow Goodness of fit, it was found that both models fit the data too well, and thus the models cannot be used to describe the relationship between the given coefficients and the probability of using a mobile payment method. Further testing of the coefficients and the model is necessary in order to be able to correctly interpret the associations and the influences of variables on the probability of a mobile payment.

6.2. Discussion

This thesis contributes to the research addressing both mobile payments in general and mobile payments used for parking purposes. It investigates the main effects of the on-going mobile adoption on on-street parking utilization. The influence of the mobile adoption on parking utilization has been examined according to three concepts, namely the parking location, the

parking moment and the parking time. The results will be discussed according to the formulated hypotheses.

H1: The number of parking transactions using a mobile parking payment method will increase as the distance of the parking location to the city centre decreases.

This hypothesis is indeed supported by empirical evidence of the city of 's-Hertogenbosch. It was proposed that a relation exists between the number of parking transactions using a mobile payment method and the distance of the parking location to the city centre. Motorists who value a short walking distance to their point of destination, which is often located in the city centre (Ferrili, 2008), value a timelier arrival at the point of destination. The same applies for parkers who use a mobile payment method, which is mostly adopted and used because of time saving motivations (Dahlberg et al. 2008; Mallet et al, 2008; Pedersen et al, 2003; Chen, 2008; Carlsson, 2006). It was found that most mobile parking transactions were performed in the city centre and that this number decreased when moving further away from the city centre.

However the portion of transactions using a mobile payment method does not follow this trend. While the portion of occupied parking places using a mobile payment method is still the largest in the city centre, this portion is reaches its minimum in the edge of the city centre instead of in the residential area. An explanation for this might be that the city centre is not the point of destination for parkers who park in the residential area, due to the large distance between the city centre and the residential area, but often is the desired point of destination of parkers who park in the edge of the city centre. Ferrili (2008) states that the parking costs increase as one parks closer to the city centre, as does the probability of an occupied parking spot. When a motorist parks in the edge of the city centre with the city centre as point of destination, it is fair to assume that one values low parking costs and a short search time for a vacant parking spot higher than a short walking distance towards the centre and a time saving parking payment method.

H2: The average parking time duration for on-street parking will decrease when using a mobile parking payment method.

The evidence of this research does not support this hypothesis. The average parking duration was significantly larger for parking actions using a mobile payment method, than for parking actions using a meter payment method. The results of the analysis of the division of different parking duration categories explain this difference. The proportion of parking actions of

which the parking duration is higher than 240 minutes is 13% for parking actions using a mobile payment method and 5.6% for parking actions using a meter payment method. Furthermore, circa 70% of the meter parking actions has a parking duration that values below 120 minutes, whereas 65% of the mobile parking actions values below a parking duration of 120 minutes. This implies that parkers are not limited by their predetermined parking duration as is necessary when paying for parking by a meter payment. An explanation for this can be that persons are no longer limited by their predetermined parking time when performing their activity, which leads to performance of additional activities or prolonging their original activity.

H3: The amount of parking transactions using a mobile payment method will be higher on weekdays than on weekend days

This hypothesis is supported by empirical evidence of the city of 's-Hertogenbosch. It was found that parkers tend to pay more often with a mobile payment method during weekdays than on weekend days. The hypothesis proposed that people tend to be more busy during weekdays than on weekend days and thus value a time efficient payment method more on weekdays than on weekend days. The concept of being less busy on weekend days is also confirmed by the results of the parking duration, which state that the average parking duration reaches its higher boundary on Sundays for both payment methods.

It can be concluded that the increased use of mobile payment methods for parking has an effect on on-street parking utilization in urban areas. Different behavioural patterns exist for parkers using a mobile payment method and parkers using a meter payment method. The average parking duration increases when using a mobile payment method and different parking preferences in terms of locations and parking moment can be depicted as well.

This research contributes to the literature on parking utilization (Gillen, 1978; Hunt, 1988; Kanafani, 1983; Axhausen and Polak, 1991; Hunt and Teply, 1993; Lambe 1996; Thompson and Richardson, 1998; Dell'Orco et al, 2003; Bonsall and Palmer, 2004; Ruisong et al., 2009; van der Waerden, 2012; Chaniotakis and Pel, 2015) by showing different parking utilization patterns for parking actions using a mobile payment method and parking actions using a meter payment method. It was found that the parking utilization behaviour differed for the two given payment methods. The average parking duration increases when using a mobile payment method and different parking preferences in terms of locations and parking moment can be depicted as well. Furthermore, this thesis contributes to the literature on the adoption

of mobile payments and mobile payments for parking (Mallat, 2007; Yang et al., 2012; Dahlberg et al, 2008, Pedersen et al., 2003; Pedersen, 2005) by providing insights in parking utilization patterns while addressing the different payment methods. As stated by Dahlberg et al (2008), the comparison of mobile payment methods and traditional payment methods in different situations is an underexposed subject, however provides increased knowledge about mobile payment behaviour. It was found that mobile parking payments are increasingly used for parking as well as that mobile parking payments are used more during weekdays than on weekend days. Additionally, it was found that mobile parking payments are used more on parking locations located near the city centre.

