CONTENTS

INTRODUCTION

Q-Park Thesis Award
Understanding the trends that impact parking

We are proud to present this collection of the winning theses from the first five years of the Q-Park Thesis Award.

Parking is and will continue to be an essential link in the mobility chain. At the same time the sector will be strongly impacted by many trends and developments in the coming decades. Socio-economic trends (aging population, further urbanisation, e-shopping), technological developments (electric, self-driving and smart cars) and the diffusion of Mobility as a Service (MaaS) applications are creating new opportunities in the parking sector, but are also introducing new players and changing power relationships.

Understanding these trends and their potential impact on parking is key for the future of the sector. And academic research performed by students for their master thesis can greatly contribute to this knowledge.

The winning thesis abstracts contained in this publication can be classified in four major themes:

- Parking demand
- Parking choice behaviour
- Parking as mobility management tool
- Parking and electric vehicles

Celebrating five years of cooperation

In cooperation with the Erasmus University Rotterdam, Q-Park established the Q-Park Thesis Award in 2014 for the best master's thesis on parking and mobility written at a University in the Netherlands or Belgium.

We have commissioned this book to celebrate the 5th anniversary of the Q-Park Thesis Award and to give an overview of the winning theses. In each of the four sections we reproduce the abstracts[1] of each thesis that was awarded a prize in the period 2014 – 2018.

[1] All authors of the theses presented in this book have given Q-Park their explicit permission to publish their abstracts in this publication.

Bridging the knowledge gap

When we established this award in 2014 our purpose was both internal and external: on the one hand we wanted to mark the retirement of our founder, Ward Vleugels. On the other we sought to bridge the considerable gap between academic research on parking and its practitioners in the parking sector[2].

As a parking operator Q-Park has welcomed the dramatic rise in academic literature on parking in the last 15 years. But we have also noted the knowledge mismatch between what practitioners need in the field and what academics have produced. Put simply, the two are driven by different goals.

But as the theses presented here show, the two worlds can come closer to generate new knowledge which combines both academic rigour and new ideas for practitioners to tackle current and future challenges.

Fourteen winning master theses in five years

In the first five years, more than 40 master theses were submitted to the Q-Park Thesis Award from leading universities in the Netherlands and Belgium; 14 received a prize, and 13 theses are presented in this publication. The theses have been assessed by a jury of academics and practitioners based on their academic and socio-economic relevance.

Each thesis should provide new knowledge for the parking sector and must be distinguishable from previous research. The theses include both qualitative and quantitative research and all of them meet rigorous academic standards[3].

Thank you

We would like to thank and congratulate all students who submitted their theses for the Q-Park Thesis Award in the last five years. All students have actively contributed to create new knowledge for the parking sector. In the coming years we hope that many more students will conduct research on parking and mobility related themes.

We are also truly grateful to all the supervisors who have helped the students to conduct their research and to graduate. We hope you will keep feeding the Q-Park Thesis Award with many students' research.

We trust that this publication will continue to build bridges by inspiring students and academics to conduct new research on parking and by encouraging practitioners to strengthen their cooperation with universities.

Maastricht, September 2019
Frank De Moor – Q-Park
Theo Thuis – Q-Park
Giuliano Mingardo – Erasmus University Rotterdam

UPT Erasmus
ERASMUS CENTRE FOR URBAN PORT AND TRANSPORT ECONOMICS

Q-PARK

[2] Parking operators, urban planners, policy makers, and advisors.

[3] For each abstract we clearly state the author, the affiliated university where the student graduated and the year of publication. Most of these theses are publicly available and can easily be found on the internet through the thesis repository of each university.

PARKING DEMAND

EFFECTIVENESS OF DOWNSIZING


DEMAND

Student information
Author: Alexander Hoss
Institution: Erasmus University Rotterdam
Graduation year: 2014

On the effectiveness of downsizing: New evidence from the service industry

"The behavioural revolution" in economics has brought about a shift in economic thinking and modelling away from the traditional assumptions of fully rational individuals to a more realistic set of assumptions incorporating aspects of bounded rationality.

This development has led to the questioning of many well-established economic "rules" which had been found not adequately reflect individuals' behaviour in a real world environment. In this spirit, our study challenges the traditional belief of the neutrality of price framing and the related proposition of rational choice models that claims unit prices to be the final standard of judgment for consumers.

More precisely, we investigate if individuals are more sensitive to a unit price increase induced by an increase in the labelled price than to an equivalent decrease in quantity. Our preferred model provides some support for this view.

An effective strategy

Using a large panel dataset on parking prices and transactions and estimating a dynamic two-way fixed effects model, we find that consumers indeed show significantly less sensitivity to a reduction in the length of the time intervals than to an equivalent increase in the labelled price.

As a result, we suggest that downsizing, the strategy of increasing unit prices by shrinking product size and keeping prices fixed, is an effective strategy also in the service industry.

FACTORS AFFECTING PARKING DEMAND

Student information
Author; Jakub Romaszewski
Institution; Erasmus University Rotterdam
Graduation year; 2014

Analysis of the parking demand for Q-Park car parks in Rotterdam

This paper sets out to explain the factors affecting parking demand. Specifically, the case of Q-Park in the city of Rotterdam is examined, in order to see what factors affect the number of cars leaving the car parks, as well as parking duration. This is done by distinguishing between internal factors, under the control of the parking operator, and external factors, which are determined by the outside environment. The study of these factors will allow to see what factors parking operators should consider to be important in their business, as well as how these can be used to reach company specific goals or objectives.

Literature review

The first step is the literature review, which highlights the study of parking price elasticity, as the main internal factor affecting parking demand. Research finds that price elasticity changes occur over time, and hence the necessity of considering these effects is highlighted.

Furthermore, **price elasticity is found to be inelastic for parking demand**. With regards to external factors, literature on the matter is quite scarce, and hence reasoning is used in order to come up with external factors that may have an effect on parking demand. These are concluded to be location desirability, built up from several indicators, as well as income.

Data from Q-Park and the city of Rotterdam

Next, data from Q-Park is used to account for the internal factors, while data on the external factors is collected from the city of Rotterdam database. This data is determined to fit a panel data analysis, and hence the fixed effects Error Correction Model is constructed.

This model is able to estimate the short run and long run effects of each variable, and is estimated for the number of cars leaving on weekdays, number of cars leaving on weekends, and parking duration.

The model finds **price elasticity to be a significant factor only in the parking duration and weekend model**, although it is highly dependent on the time and location.

The external factor number of households is found to be a significant factor affecting parking demand in both the weekday and weekend models, along with the number of companies and employment being significant in the weekend model, but all external factors lack significance in the parking duration model. The exception is the monthly external factor dummies, which show differing levels of significance for different months in each model.

Price elasticity, time and location

The paper concludes to find that price elasticity is an important factor to consider, but is highly volatile depending on time and location. Furthermore, the number of households has a significant effect on parking demand, although it differs between the weekdays and weekends. Trends of external factors however can be used in order to find suitable location for parking garages. Furthermore, price elasticity can be used in order to maximise certain company specific goals, such as high profits or high occupancy rates. These do however require more flexible parking policies.

"Price elasticity is an important factor to consider, but is highly volatile depending on time and location."

PREDICTING PARKING SPACE OCCUPANCY

Student information
Author: Robert Boer
Institution: Erasmus University Rotterdam
Graduation year: 2017

Know before you go: predicting parking space occupancy by exploiting publicly accessible data

Global urban population is growing at rapid pace and as a result, the demand for mobility in urban areas is exploding. Nowadays, road networks become increasingly congested and as a consequence massive amounts of time, fuel and money are wasted. In certain urban areas, a significantly large amount of 30 to 45% of overall traffic is caused by cars in search of a parking space.

In an attempt to guide motorists towards vacant parking spaces, currently existing solutions provide real-time parking space availability information. These solutions are far from optimal, as the information disseminated might have already become obsolete by the time of arrival.

It would therefore be of great benefit to motorists when parking space availability upon arrival can be predicted in an accurate manner well ahead of time.

Although previous research has attempted to predict parking space by including external variables in predictive models, it falls short in attributing significant attention to the identification of external variables that are capable of improving accuracy obtained from prediction algorithms.

Furthermore, prior literature has failed to investigate the impact of extending the time horizon of predictions on the prediction error of the models.

