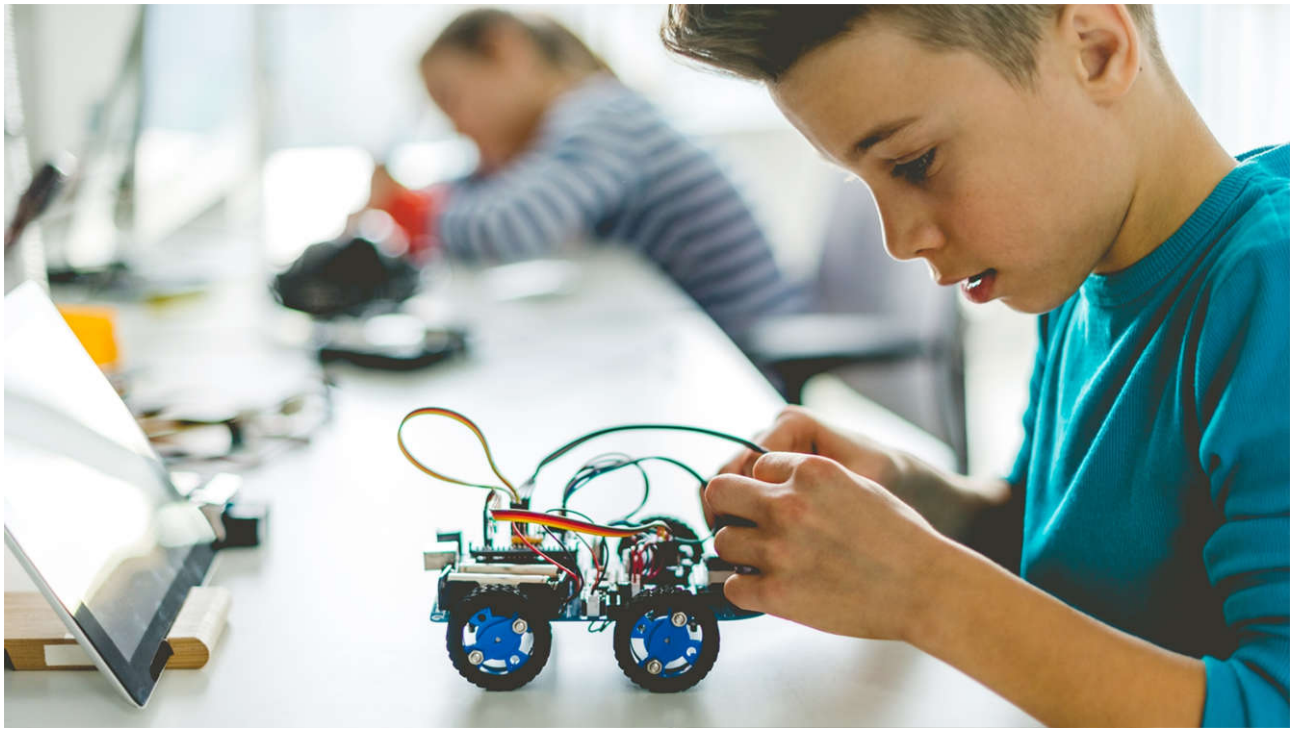
STUDENT AWARDS

QPARK Quality in parking

CONTENTS

INTRODUCTION



Q-Park Student Awards
Understanding the trends that impact parking

We are proud to present this collection of the winning Q-Park Student Awards since 2014.

Parking is and will continue to be an essential link in the mobility chain. In the coming years, the sector will continue to be influenced by many trends and developments as well as new players and changing partnerships. Opportunities in the parking sector are being created by:

- sustainability and liveability needs: reducing emissions and urban accessibility;
- socioeconomic trends: aging population, further urbanisation, e-shopping;
- technological developments: electric and smart cars;
- diverse Mobility as a Service (MaaS) applications.

Understanding these trends and their potential impact on parking is key for the future of the sector. Academic research performed by applied science and academic students can make valuable contributions to this knowledge.

The winning 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 10 years of cooperation

In cooperation with the Erasmus University Rotterdam, Q-Park established the Q-Park Student Award in 2014 for the best project or research conducted on parking and mobility written at a college or university in Europe.

We have commissioned this publication of abstracts to share knowledge with the industry and interested parties. We more than appreciate your feedback, but more importantly, we value your commitment and sponsorship to increase relevant knowledge and accelerate the journey towards sustainable urban mobility.

Bridging the knowledge gap

When we established this award in 2014, our purpose was twofold: 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 research on parking and practitioners in the sector.

As a sustainable mobility partner, Q-Park has welcomed the dramatic rise in research on parking in the last 20 years. But we have also noted the knowledge mismatch between what practitioners need in the field and what students have produced. Put simply, the two are driven by different goals.

But as the abstracts presented here show, these two worlds can come closer to generate new knowledge which combines both research rigour and new ideas for practitioners to tackle current and future challenges. Student research projects make a valuable contribution to bridging the knowledge gap.

Winning abstracts

Since its inception in 2014, more than 80 theses and projects have been considered for the award, which is open to all European universities and colleges.

Each year, a shortlist of is selected based on academic and socioeconomic relevance quality. A panel of Parking & Mobility experts assesses the submissions and selectes three finalists. Each of the winning students gives a brief presentation of their research and findings.

Increasing breadth and depth

Today, we welcome research from colleges and universities throughout Europe – on parking *and* sustainable mobility challenges. Ensuring that both applied sciences and academic students are positively influenced to contribute to sustainable urban mobility challenges.

Thank you

We would like to thank and congratulate all students who submitted their research for the Q-Park Student Award. 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 Student Award.

We trust that this publication will continue to build bridges by inspiring students and academics to conduct research on parking and sustainable urban mobility.

Maastricht, November 2024
Frank De Moor – Q-Park
Theo Thuis – Q-Park
Giuliano Mingardo – Erasmus University Rotterdam

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, 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, 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.