6.3 Managerial implications

From the managerial point of view, this thesis highlights several important trends in urban areas. Firstly, the increased use of mobile parking payments occurs at the expense of traditional meter payments and, following the trend of the recent years, is likely to increase further in the following years. New insights on parking utilization using mobile payments can thus serve as the base for argumentation of decision-making and the implementation of policy practices that fulfil the needs of the city (Martens, 2010), while keeping in mind that meter payments are decreasingly acting as a revenue system for cities. Moreover, the deployment of mobile parking data gives more precise insights in the parking utilization in urban areas, since it provides the exact start and end time of a parking action.

It has been found that motorist using a mobile parking payment are largely parking at locations near the city centre, putting high emphasis on a short walking distance and time efficient parking services, while accepting both the monetary and non-monetary costs of parking (Ferilli, 2010). Targeted marketing practices can for example be developed for parkers preferring to park near the city centre, to promote the use of mobile parking services. At the same time, mobile parking applications can be used as a channel to stimulate certain parking behaviour or promote other concepts that are relevant for cities, such as promoting parking at the edge of the city centre to reduce congestion or promote a city event. Furthermore, the use of mobile parking payment allows for demand-based pricing. Pierce and Shoup (2013) found that changes in price can influence extremely over occupied and under occupied on-street parking locations. The use of mobile devices to pay for parking facilitates flexibility in parking prices.

Furthermore, giving insights in mobile parking behaviour can serve as the base for further development of additional mobile parking services and new business models. Applications

can for example offer the reservation of parking spaces, as is implemented in the city of San Fransisco (Chen, 2014). Reservation systems can offered for both public and private parking locations, enabling optimization of the use of spatial areas in the city centre.

Moreover, the use of mobile devices allows for insights in both demographic data and precise geographic data. A subscription is often required prior to the usage of a mobile parking application, allowing for insights in demographic characteristics of a mobile payment service user. Furthermore, geolocation technologies and wireless communication technologies allow for the knowledge of the exact location a mobile parking service user (Kane et al., 2009) Linking this readily available data to parking transaction data allows for parking policies targeting specific groups, providing user-relevant information and adding user relevant additional services. A parking action can for example be performed in the city centre of 's-Hertogenbosch. Knowing from the available demographic data that the parker is female and aged between 20-25 years old, the locations of low-priced parking lots nearby can be provided in order to promote parking in the edge of the city centre. Furthermore, a promotion message of a clothing shop nearby can be provided in order to stimulate monetary spending in the city centre, or a promotion message about a city event can be provided for city marketing purposes.

6.4 Limitations and future research

This research only focuses on the adoption of mobile parking services and its impact on on-street parking utilization, excluding the existence and deployment of off-street parking locations. This is due to the fact that off-street parking locations do not allow for mobile parking payments at this moment. Therefore this research does not give a complete overview of the parking environment in urban areas. On-street and off-street parking locations have an influence on parking choice behaviour (Hunt, 1988; Hunt and Teply, 1993, Ruisong et al., 2009; van der Waerden, 2012). An experiment facilitating parking using a mobile parking payment method should therefore be conducted in future research to investigate the relation between on-street and off-street parking locations and the adoption of mobile payment methods.

Additionally, all parking transactions have been limited to the maximum parking duration of one day, due to the explained unknown parking end time of motorists when performing a meter payment. However, this research provides no insights in parking actions that continue for more than one day, limiting the research scope. It has been concluded that the parking duration differs for parking actions using a mobile payment and parking actions using a meter

payment. Results may differ when including the parking transactions that continue for more than one day.

Furthermore, it was found that the average parking duration values higher for parking actions using a mobile parking payment than when using a meter payment. The parking duration should be examined in relation to the performed activity, and it should be indicated whether there is a difference in the performed activity in terms of time, amount and sort of activities.

The two proposed logistic regression models showed overfitting. The model was therefore not used to describe the relationship between the coefficients parking date, parking start time, parking location, day of the week, month of the year and the probability of a mobile payment method. The model should be further tested with different variables, in order to be able to make statements about the relation between the proposed coefficients and the probability of a mobile payment method.

Additionally, no distinction is made between motorists who have been using the mobile parking services for a longer time, motorists who have just adopted the mobile parking services, motorist who have used a mobile parking services but prefer meter payments and motorists who alternate between the two available payment options to pay for on-street parking space and time as proposed by Yang et al. (2010). It was found that social influences are no longer of substantial influence on the intention to use mobile payments after initial adoption, while personal characteristics remain an important factor (Yang et al, 2010) Behaviour may thus differ across these groups, which should be included in further research.

Moreover, demographic factors should for example be included in future research. Age, sex and income for example are said to have an impact on parking behaviour (Chaniotakis and Pel, 2015), which are variables that have not been addressed in this research but might offer valuable insights on the usage of mobile payments and parking utilization. Furthermore, it could be investigated how mobile payments for parking purposes are adopted among local motorists and tourists and if this influences parking utilization.

Lastly, the type of parking service provider should be investigated. Mobile parking applications as Parkmobile, Park-line and Yellowbrick (Parkeerdata, 2017), might vary in application. Do motorists using different parking providers behave differently and what causes these differences in behaviour? The development of this possible effect should be addressed and examined under the entrance of more competition in the market.

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