In order to close these gaps in literature,

1. we identify to what extent the inclusion of external, publicly accessible data in the parking space prediction model influences its predictive performance and
2. we assess the effect of extending the forecasting horizon up to 24 hours on the predictive performance of parking space prediction models.

Inclusion of external variables

For this purpose, we leverage data on three distinct parking facilities in the city of Amsterdam, the Netherlands. Our research shows that the inclusion of external variables in prediction models for parking space occupancy can significantly improve its performance. Compared to baseline models that only leverage historical occupancy, we are able to reduce error rates with up to 49.15% by including external variables.

However, the choice for which external data sources to include in these models is heavily dependent on the parking facility studied and the predictive modelling technique used. Nevertheless, we find evidence that including Fourier terms as external variables leads to improved forecast accuracy in nearly all situations.

Inclusion of event information

Furthermore, we find that the inclusion of event information as external variables in Artificial Neural Networks leads to significant forecast improvements, particularly for parking facilities situated in areas where (large-scale) events happen on a regular basis.

Moreover, we find that including all external variables into the predictive model, does not necessarily lead to the best predictive model in terms of accuracy.

Furthermore, our results show that, although forecast errors increase rapidly for small step ahead predictions, error rates typically converge to a stable and acceptable maximum error rate after predicting six hours ahead of time. This paves the way for informing motorists by disseminating parking space predictions in real

time via web-based - or smartphone applications or other media.

SOCIAL COSTS OF ON-STREET PARKING

Student information
Author: Michael McIvor
Institution: Free University of Amsterdam
Graduation year: 2017

The social costs of on-street parking: searching, policy and unpriced externalities

We introduce a methodology to estimate the marginal external costs of parking by extending the theoretical model introduced by Zakharenko (2016), which allows for endogenous parking durations.

External parking costs

External parking costs encompass both additional in-vehicle search and walking time costs incurred by arriving motorists.

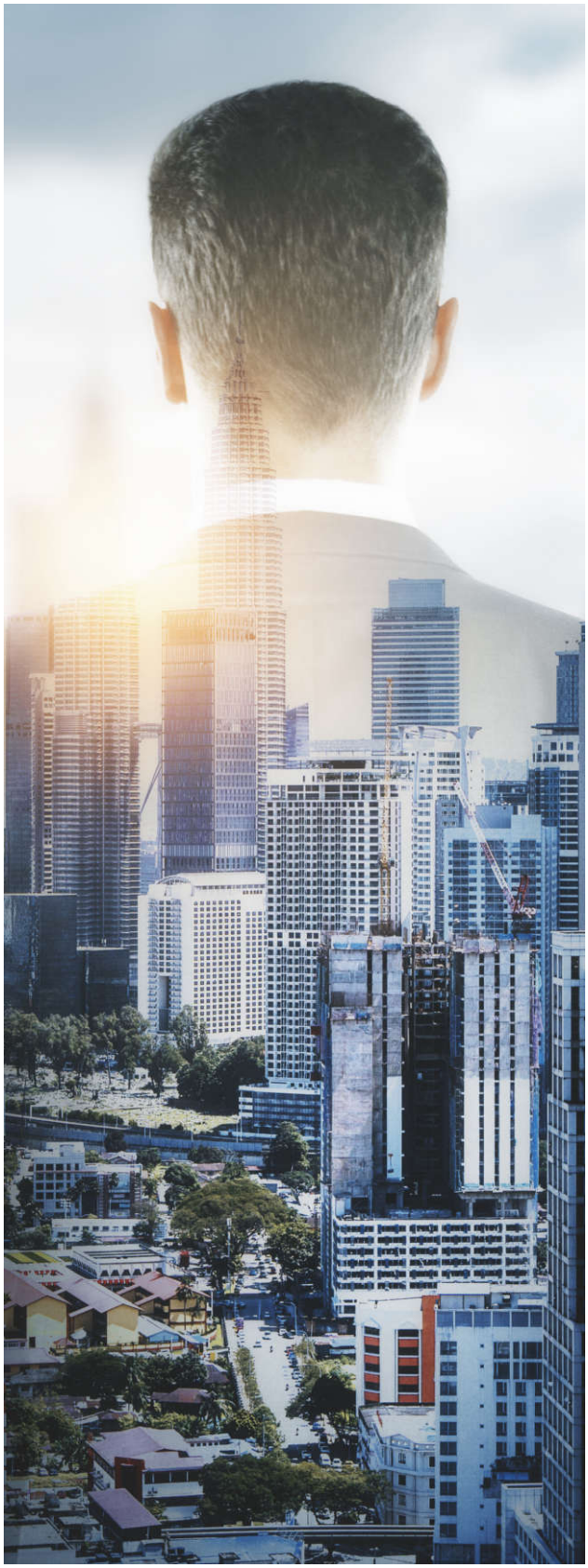
We show that the unpriced marginal externality is the key metric that parking authorities should use to inform their parking policies. We apply this methodology to the city centre of Melbourne, where strict time limits are combined with on-street parking prices that are below short-term off-street parking prices.

Using parking externalities for parking policies

We demonstrate that generally parking externalities are low and far below their optimum, so relaxing many of the current parking time limits will increase welfare.

Alternatively, on Sundays in many areas parking externalities are high while parking is free, so introducing paid parking will also increase welfare.

Similarly on weekdays and Saturdays late in the evening just before restrictions end parking externalities are high, and so extending their hours of operation will also improve welfare.



OPTIMISING REVENUES OF AIRPORTS

Student information
Author: Frank Siebers
Institution: Erasmus University Rotterdam
Graduation year: 2018

Optimising non-aeronautical revenues of airports: the case of Rotterdam The Hague Airport

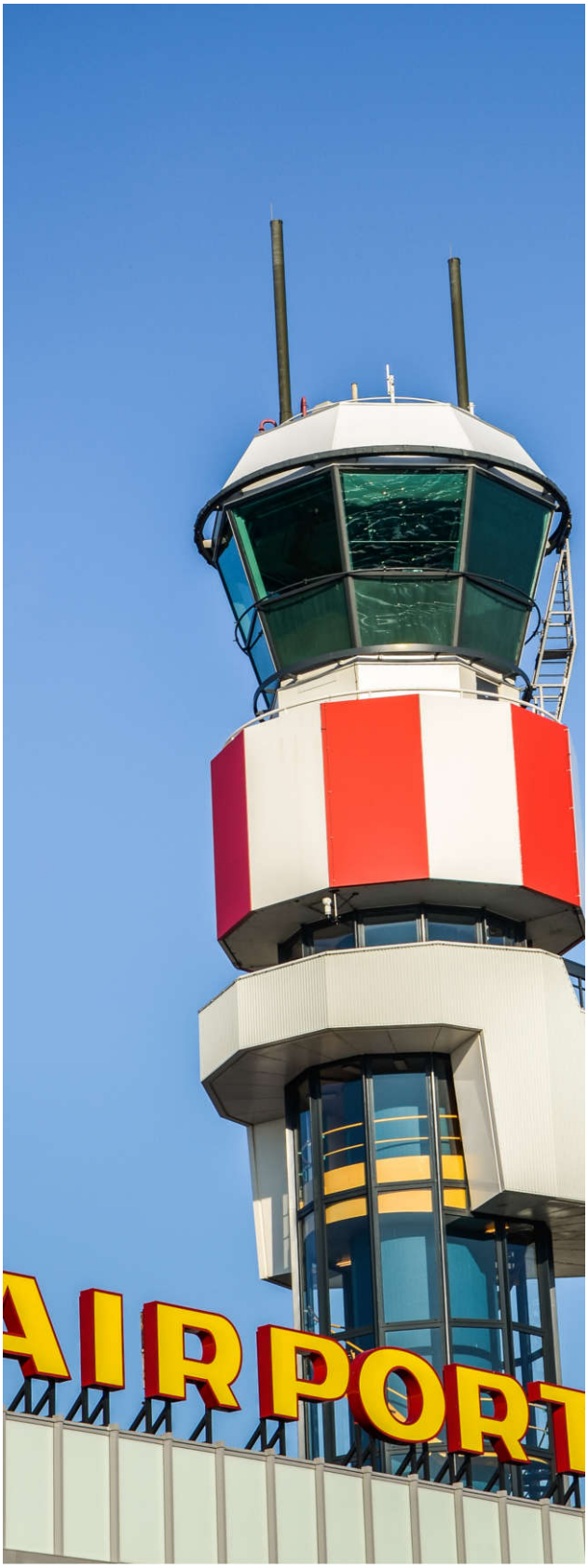
This study examines the possibilities of optimising non-aeronautical revenues of Rotterdam The Hague Airport. This is done by assessing the price elasticities for all different segments over the years 2013 -2017.