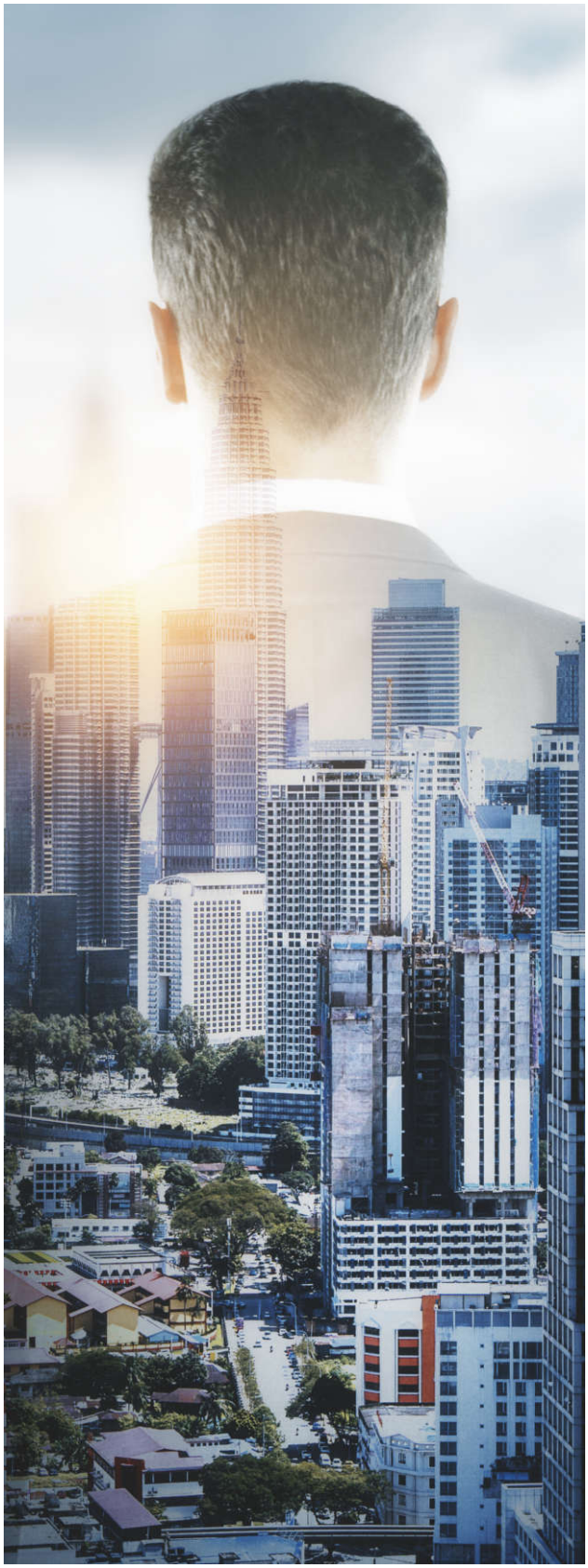
We show that the unpriced marginal externality is the key metric that parking authorities should use to inform their parking policies. We apply this methodology to the city centre of Melbourne, where strict time limits are combined with on-street parking prices that are below short-term off-street parking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

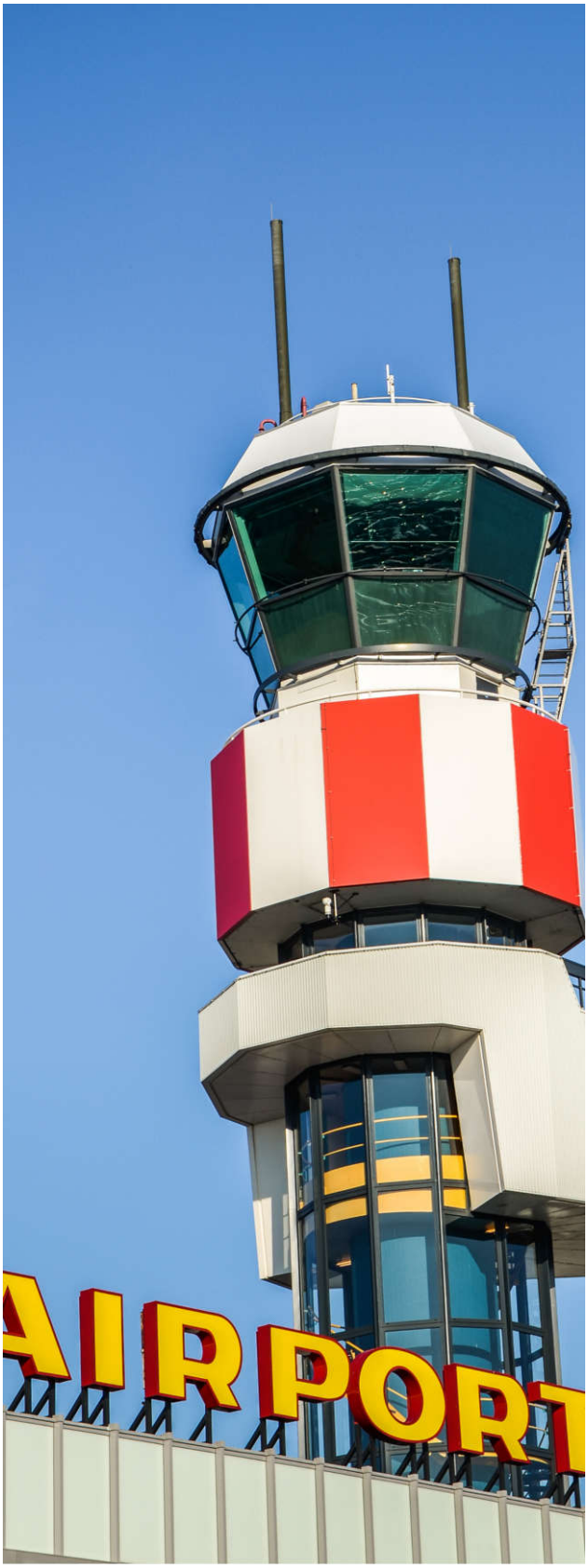
This study examines the possibilities of optimising non-aeronautical revenues of Rotterdam The Hague Airport. This is done by assessing the price elasticities for all different segments over the years 2013 -2017.

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.



PERFORMANCE PREDICTION

Student information
Author: Mateusz Wiza
Institution Maastricht University
Graduation year: 2021

Parking facility performance prediction using multi-target conformal regression

This thesis proposes a multi-target conformal regression approach for estimating the performance of new parking facility locations to be acquired by Q-Park.

Such forecasts should eliminate the need for consultancy reports prior to the development, sale or lease of new car parks: the basic parameters can be inserted into the algorithm and the artificial intelligence does the rest.

The basic data for the *machine learning model* include the capacity of the new car park, other car parks within a 1 km radius and their capacity, the presence of a train station within 500m and the numbers of offices, shops, hotels, restaurants and bars, educational institutions, industry and other buildings within 350m derived from OpenStreetMaps. Data relating to the floor space of shops, numbers of rooms in hotels and the like was not available for this research.

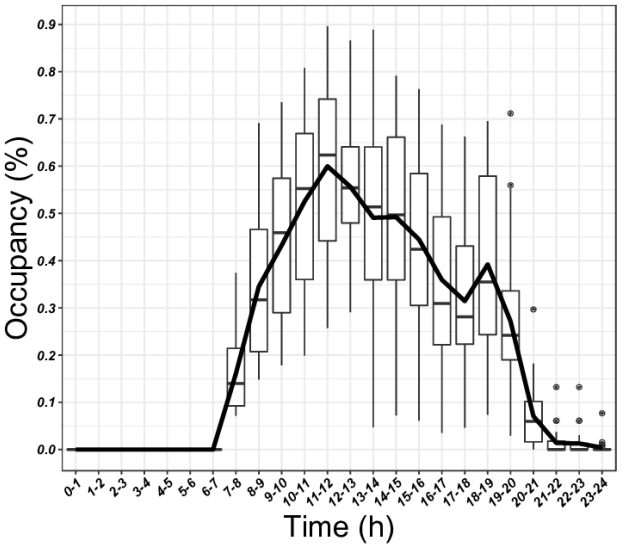
Data was collected for 1,037 existing Q-Park parking facilities in seven different countries. For these car parks, data including the number of hours parked, access and exit times, average length of stay, average occupancy and parking turnover per day were entered into the system. In addition, distinctions were made per country.

Various artificial intelligence techniques were applied to this database to identify which self-learning computational method best approximates the data imported. During the study, a prediction technology emerged which gave the best results. However, further research with more deep learning would be valuable.

Furthermore, additional more detailed basic data, such as shop floor area, numbers of workstations in offices, and numbers of hotel rooms, as well as results from existing car parks would make the artificial intelligence results even more reliable.

The thesis identifies the configuration of the regression model best suited for the task and compares the performance of different combinations of single and multi-target regression and conformal prediction. It also suggests the conformal method resulting in the most informative prediction regions.

Figure 1: Hourly evolution of parking occupancy for 30 regions (%). The line graph indicates the mean value of occupancy for all regions.



SHARED MOBILITY HUBS

Student information
Author: Rik van den Bogaerdt
Institution: Delft University of Technology
Graduation year: 2023

Shared mobility has found its way into the urban landscape over the last decade. Studies increasingly point to mobility hubs as a means of providing shared mobility options, usually run by actors within the mobility sector. However, shared mobility hubs have not been extensively studied from an urban development perspective.

This research examines the integration of shared mobility hubs into urban developments, and assesses how developers can manage this integration in both the development and functional phases, with a focus on so-called neighbourhood hubs.

Desk research was conducted to gain insight into current thinking on mobility hubs. This revealed that mobility hubs often encompass more than just mobility. Characteristics of mobility hubs include:

- connected to physical and digital networks;
- embedded in the urban fabric;
- focus on people and/or goods;
- cluster of facilities and functions, including shared mobility.

The desk research was followed by three case studies. Each involved plans for mobility hubs in different contexts. The semi-structured interviews explored the experiences of stakeholders in collaborating and guiding the integration of shared mobility hubs into urban development.

For example, the city of Rotterdam, where one of the case studies was based, would like to see a citywide network of hubs. There would be some common services and other offerings depending on the location and size of the hub.

The key takeaways can be summarised under two subtopics:

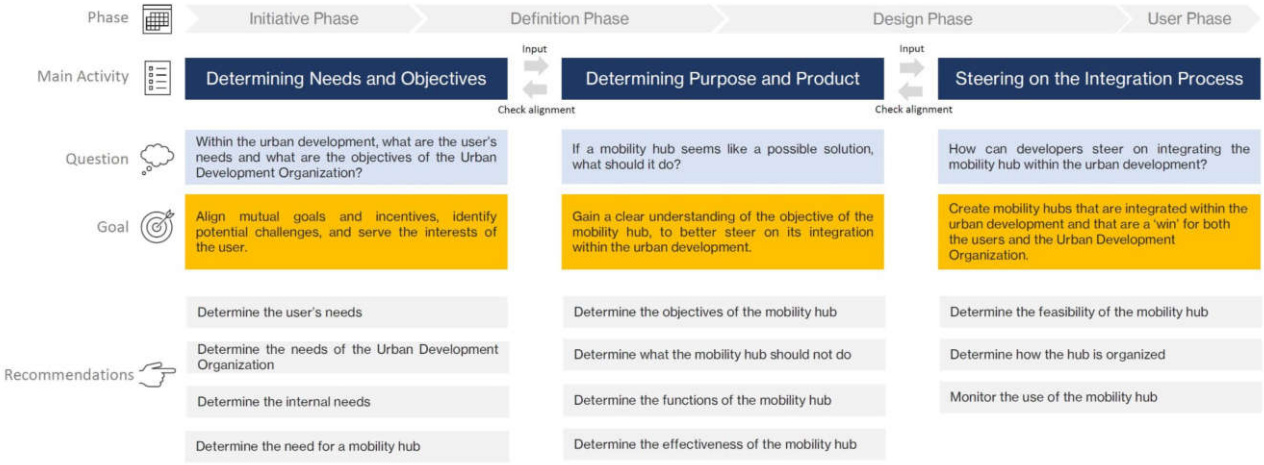
- **mobility hub concepts**: design and adaptability, digital integration and mobility as a service (MaaS), users and behaviour, including demand, transport modalities and operations, and energy;
- **urban development organisations**: organisation and management, business case, business-to-customer (B2C), parking.