Results indicate that price adjustments can be made to increase non-aeronautical revenues.

The overall price elasticity for parking on the airport is -1.13. This elasticity coefficient lies above unit elasticity, due the busiest months of the year.

In these months, relatively more leisure travellers, which are price elastic, are travelling via the airport.

Therefore, increasing the price in the busiest months is desirable due to possible capacity problems at the airport. In all other months, an increase of the price would result in an increase of revenues, due to the relatively inelastic coefficients of these months.



PARKING CHOICE BEHAVIOUR

INFLUENCE PARKING CHOICE BEHAVIOUR

Student information
Author: Barbara Jepma
Institution: Erasmus University Rotterdam
Graduation year: 2016

Providing information to influence dynamic parking choice behaviour in urban areas

This thesis discusses how information should be provided to support the optimisation of dynamic urban parking choice behaviour.

To influence motorists' dynamic parking choice behaviour the right information should be provided at the right moment in time.

By means of survey based research, it is studied what information sources are typically utilised, what factors influence parking choice behaviour and at what moment in the decision making process, motorists make their parking choice.

To bridge the gap between academic knowledge and practical questions, the theoretical findings are applied to the current parking situation in Leeuwarden.

Eventually recommendations for investing in information supply infrastructure for the municipality of Leeuwarden are provided, and an experiment is designed to measure the success of the recommendations based on actual behaviour.

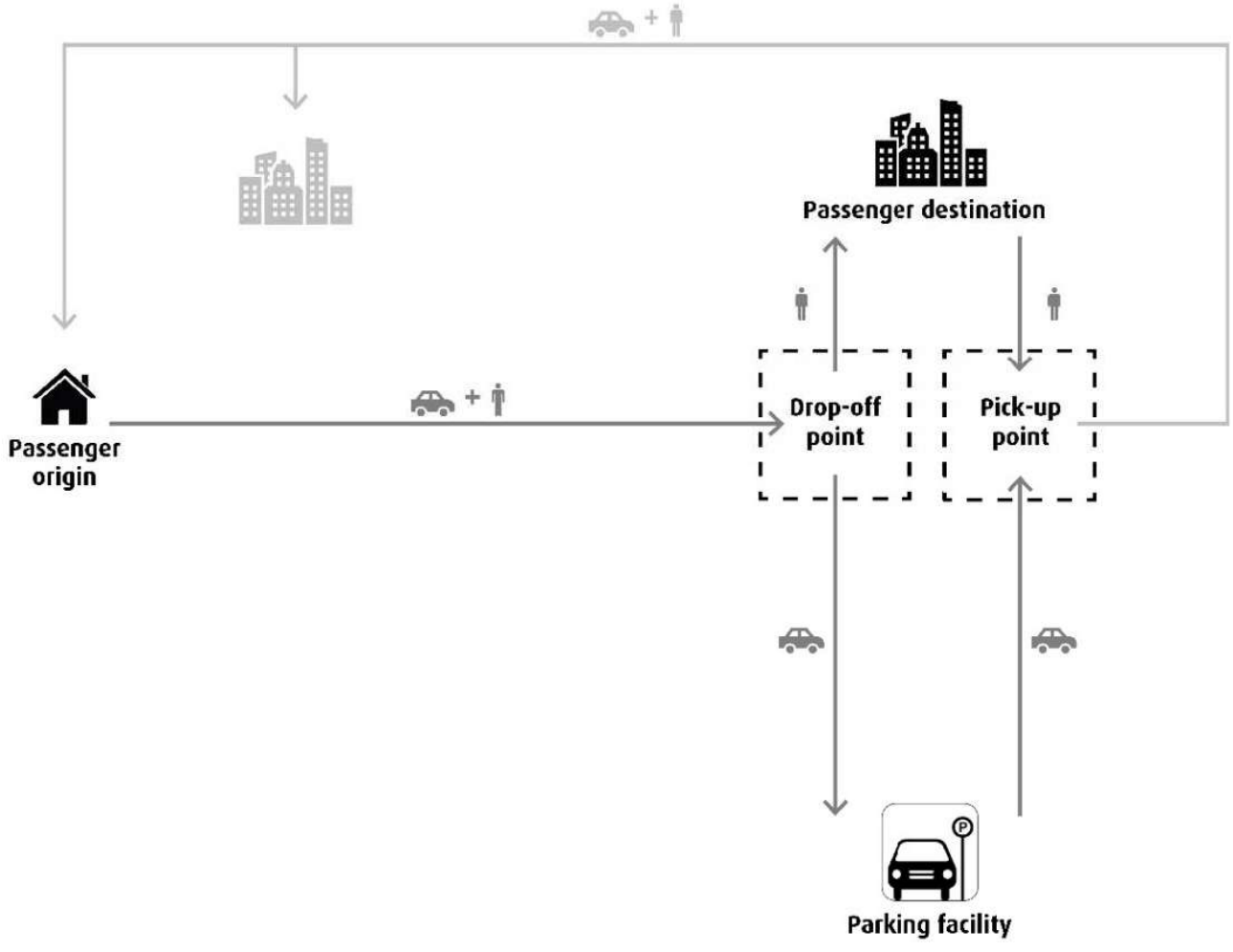
EFFECTS OF AVS ON PARKING CHOICE

Student information
Author: Daphne Elisabeth Maria van den Hurk
Institution: Delft University of Technology
Graduation year: 2017

An empirical study into the effects of private automated vehicles on motorists' parking location choice: an application to the city of The Hague

Automated vehicles (AVs) have been receiving increased attention all over the world, since the first fully AVs are already operating on the public road network. AVs could not only have a tremendous impact on the urban environment but also on human travel behaviour. With the capability of AVs to ride and park themselves instead of being operated by a human driver, it is likely that parking choice behaviour will change when conventional vehicles (CVs) are replaced by AVs. In order to make investment decisions, it is important for governments to gain insight into the impacts of AVs. The objective of this research is to find the importance of different factors and constraints that could influence drivers' parking location choice for a future situation in which private highly AVs will become available for passenger transport. The results of this study have been used to provide guidelines for governments on how to develop their parking policy for this future situation. The main research question of this thesis is formulated as follows:

Figure 1: Schematic overview of the different steps of a trip with a private highly AV



'' What is the effect of private highly automated vehicles on drivers' parking location choice, based on parking constraints? ''

AVs can either be privately used or shared with others. This research is focused on the private use of AVs. A schematic overview of a trip with a private highly AV is visualised in Figure 1. The trip with a private highly AV starts from the 'passenger origin' and develops in the direction of the 'passenger destination'. Space to drop-off the passenger is needed to avoid congestion caused by dropping-off passengers on the road itself. On-street parking space is used for the drop-off manoeuvre. When the passenger is dropped-off at a drop-off point, the passenger walks to the destination.

Simultaneous to this walking leg, the private highly AV drives empty from the drop-off point to a parking facility. The two considered parking locations are 1) parking in the inner city (PIC) and 2) parking at the edge of the city (PEC), both at off-street parking facilities. When the passenger's activity has ended, he/she walks to a pick-up point. On-street parking space is used for the pick-up manoeuvre. Simultaneously, the private highly AV drives empty from the parking facility to the pick-up point. When the passenger and the private highly AV have both arrived at the pick-up point, the vehicle trip from the pick-up point to the passenger's home or to another destination starts.

A literature review and brainstorm sessions with experts were conducted to define factors and constraints that could influence drivers' parking location choice. Factors and constraints for the Stated Preference (SP) experiment were selected by means of a Multi-Criteria Analysis (MCA). The selected factors and constraints can be divided into different categories: context factors, attributes, perceptions and exogenous variables. A SP data collection method was used in this research to examine which factors and constraints, and to which extent, influence a driver's parking location choice. Private highly AVs as described in this study are not operating on the public road network yet, which makes the need for hypothetical choice situations necessary. SP data is based on individuals' reactions to hypothetical situations: it is asked what an individual would choose in a specific situation. In this research the environmental conditions, road network configuration and parking constraints of the city of The Hague are used specifically, however, the generic methodology applied in this study could be applied to any large scale city.