Municipalities and developers have different perspectives and different objectives for mobility hubs, which are clearly reflected in the level of initiative taken by each. Possible explanations for these differences could be related to the municipality's level of experience with mobility hubs, differences in the political approach to mobility, housing demand, the existing infrastructure and public transport, and the size of the development.

Developers need to be aware that there's no fixed blueprint for a mobility hub that can be implemented in the same way everywhere. Smart hubs include a range of services in addition to mobility. Recommendations for developers working on mobility hubs include:

- guide the integration of shared mobility hubs into the urban environment by identifying the needs of the neighbourhood and the objectives of the developer;
- clearly define the purpose of the mobility hub and the products and services it will offer to residents and visitors.

Management Guide



DROP ZONE LOCATIONS

Student information
Author: Evi Rombouts
Institution: University of Antwerp
Graduation year: 2024

Finding suitable drop zone locations for free-floating forms of micromobility

Over the past decade, shared scooters have become increasingly visible on the urban streetscape, complementing traditional means of transport such as shared bicycles and public transport. Thanks to their eco-friendliness, limited spatial impact and constant availability, shared scooters can contribute to urban traffic, particularly through their potential to reduce the number of cars in the city. Although shared scooters are currently mainly used recreationally by young, affluent men, there are opportunities to encourage their use and realise the full potential of this service.

However, there are some problems with shared scooters that negatively affect public opinion. A key problem is that shared scooters are often parked in a way that blocks the pavement, as they are free-floating and can be left anywhere. This research focuses on solving this problem by locating drop zones so that the scooters can become station-based, without users having to walk long distances to their destination.

Research methods

To localise these drop zones, two methods were used in this research: the unsupervised learning method *k-means clustering* and the optimisation model *MCLP (Maximal Coverage Location Problem)*. Both methods have their own strengths. K-means clustering performs better in terms of mean and median distances, meaning users on average have to walk less far to reach a shared scooter. MCLP, on the other hand, maximises coverage, serving a larger percentage of demand within a 200-metre radius.

Comparison of K-means clustering and MCLP

As the number of stops increases, the performance of k-means clustering and MCLP start to come closer together, especially in terms of coverage ratio. This suggests that with enough stops, the choice between the two methods becomes less crucial. K-means clustering tends to generate a balanced distribution of stops throughout the study area, resulting in lower average distances. MCLP, on the other hand, distributes stops more towards the centre where demand is concentrated, which can be advantageous in urban centres with high demand. A disadvantage of MCLP is that it neglects the suburbs and the capacity of stops can still be high.

A possible improvement for MCLP is to implement a capacitated MCLP, setting a maximum capacity per stop as an additional constraint. However, this could lead to a higher concentration of stops at congested locations such as near the central station, which requires a larger number of stops to achieve the same coverage ratio.

K-means clustering can be affected by the random initial point distribution, which can lead to variable results. To improve k-means clustering performance, the method can be run multiple times to compare different local optima. Besides performance indicators such as distance and coverage ratio, practical aspects including the workload for providers to redistribute and possible pavement blockages should also be considered. Moreover, adjustments such as moving stops to wider locations may be necessary, which may slightly worsen performance indicators.

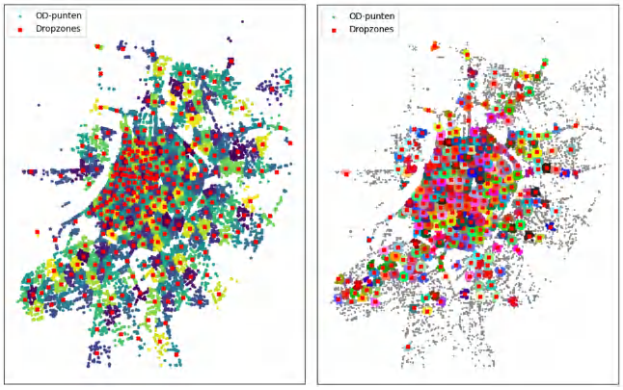
Evaluation of mobility hubs

The evaluation of mobility hubs based on MCLP and k-means clustering logically shows that the introduction of these hubs does not lead to improvements in walking distance and availability of drop zones within a 200-metre radius.

For MCLP mobility hubs, performance indicators for a 50-metre radius are almost identical to those for 100 meters, probably due to the impact of high demand drop zones in the city centre, such as at the Central

Station and Groenplaats. Small shifts in those busy zones have a big impact on performance. MCLP uses a grid to concentrate demand in specific points. Small shifts in drop zone location can cause these points to fall outside the coverage radius, which can significantly reduce performance. As a result, the coverage ratio of MCLP mobility hubs remains low compared to that of k-means clustering hubs making it recommended to use a different method if one would like to use the current public transport network for locating shared scooter stations.

K-means clustering distributes drop zones more evenly across the city, even with increasing values of k, allowing neighbouring drop zones to absorb demand when shifts occur and reducing the impact of changes. Therefore, in the case of k-means clustering, one could conclude that the creation of mobility hubs does add value.