Two pilot surveys were conducted in order to design the final questionnaire. An orthogonal design was used to create the hypothetical choice situations for both pilot surveys, because there is no information on prior parameter values. The aim of both pilot surveys was to test if the respondents understood the questionnaire and the concept of automated driving. Furthermore, the results of both pilot surveys were used to find prior parameter values. A final survey was made, based on the results of both pilot surveys. The final survey consists of introduction questions, hypothetical choice situations (part 1), statements on automated driving (part 2) and general questions on personal characteristics (part 3).

In the introduction questions, respondents' fill in the trip characteristics (trip purpose, trip duration and trip reimbursement) of their most recent trip to the inner city of The Hague. The trip characteristics are the context factors that apply for the hypothetical choice situations which were asked in the first part of the survey. Preferences regarding the attributes were collected via the different hypothetical choice situations. Attributes included in the design are: 'parking cost', 'surveillance of the parking facility', 'risk of extra waiting time' and 'risk of parking fee'. The two latter attributes are new concepts for individuals, describing respectively the result of the vehicle arriving too early at the pickup point and the vehicle arriving too late at the pick-up point. An efficient design was used to create the hypothetical choice situations, because the pilot survey provided information on the prior parameter values. In the second part of the survey, statements were presented in order to receive information on respondents' perceptions on automated driving. Information about respondents' exogenous factors was collected via general questions in the third part of the survey.

In total, 421 respondents filled in the online questionnaire. 388 responses were valid and used for the data analysis. Results of the descriptive analysis showed that 16.2% of the respondents have a fixed preference for PIC, compared to 11.6% of the respondents that have a fixed preference for PEC. Trip characteristics explain the fixed preference for either PIC or PEC. Results of the Multinomial logit (MNL) model estimation on the hypothetical choice situations show that all attributes are significant, which means that these attributes are of influence on drivers' parking location choice. From the results of the hypothetical choice situations, it can be concluded that in general PIC is preferred over PEC. The 'parking cost', the 'risk of extra waiting time' and the 'risk of parking fee' have a negative influence on drivers' parking location choice. 'Personnel surveillance' has a positive influence on drivers' parking location choice. The parameter for 'camera surveillance' is not significant, which means that individuals are not sensitive for the presence of cameras in a parking facility. Personal characteristics (exogenous factors), trip characteristics (context factors) and perceptions resulting from the MCA were included in the MNL model as interaction effects to test if these characteristics affect the attributes that influence drivers' parking location choice. Results of the MNL model estimation on the interaction effects showed that only a few interaction effects are significant. Despite their significance, several of these interaction effects are based on a small sample and others cannot be explained. The following interaction effects are based on a large sample and can be explained:

- Individuals with a high income are more sensitive for 'risk of extra waiting time'. This was expected, since the research pointed out that on average, individuals with a higher income have a higher Value of Time (VoT) and Value of Reliability (VoR).
- Individuals with a relatively high purchase value of the car are less sensitive for 'risk of extra waiting time'. A reason for this might be that individuals with a high purchase value of the car find it more important that the car arrives safely at the passenger's destination. In this case, the individual accepts the 'risk of extra waiting time'.
- Individuals who consider safety during the empty vehicle trip to be important, are less sensitive for the 'risk of extra waiting time' and the 'risk of parking fee'. Apparently, these individuals care more about the safety circumstances during the empty vehicle trip than about extra time and costs.

When a large amount of interaction effects do not play a role, a more generic model can be estimated that works for the same conditions. Therefore, it was chosen to conduct the scenario analysis based on a model without interaction variables. This means that the same model applies for individuals with different characteristics, trip purposes and perceptions.

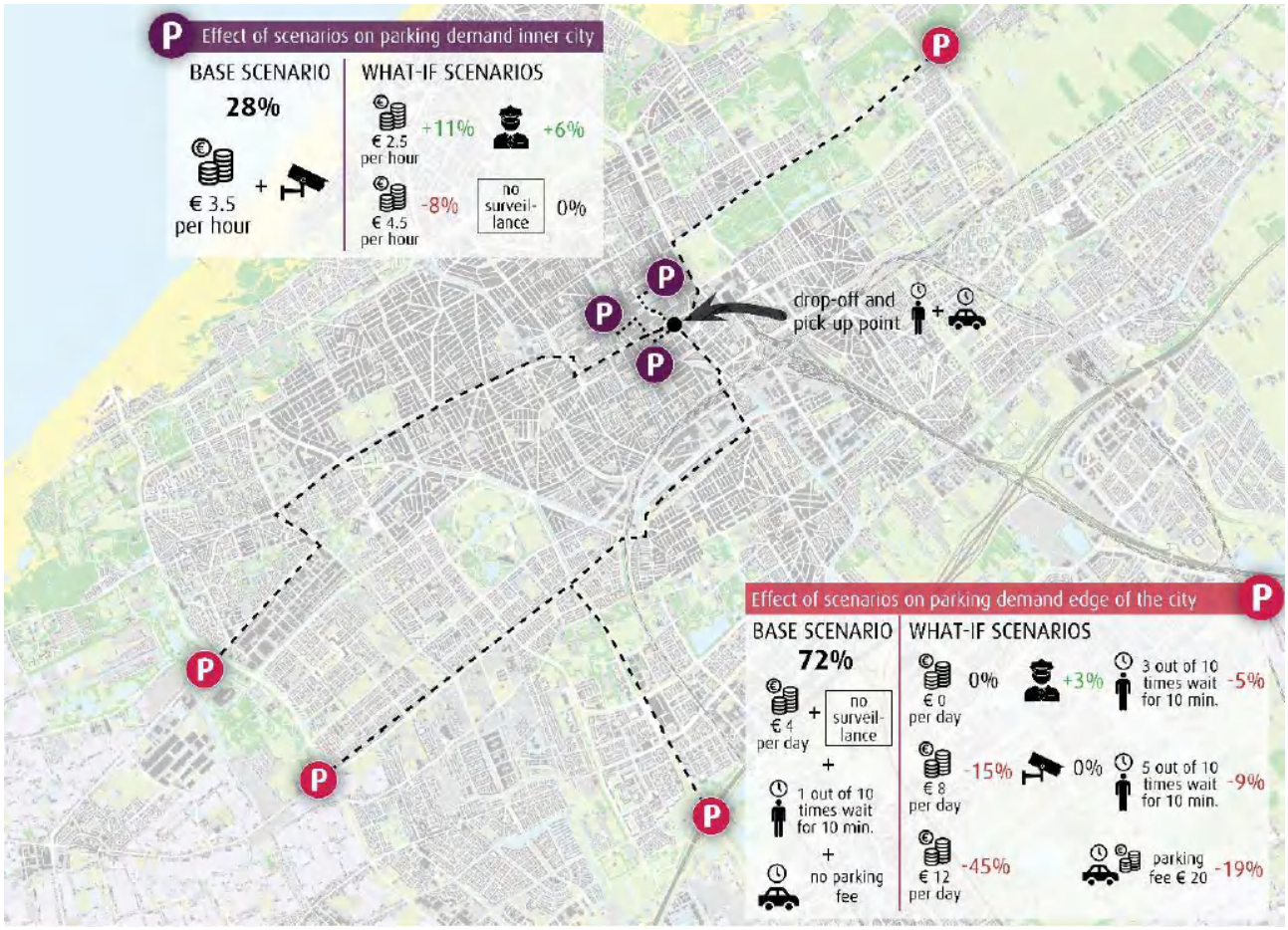
The results of the scenario analysis are visualised in Figure 2. From the results of the scenario analysis can be concluded that individuals are most sensitive for a change in direct costs, i.e. the 'parking cost' at the parking facility and the 'parking fee' for temporary parking the highly AV at an on-street parking place near the passenger's destination. When the parking cost in the inner city is decreased with €1 per hour, parking demand will increase with 11%. Furthermore, it could be expected that when the parking cost in the inner city will be increased with €1 per hour, parking demand will decrease with 8%. When there are no parking costs for parking at the edge of the city, parking demand will remain the same. When the parking cost at the edge of the city will be increased from €4 per day to €8 per day or €12 per day, it is expected that parking demand will drastically decrease with 15% and 45% respectively. When a parking fee of €20 is implemented for temporary parking the highly AV at an on-street parking place near the passenger's destination, parking demand at the edge of the city will decrease with 19%. This has the same effect as increasing the parking cost at the edge of the city from €4 to approximately €8.50 per day. From the results of the scenario analysis can be concluded that individuals are less sensitive for 'personnel surveillance' and 'risk of extra waiting time'. The presence of personnel surveillance has a positive influence on drivers' parking location choice. When