K-means clustering (k=300) and MCLP (n-300) results

Recommendations

These study results could be used by the city of Antwerp to require providers of free-floating shared scooters to use designated drop zones. The choice of method and optimal number of stops depends on the city authorities' interests and objectives. However, the recommendation is to implement more than 100 stops, as the results for this number are significantly worse than for larger numbers.

Limitations of the Study

Note that this study was conducted with data from only one of the three shared scooter providers in the city. While the dynamics of other providers are expected to be similar, it may be relevant to include them all in the clustering or optimisation exercise. In addition, required drop zone capacity is currently based only on one provider's fleet. Another limitation is that only data from the month of June was used. Other months may show different trends, as use of shared scooters can be affected by seasonal influences such as weather.

PARKING DEMAND PREDICTION

Student information
Author: Agata Oskroba
Institution: Maastricht University
Graduation year: 2024

Parking Demand Prediction: Time Series Forecast for Subscription and Reservation Customers with Event-Correction Framework

This research explores time series forecasting of parking demand for subscription and reservation customers. Regression models were implemented in a rolling window setting in two different tasks.

- A classical time series regression model predicts subscription customer occupancy.
- An event correction framework to calculate parking demand in time for subscription customers based on two separate models forecasting differences between scheduled and actual arrival/departure time, and arrival and departure times of expected returns.

Outline

The mobility sector and parking industry are experiencing continuous global growth. For Q-Park, a leading parking provider in western Europe, the resulting challenge is to manage high parking demand. The primary issue involves efficiently prioritising and allocating parking spaces to different customer categories to optimise profit and efficiency.

Three customer categories are defined: Long Term Parking (LTP) customers, Pre-booking (PB) customers, and Short-Term Parking (STP) customers. LTP customers hold contracted subscriptions for parking, ensuring they have guaranteed spots. PB customers reserve their spots online in advance, securing their parking needs in advance. In contrast, STP customers are unregistered and unplanned visitors who require parking on an as-needed basis. The problem thus involves finding an optimal solution to prioritise and allocate parking spaces to LTP and PB customers while maximising the utilisation of these spaces for STP customers.

The current management process involves reserving parking spots according to subscription and reservation hours, assuming that customers will use the parking spaces during these pre-scheduled times. However, according to company management, this approach is inefficient, as customers do not always adhere to their subscriptions or reservations.

If there were a way to determine precisely when the LTP and PB customers will arrive, the spots could be offered to STP customers.

This challenge can be effectively addressed as a time series prediction task. Parking occupancy forecasting enables more efficient reservation and allocation process management. Compared to the current process, it is expected to produce more accurate and informative forecasts. Based on historical occupancy and transaction data, it is possible to predict LTP and PB customers' parking demand. This would facilitate informed decisions for STP customers intake and improve planning.

A traditional approach to time series forecasting is to implement commonly used statistical models as the results are easy to implement and interpret. The fundamental assumption in this approach is consistent data relationships over time. However, it may fail to capture complex patterns changing over time and may struggle with non-stationary series, requiring extensive preprocessing to stabilise the mean and variance. To address these issues, machine learning regression models provide a versatile strategy to manage irregularity, non-stationary and nonlinearity in time series data. So, several regression models were implemented and compared.

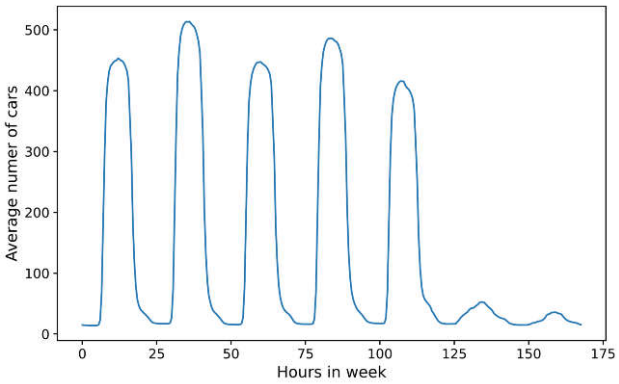
Although, Q-Park faces capacity management issues in several facilities, it was decided to apply the methodology to only one. Parking facility 'Zuidplein 1' in Rotterdam was selected for this project due to its importance and the reliability of data available.

Given the diverse data sources and types involved in this project, distinct methodologies were deployed to address the volume of LTP and PB customers. LTP customers, with long-term contracts, are expected to visit the parking facility regularly over an extended period, for example: office workers. For these customers, a simple time series regression model is implemented to predict the number of cars in the parking facility at any given time. In contrast, pre-booking demand depends on online reservations and is irregular over time. To forecast demand for PB customers, the relative differences between actual arrival and departure times and the pre-booking start and end times are predicted using regression models to estimate expected arrival and departure times. This approach serves as a correction mechanism for reservation times. Thus, it is refereed in this project to as event-correction framework.

Developing a solution requiring minimal maintenance is an additional objective. The company management therefore prefers establishing global parameters for the prediction models that remain constant over time and do not need regular optimisation. This project aims to assess the feasibility of having such globally optimised parameters.

This thesis investigates how time series forecasting can facilitate parking management. In particular, the experiments focus on answering the research questions:

- to what extent can time series regression models accurately predict the parking demand of subscription (LTP) customers;
- how effectively can regression models estimate the relative differences between pre-booked reservation times and actual arrival and departure times;
- to what extent can the event-correction framework provide accurate and informative predictions for the parking demand of reservation (PB) customers;
- does global parameter optimisation result in performance improvement for subscription and pre-booking predictions within the parking facility.



Average weekly occupancy LTP

Conclusions

For predicting parking demand of subscription (LTP) customers, the results demonstrated that Lasso, treebased models and SVR outperformed OLS and provided good results, capturing occupancy patterns and non-linearity effectively. On average XGBoost achieved the best results. These forecasting models could be successfully used in business decision-making.

For PB predictions, Random Forest and XGBoost performed best in estimating time differences between scheduled and actual arrivals and departures although no statistically significant differences were found between these models and Decision Tree or SVR. There is room for improvement for model stability and accuracy over time.

The research confirmed that time series regression models could accurately predict PB parking demand. The event-correction framework demonstrated its potential in providing accurate PB occupancy predictions, showing remarkable potential for increasing business revenue and parking spot allocation management.

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.

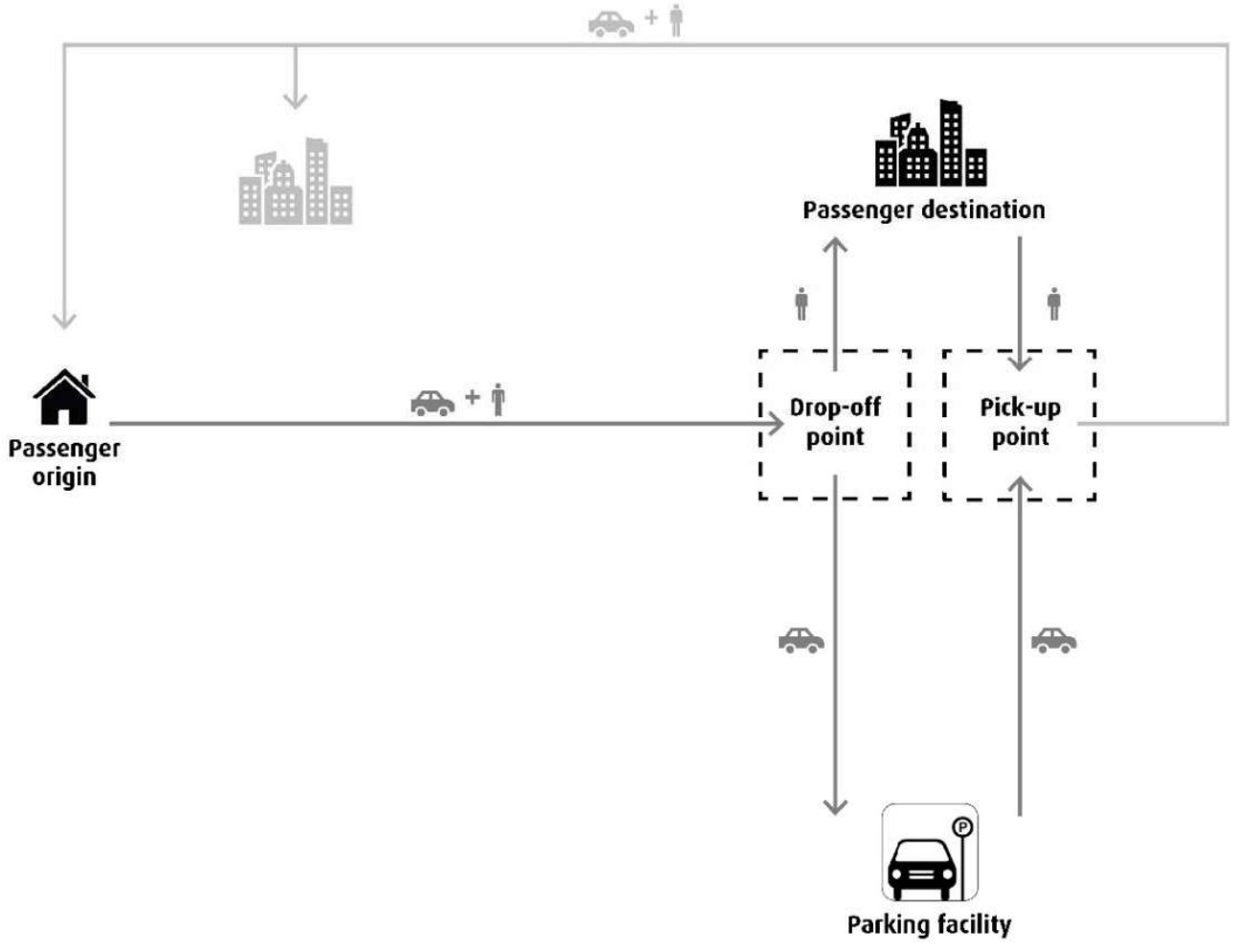
EFFECTS OF AVS ON PARKING CHOICE

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.