personnel surveillance will be available at a parking facility, parking demand will increase with 6% in the inner city, compared to 3% at the edge of the city. From the results of the model, it was concluded that camera surveillance is not significant, which means that camera surveillance is valued the same as no surveillance. This means that when the parking facility is supervised by means of cameras, it is expected that this will not lead to an increase or decrease in parking demand. The risk of extra waiting time (for 10 minutes) during the off-peak period is 1 out of 10 times. When no separated lanes for highly AVs exist, the risk of extra waiting time during the peak period is likely to be higher. When the risk of extra waiting time is increased to 3 out of 10 times or 5 out of 10 times during the peak period, and no separated lanes for highly AVs are available, the parking demand at the edge of the city will decrease to 5% and 9% respectively.

Directions for parking policies are related to different topics regarding parking regime, parking price and parking capacity. The directions for parking policies are visualised in Figure 3.

1. First, in order to reduce the number of on-street parking spaces, it is advised to forbid the parking of highly AVs at on-street parking spaces. Consequently, released space could be used for drop-off and pick-up manoeuvres. It is not expected that all on-street parking space is needed for drop-off and pick-up manoeuvres. Similar to the current situation, it might be considered that inhabitants of the city of The Hague are allowed to park their highly AV

Figure 2: The influence of the what-if scenarios on the distribution of parking demand

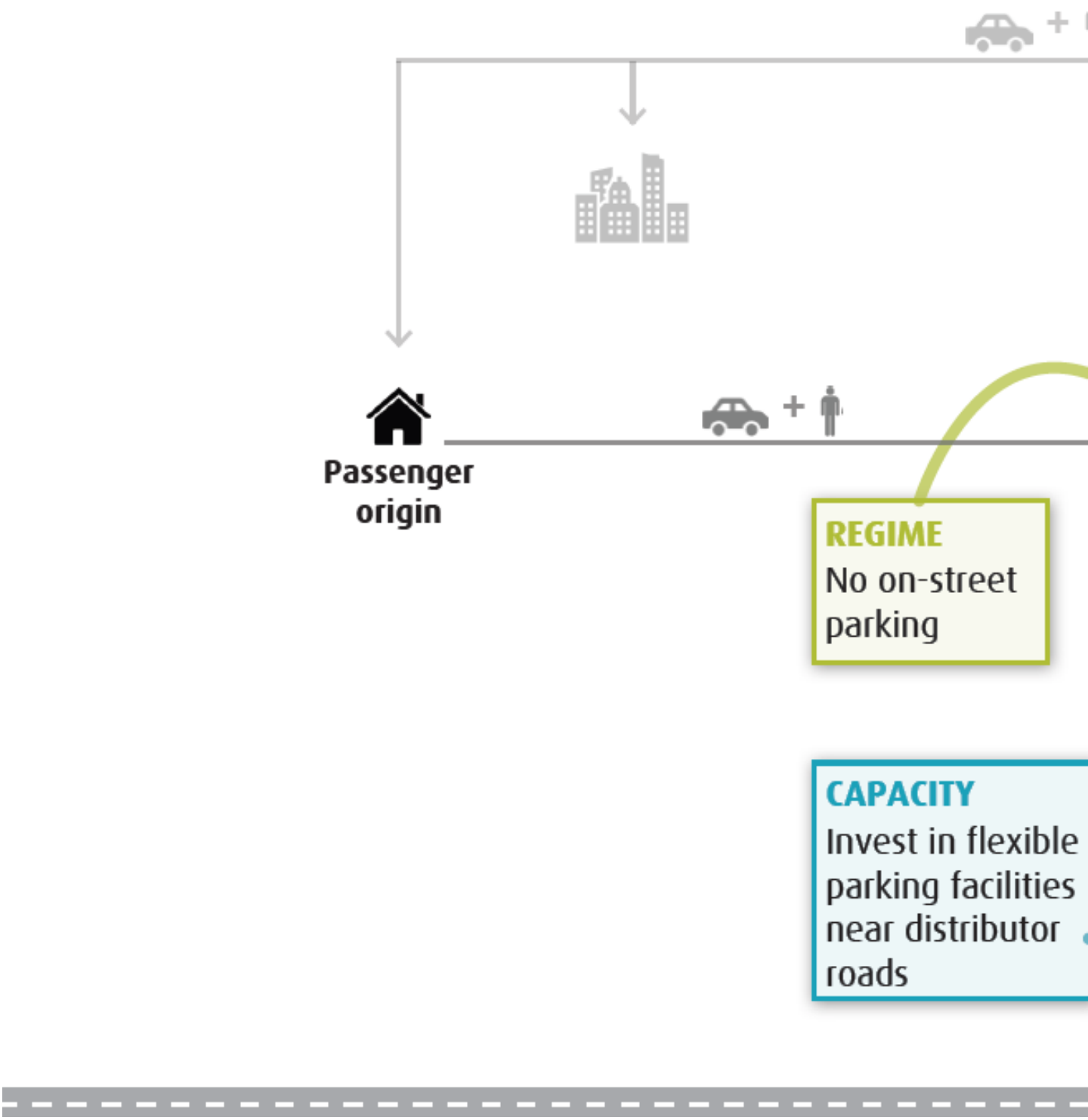


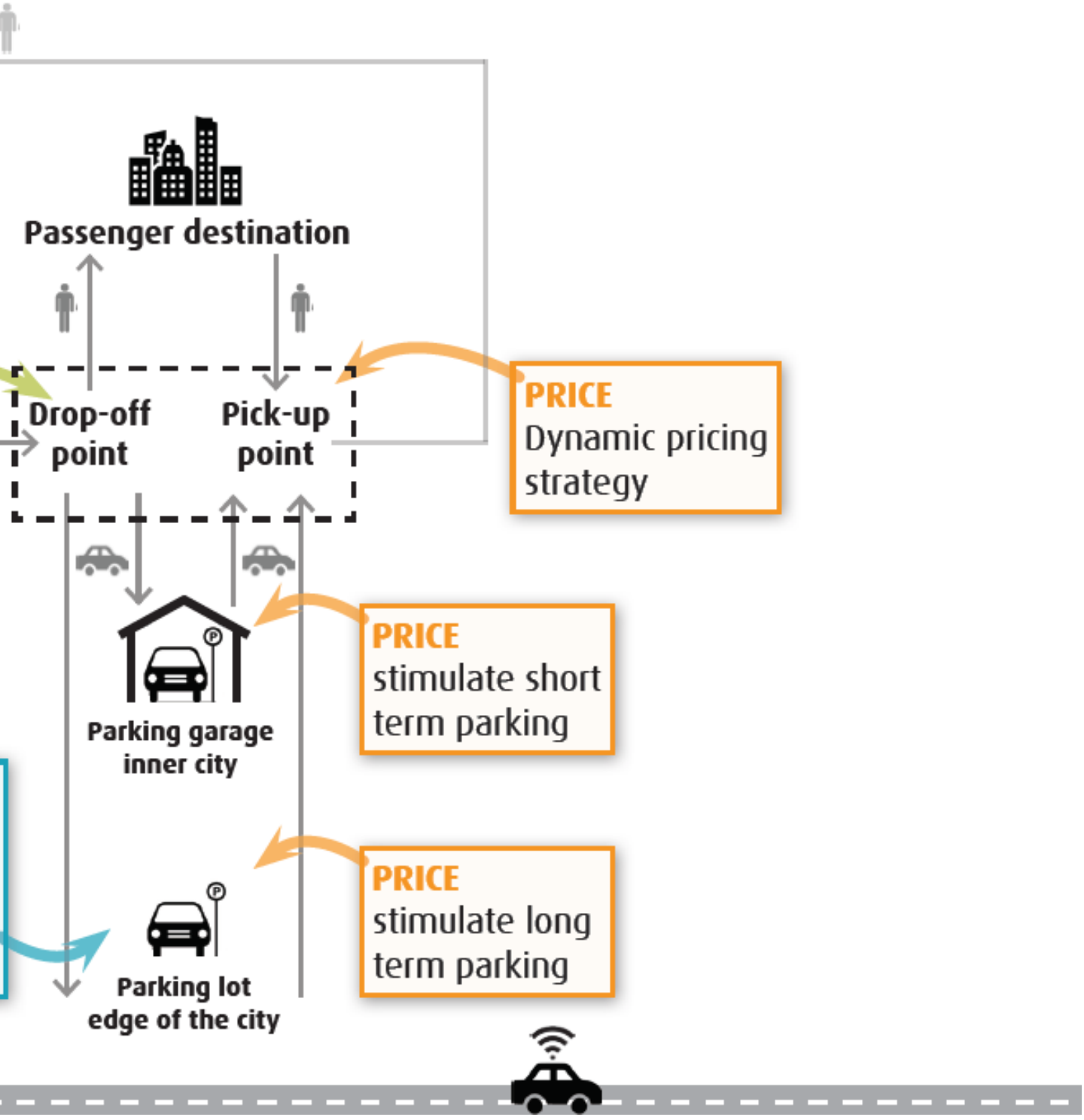
on-street with a parking permit. Furthermore, released on-street parking space could be used for greenery or extra space for bicyclists and pedestrians.