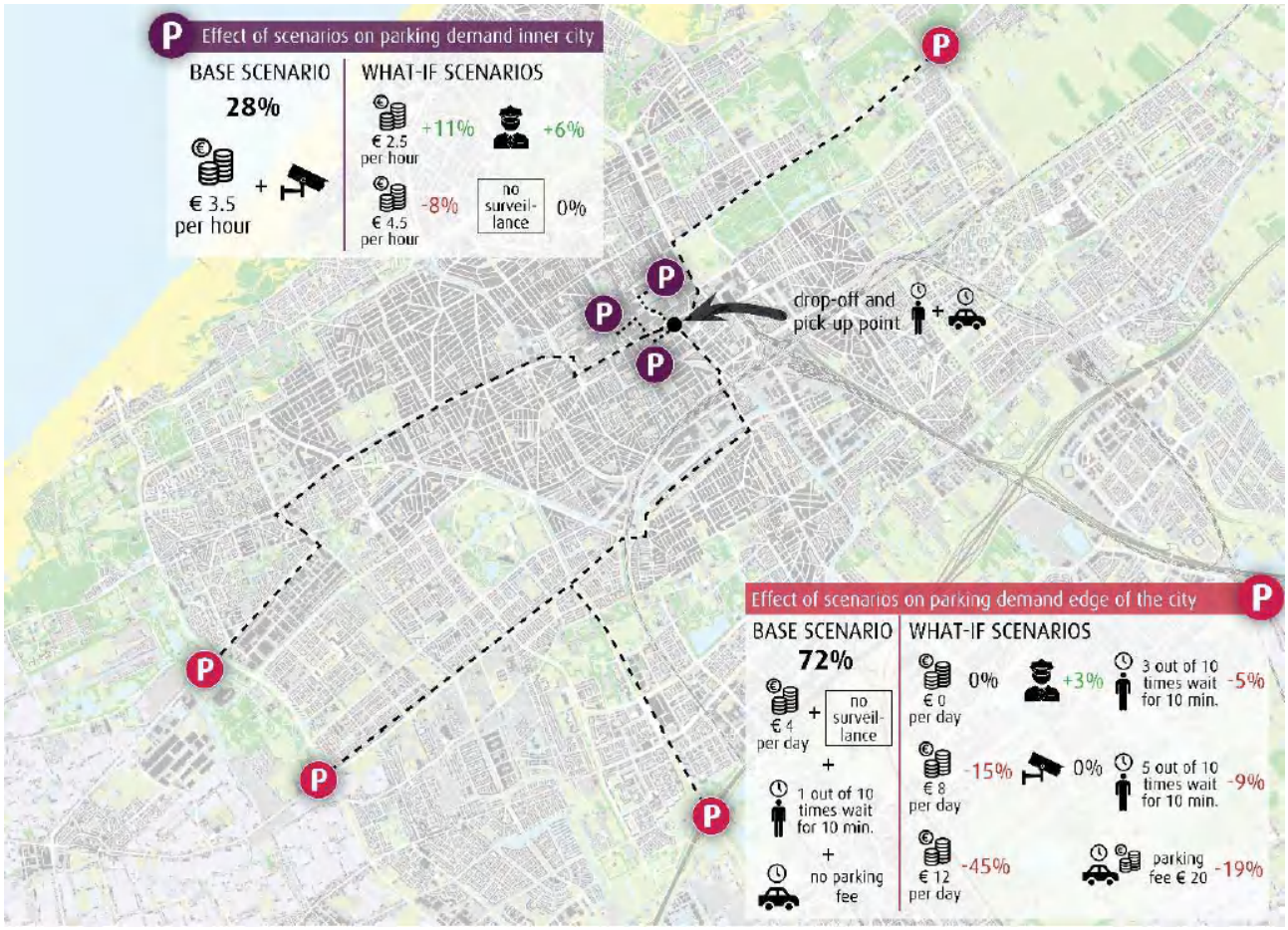
The results of the scenario analysis are visualised in Figure 2. From the results of the scenario analysis can be concluded that individuals are most sensitive for a change in direct costs, i.e. the 'parking cost' at the parking facility and the 'parking fee' for temporary parking the highly AV at an 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