2. Second, in order to minimize the number of empty vehicle kilometres, it is advised to stimulate short term parking of highly AVs in the inner city and stimulate long term parking of highly AVs at the edge of the city. This could be done by increasing the parking cost of parking at the edge of the city from €4 to €10 per day. Consequently, approximately 55% of the individuals would park their highly AV in the inner city, compared to 28% that parked their highly AV in the inner city in the base scenario.
3. Third, it is advised to implement a dynamic pricing strategy for the parking fee that is asked for temporary parking the highly AV at an on street parking place near the passenger's destination, when the highly AV arrives too early. When implementing a dynamic pricing strategy, the municipality is able to 1) control supply and demand, 2) account for competitor pricing and 3) account for external factors (e.g. peak periods). When a parking fee of €20 is implemented, approximately 47% of the individuals would park their highly AV in the inner city, compared to 28% that parked their highly AV in the inner city in the base scenario. Fourth, when more parking capacity is needed, it is advised to invest in flexible parking facilities at the edge of the city near distributor roads. When the parking facility is supervised by personnel, parking demand will only increase with 3%. To increase the attractiveness of parking highly AVs at the edge of the city, it is advised to reserve space for additional services (e.g. pick-up point for groceries and day-care).

Further research is needed to examine which services positively influence drivers' parking location choice. Recent studies show that automated vehicles could induce an increase of travel demand due to changes in destination choice, mode choice and mobility (Milakis, Arem, & Wee, 2017). Hence, more parking capacity might be required. Furthermore, the level of sharing and the penetration rate of AVs should be taken into account when making policy decisions, because these developments might have an influence on the number of parking spaces required. This research succeeded in capturing the change of drivers' parking location choice in the case when private highly AVs will become available for passenger transport. As a result of choices made by respondents in the hypothetical choice situations, insight was gained in individuals' preferences and trade-offs. The presented results and guidelines can be used in future research on the effects of highly AVs on parking location choice where, at the same time, it can be used by governments to develop their parking policy for this future situation.

Figure 3: Visualisation of the directions for promising parking policies




Passenger destination
Drop-off point
Pick-up point
PRICE
Dynamic pricing strategy
Parking garage inner city
PRICE
stimulate short term parking
Parking lot edge of the city
PRICE
stimulate long term parking

PARKING CHOICE AND SOCIAL INFLUENCE

Student information
Author: Stefan C. Laro
Institution: Eindhoven University of Techonology
Graduation year: 2018

Parking choice and the role of social influence

Objectives and methodology

The implementation of parking policies has provided limited success in terms of meeting the goals set out by municipalities such as reducing congestion and pollution (Shoup, 2006). Models trying to predict the behaviour of car drivers often only include attributes of the parking facility as predictors. One of the factors that may play a role in the decision making process is the influence of an individual's social circle which has not yet been commonly discussed topic in the field of parking research (Sunitiyoso, Avineri, & Chatterjee, 2011). This research aims to contribute to the possibility that social influence may be a factor in the decision for an individual to choose for a certain parking facility.

Data from an earlier study by (Iqbal, 2018) was gathered with the use of a web-based questionnaire which featured four attributes relating to the characteristics of the parking facility itself being: parking tariff, walking distance to the final destination, type of parking space and type of security. Also included were the advices of four groups that may exist in one's social network being: family, friends, colleagues and experts. Respondents were asked to choose between five ranking option that indicated the likelihood of choosing to park at the presented parking facility.

Data of 377 respondents that completed the survey have been included in the estimation of three different logit models: multinomial logit (MNL), latent class (LC), and mixed logit (ML). The differences in these models allow for more insight in the preferences of respondents regarding the attributes that have been used in the survey. MNL models are restricted in the sense that the interpretation of the results can only be ascribed to the average opinion of the sample of respondents. LC models allow for a distinction of respondents in latent classes with response patterns determining the differences between the classes. The likelihood of a respondent belonging to a certain class can then be derived by matching the estimated parameters of one class with the parameters from a single respondent. ML models are used to identify whether heterogeneity is present for certain attributes which in turn can be further investigated by using, for example, sociodemographic characteristics to see whether these can be defined as the source of the heterogeneity being present.

Results and conclusions

The MNL model showed that the most influential attribute regarding the choice to park at a given location is the parking tariff. The second most influential attribute was found to be the security measures being present with a large preference for security staff over security cameras. Latent classes were not able to be estimated with the inclusion of all attributes. This indicates that respondents were either too homogenous in their responses or that no regularity could be based on response patterns. Estimating latent classes when only including alternative-specific constants (ASC's) showed that there is a group of respondents that rarely stated they were unlikely to park at the described parking facility given in the survey. Because no more information could be derived with the use of the LC model further analysis has been done with the use of the MNL model with data being separated based on socio-demographic characteristics of the respondents which were: age, gender, educational level, nationality and family situation (whether respondents had children or not).

Of these five characteristics, two were further investigated as they were estimated to show differences when separated into two groups. Four MNL models were estimated, two based on gender and two based on nationality of the respondents. The MNL model that included only male respondents showed more significant parameter estimates for different attributes indicating that they were either more homogenous in

their taste preferences or considered more attributes to be of importance. Differences showed that male respondents were more likely to prefer a short walking distance to their final destination compared to women and that they disliked on-street-parking more than women as the latter attribute was not found to be significant for the model with only female respondents. Social influence was found to be significant for the positive ranking options. The male only model showed three significant parameter estimates concerning advice from family, friends and experts for the "very likely" ranking option with the latter two stating the parking facility was the cheapest and advice of family being that the parking facility was the safest. The female only model only showed one significant parameter estimate concerning social influence which was an expert stating that the parking facility was the safest for the "very likely" ranking option.

Comparing the models whereby the response sample was based on region of origin (one model for EU citizens and one model for non-EU citizens) showed that parking tariff was less likely to be of importance for non-EU citizens compared to EU-citizens. If the described parking facility was on street, the probability that a positive ranking option was chosen decreased according to the model with only non-EU respondents whereas the same attribute was not estimated to be significant for the model with only EU-citizens. Similarly to the models comparing gender, social influence seemed to play a role for the positive scoring options whereby the model with only EU-citizens estimated advice from all four included groups to be significant. Non-EU citizens were most likely concerned with the advice of their family. Both models also show that whenever the advice is concerned, the likelihood of a positive ranking option being chosen increased whenever their family stated the parking facility was the safest. The mixed logit model confirmed that heterogeneity was present for all ranking options as was also found in the MNL and LC models. Estimated standard deviations were found to be significant for the ASC's for all ranking options indicating that not only the model did not capture all attributes that would explain the reason why a certain ranking option was chosen but also that respondents have different reasons for choosing said option. Other attributes with a significant standard deviation estimate were the parking tariff, walking distance, parking type and security level. Further analysis whereby socio-demographic characteristics of respondents were taken into account confirmed the findings as done with the MNL model that heterogeneity was present for regional differences concerning the importance of parking tariffs and walking distance.

With regards to the significance of the models each addition proved to be significant in terms of model fit according to the four goodness-of-fit methods used in this study. The MNL model although limited in its use did prove to be of worth, especially when manually separating respondents into groups based on socio-demographic characteristics and comparing the models. Comparing the MNL and ML model it is clear that the interpretation of the MNL model is easier but it also lacks the depth of taking heterogeneity into account which was found to be present in the dataset. The ML model performed better but also required much more parameters complicating the interpretation of results and also making the model less parsimonious, i.e. less likely to be practical for other datasets. Future research should take into consideration if individual tastes are needed to be investigated or whether taste preferences based on groups are good enough for the model.

PARKING AS MOBILITY TOOL

THE EFFECT OF PARKING MEASURES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Graduation year: 2015

The effect of parking measures in an urban context

As the population of the world continues to grow, as well as the portion of people living in cities and the number of privately used cars, it becomes increasingly important to create an urban environment which is sustainable and of good environmental quality.

Decision makers and urban planners have a whole plethora of measures that they can use at their disposal. One category of those measures is traffic demand management or TDM for short.

Traffic Demand Management

TDM combines both pull and push measures which can be used in conjunction to create a more equitable and sustainable transportation system.

- Pull measures aim to increase the use of mode choices by improving them; either by appeal accessibility cost or performance.
- Push measures aim to dissuade particular behaviour by implementing economic costs or other measures. These usually raise revenue, as well as quantify the cost of particular transport behaviours.

One particular category within TDM is that of parking measures, which have been in use for quite a while.

Particular parking measure

Parking pricing is the most known example of this. While decision makers and urban planners are aware of the tools at their disposal, they are often less certain of their effects in the setting that applies to them specifically. This report aims to shed light into that unknown, identifying the possible reactions that car users may show when confronted with a particular parking measure.

By submitting a sample in the population of the city of Geel to a self-completion questionnaire, data is gathered regarding their current transport behaviour, mobility options and reactions to five hypothetical scenario's of parking measures.

First an online survey was used by distributing flyers with a URL, then a paper version was used to obtain a large enough sample.

This data led to the conclusion that road users indeed change their behaviour to evade parking measures, and the reaction to parking pricing is not as strong as a decrease in the number of available parking spaces.

Use of private car remains popular

Additionally, changing transportation modes, a switch to public transportation or the bicycle, is not as popular as continued use of a private car. Different people have different reactions, but no particular characteristic of individuals was influential across all distinct hypothetical cases and strategies.

Included in the report are recommendations for decision makers questioning how to shape their urban environments, as well as a reflection for future research on the topic.

"The reaction to parking pricing is not as strong as a decrease in the number of available parking spaces."

LESSONS FROM POLICY IMPLEMENTATION

Student information
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Mobility management at Erasmus University Rotterdam: lessons learnt from policy implementation and how to move forward

This thesis evaluates the mobility management policy that was put in place by the Erasmus University Rotterdam (EUR) in 2011. The goal of the policy was to see a reduction in car commuters in order to become a more sustainable campus.

Several policies were put in place. This thesis gives special attention to the introduction of parking charges since June 2013. The analysis is based on three years of data, which is provided by the EUR via surveys in 2010, 2014 and 2016.

The statistical analyses find four factors that predict car commuting:

- car availability,
- arrival time,
- type of function of the employee and
- number of days one commutes per week.

The perceived accessibility has decreased since 2010, and there has been a reduction of car commuters by 6.80% points. The introduction of parking fees shows a decrease in car commuting. Furthermore, an estimation of the reduction in CO_2 is made, which finds a total daily reduction of 1137.8 kg CO_2 in 2016 compared to 2010.

The results suggest that the EUR is well on its way to realise their aim in reduction of employee commuting, and that future policy measures are likely to be found in behavioural as opposed to parking measures. Overall, the EUR has become a more sustainable campus since 2010.

SMART MOBILITY: A STRATEGIC SOLUTION

Student information
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Graduation year: 2018

Smart mobility: a strategic solution in urban development

Shared and autonomous vehicles provide municipalities with a strategic solution in urban development. Smart mobility can be a game changer in realising the ambitions of a safe, liveable, sustainable, and attractive city.

Consider spatial implications of smart mobility

Former policies on mobility however have resulted in long term undesirable effects. This increases the urgency for municipalities to already consider the spatial implications of smart mobility. A lot of research has been carried out already on the effects of smart mobility, but these focus only on first order local effects.

To the best of the authors knowledge, no literature exists on how, where and if the effects of smart mobility can be used for the restructuring and transformation challenges of the public space.

The main question of this research is:

"To what extent can autonomous and shared mobility contribute to the restructuring and transformation of the public space and help to achieve a region's public ambitions, taking into account the different mobility scenarios?"

To answer the research question, both a quantitative and qualitative approach were used. First a conceptual model was developed using existing literature and findings out of the expert interviews. Secondly, the conceptual model was used to develop a mathematic model in the programming language Python.

The Python model helped to analyse several large datasets for the different scenarios. Subsequently, the Python output was visualised in Tableau. Tableau helped to analyse and discuss the different research questions.

Reduction of parking capacity

It was found that smart mobility can, depending on the scenario, result in a reduction of parking capacity between 0% and 88%. This bandwidth depends on the market share of shared and autonomous mobility, as well as on the change in extra kilometres travelled, the replacement ratio of shared vehicles, and the reduction of the parking footprint per scenario.

The reduction in parking capacity results in freed up space, which can be transformed into a new function and contribute to the restructuring and transformation of the public space.

How and to what extent smart mobility can contribute depends on the location and type of parking, the dynamics of the housing stock, and the policy of the government.

In urban areas with a dynamic housing stock and a relatively large capacity of the different types of parking, smart mobility can contribute the most to both the development of new houses and the improvement of the public space.

It can furthermore help to increase the housing density in urban areas, which has a beneficial effect on car use.

In more rural areas, where the housing dynamic is lower and where mostly street parking is available, smart mobility can only contribute to the improvement of the public space and the attractiveness of the region.

Smart mobility has shown to have an indirect effect on the economic, health, social, environmental, and ecological spatial value.

Spatial value

How the maximum spatial value can be realised during a restructuring and transformation challenge, will depend on the ambitions of the municipality, the characteristics of an area, but moreover on the governance of the government.

In order to realise the maximum effect, it should dare to significantly change its parking policies, while acting as a facilitator for smart mobility, in which it solves legal and trust issues, enables innovation and acts as partner in new mobility businesses.

The research discusses several important limitations, regarding the method and model. These need to be taken into account to avoid misjudgements and over-generalisation of the results.

The limitations regard the scope, the selection of the experts, the chosen municipality for the deep dive analysis, the sensitivity of the transition variables, and the assumptions that had to be made in order to do the analysis. These limitations give grounds for the recommendation for further research.

The effect of smart mobility on the road network was set outside the boundaries of this research, however it is expected that it will affect the public space.

It is recommended that further studies will be performed on these effects related to transformation and restructuring challenges. Furthermore, it is recommended that future research will analyse the effects on private parking.

Also, to reduce the uncertainty that exists with the transition variables, extra kilometres travelled and the replacement ratio, it is recommended that further research is conducted on both topics. Finally, it is recommended that the possible increase of the housing density is further analysed.

PARKING AND ELECTRIC VEHICLES

CAR PARK POWER PLANT

Student information
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Graduation year: 2015

Exploring the operation of a Car Park Power Plant - Formalising the operation of a system innovation with the Actor-Option Framework

The Car Park Power Plant (CPPP) concept is in its essence a parking garage in which parked fuel cell vehicles (FCVs) are used for the generation of electricity.

On-site hydrogen production

By including on-site hydrogen production methods, the CPPPs could purchase electricity when it is cheap, store it, and convert it back to electricity when the electricity price is high.

System innovations such as the CPPP concept lead to large scale changes in infrastructure systems such as the electricity and the passenger transport infrastructure.

The infrastructural systems are complex systems in which designers of new elements are unable to control the use of these elements once deployed.

Knowledge is currently lacking concerning the influence of CPPP design choices and environmental uncertainties, on the possible future operational performance of the installation.

In order to aid in the delineation of the possible design space of CPPPs, we have set the objective of providing an approach that is capable of identifying possible barriers for the successful operation of a CPPP.

To structure our research we have used the following research question:

Which Car Park Power Plant design elements or environmental factors could form barriers for the successful operation of an introduced CPPP installation?

To answer this question a literature study was conducted to find an appropriate theory to guide the identification of a relevant but delineated system representation. The Actor Option Framework was selected to serve this purpose.

Six factors form possible barriers

The system delineation was used to construct an agent based model that has been explored for possible behaviours of the CPPP and its surroundings. With the aid of the model we identified six factors that in sets of three form possible barriers for a successful operation of a CPPP:

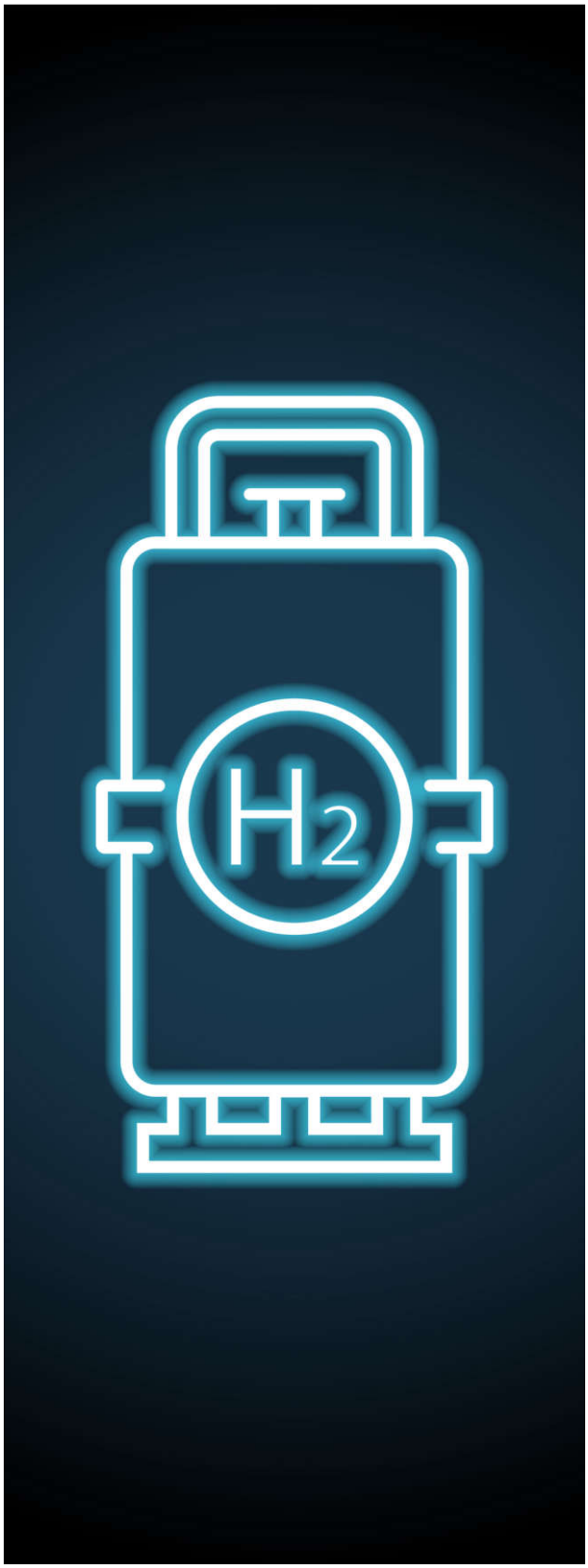
- The usage of simple CPPP operation tactics will result in CPPPs to produce electricity at all moments that satisfy the selected use-case. As a result the CPPP desires to produce electricity during many hours of the day.
- FCVs are expected to have production capacities of around 100 kW. If the conversion efficiencies of FCVs remain in the range of what they are now, the FCVs could require an amount of hydrogen per hour that comes close to the daily capacities of today's on-site hydrogen production devices. Combined with the desire to produce electricity during many hours a day, an unsatisfiable hydrogen demand and a continuous hydrogen production emerges.
- Without the possibility to determine profitable hours of hydrogen production, the possibility of making use of the price differences of electricity during a day will no longer be present. As a result the value of storage becomes too small to compensate for the conversion losses within the

CPPP. In these cases the CPPP can be expected to make operational losses due to the absence of a positive profit margin.

- Choosing to reward motorists who park at a CPPP with a free refill of hydrogen is unlikely to have significant effects on their perceptions. Due to the fact that FCVs consume a small amount hydrogen per driven kilometre, the perceived monetary value of the received free hydrogen is insufficient to structurally persuade motorists to park at the CPPP.
- Also the effect of the existence of a CPPP on the decision of a motorist with respect to the choice between purchasing an FCV or a conventional vehicle could be limited. Benefits that a CPPP could offer for FCV owners are a reduction in fuel costs and an improved environmental performance of their vehicle. The valuation of these benefits by motorists is however insignificant when compared to the valuation of the purchase price of vehicles.
- If both the share of motorists with an FCV and the share of these motorists that park their car at a CPPP are low, the CPPP will have to rely on a very large motorist population. This would make it difficult to find a suitable location that such a large base population would consider to use as a daily parking location.

We observe that the approach as we have used it is capable of identifying possible operational barriers for CPPPs and possibly for system innovations in general.

The knowledge gained from this study can be used as a base to further explore the possible operation of CPPPs, as a base for discussion concerning possible CPPP designs or as substantiation for research towards the identified factors.



CHARGING EVS AT THE WORKPLACE

Student information
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Advancing sustainable transportation by charging EVs with PV power at the workplace: an optimal charging strategy

Arguably, the most important challenge of our time is climate change. In The Netherlands in 2014, 30% and 21.5% of total CO_2 emissions were emitted by the electricity producing and transportation sector, respectively.

Electric vehicles (EVs) have therefore gained interest as they do not emit carbon dioxide whilst driving and therefore do not pollute, at least directly.

Nevertheless, when EVs are charged with electricity produced by a fossil-fuel power plant there are indirect emissions. Additionally, high penetration of EVs will inevitably lead to increased stress on the grid and consequently capital expenditure.

A viable solution to mitigate both these disadvantages is by charging EVs at the workplace with locally produced photovoltaic (PV) power. The high level of coincidence between parking time and solar power paves way to charge EVs in a sustainable and cost-efficient manner.

Energy Management System

The thesis work presents the design of an energy management system (EMS) capable of forecasting PV power production and optimising power flows between PV system, grid and EVs at the workplace.

The aim is to reduce energy demand on the grid by increasing PV self-consumption while minimising charging costs and consequently increasing sustainability of the EV fleet.

The developed EMS consists of two components: an autoregressive integrated moving average (ARIMA) model to predict PV power production and a mixed integer linear programming (MILP) framework that optimally allocates power to minimise charging costs.

The EMS is designed such that it can be implemented in practice and moreover, is versatile, implying that it can be utilised for alternative purposes as well. Additionally, the predictive quality of the system enables it to anticipate and act accordingly, rather than solely react.

In order to perform sensitivity analyses, case studies will be formulated in which the effectiveness of the system can be ascertained.

The results show that the developed EMS is able to reduce charging costs significantly, while simultaneously increasing PV self-consumption and reducing energy demand from the grid.

Furthermore, during a case study analogous to one repeatedly considered in literature, i.e. dynamic grid tariff and dynamic feed-in tariff (FIT), the EMS reduces charging costs by 118.44% and 427.45% in case of one and two charging points, respectively.

Moreover, stress on the grid is alleviated through both load shifting and power injection during peak demand. In addition, the EMS proves that vehicle-to-grid (V2G) leads to optimality only in extraordinary cases.

The optimisation problem is modelled in GAMS, whereas the ARIMA process is modelled in Matlab and subsequently, the EMS is simulated in Matlab.

Q-Park has assured a number of its activities under NEN-EN-ISO 9001.

Q-Park has received several ESPA and EPA awards.

For more details and up-to-date information about Q-Park's products and services please visit: www.q-park.com.

Quality in parking

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