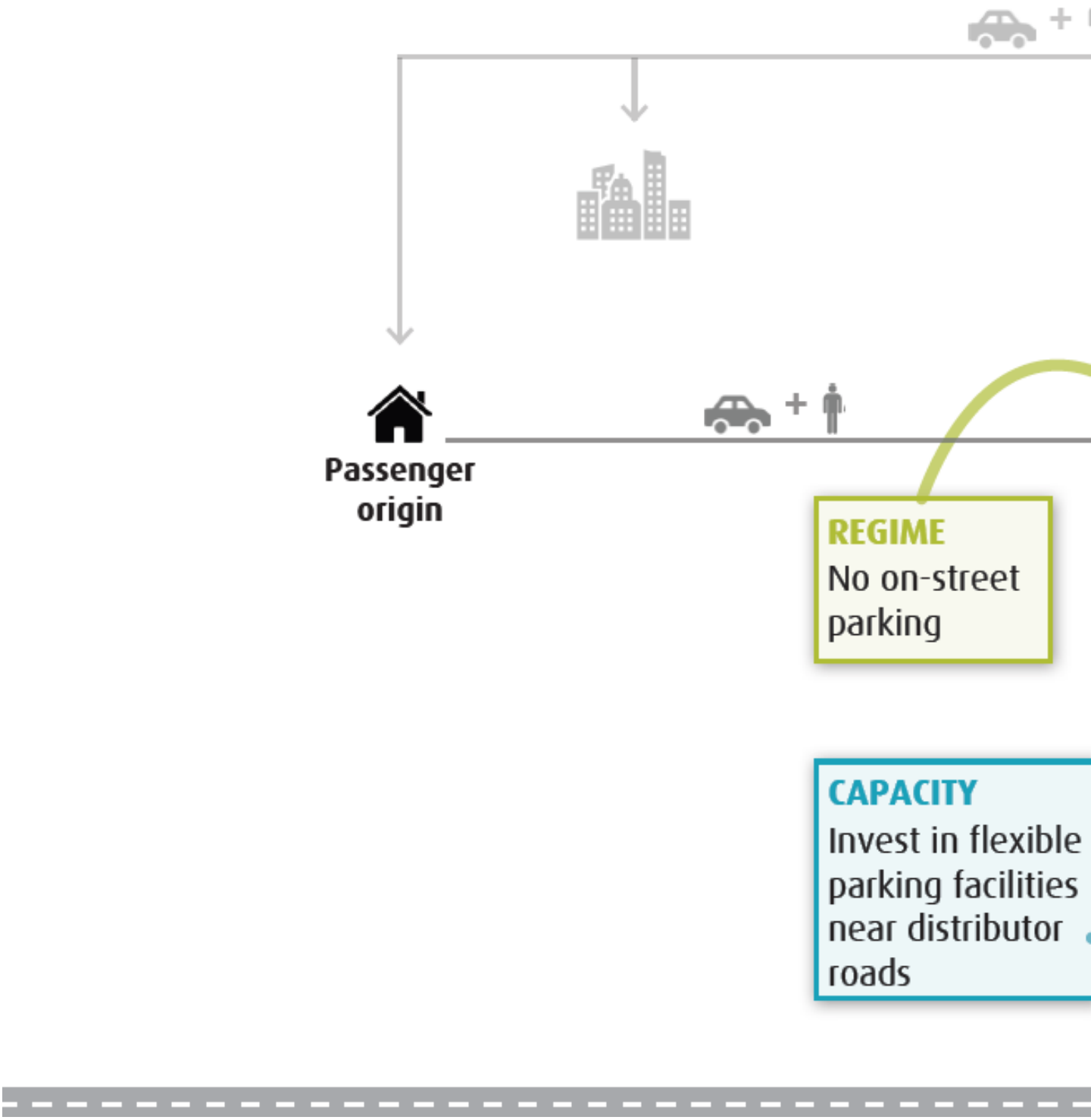


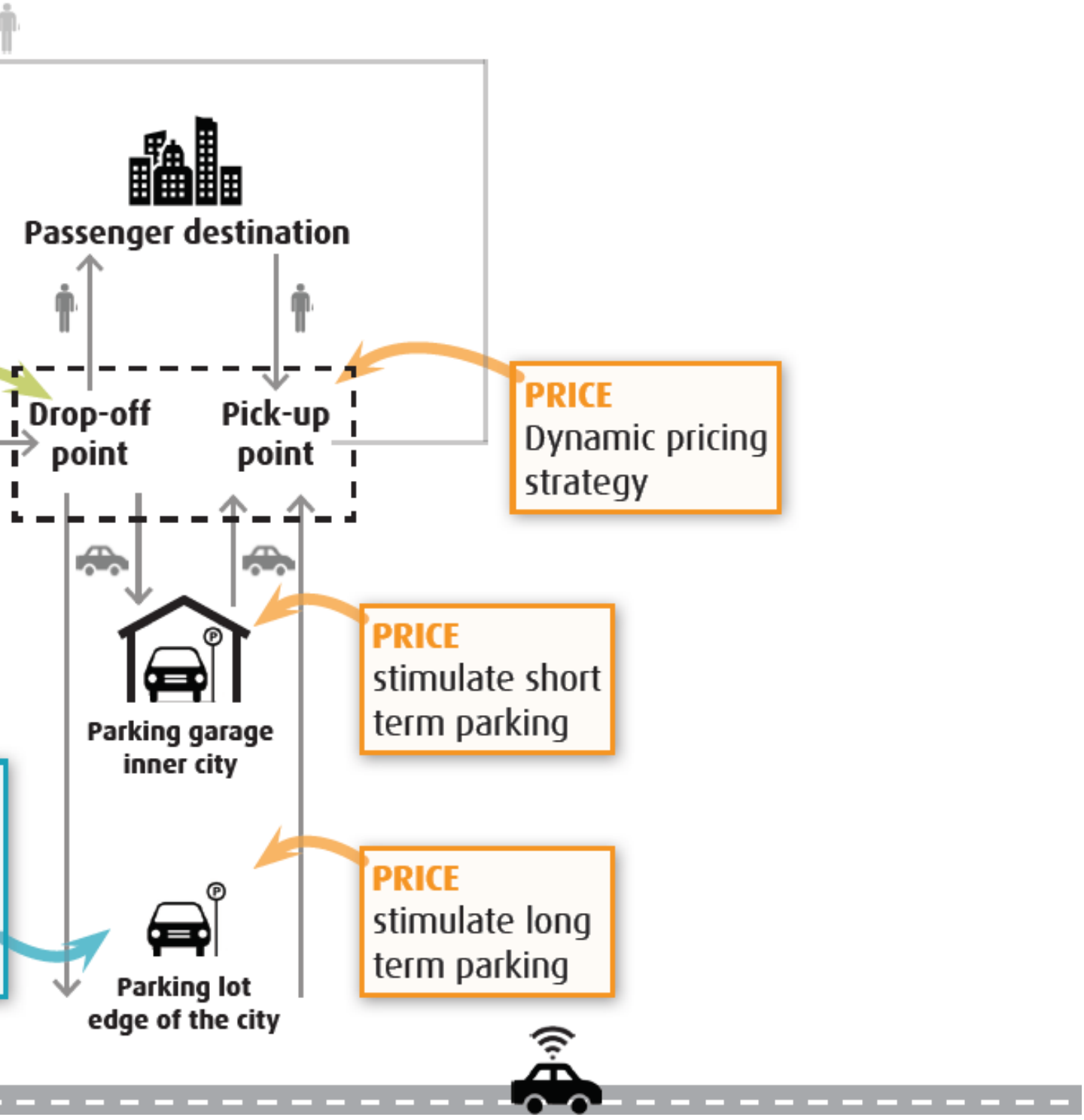
on-street with a parking permit. Furthermore, released on-street parking space could be used for greenery or extra space for bicyclists and pedestrians.

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

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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.

PERSPECTIVE ON RESIDENTIAL PARKING

Student information
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Graduation year: 2021

A new perspective on residential parking policy: A multiple regression model to explain visitor parking demand in Dutch urban residential areas.

As cities expand, municipalities face mobility challenges to keep their cities sustainable, liveable and accessible. In Europe, individual mobility focuses on personal car use, which makes the availability of car parking spaces an essential and challenging aspect in development projects.

This thesis aims to identify factors which explain visitor parking demand and what this means for the visitor parking standards. The conceptual framework developed showed that visitor parking demand depends on the demographic, geographic and policy characteristics of the residential areas of both the host and the visitor.

The traditional CROW standard makes a distinction between type of dwelling and socio-economic differences, but for visitor parking a universal mark-up of 0.3 parking spaces per dwelling unit applies. With declining car ownership per household, this fixed component is becoming an increasingly large proportion of the parking spaces to be realised in urban new build projects, and is consequently driving up costs and housing prices.

Literature advocates implementing context-specific parking standards related to the local residential area conditions. However, these studies lack insight into actual usage and neglect the visitor parking standards. In practice, there is often an oversupply of visitor parking.

Visitor parking needs were analysed based on the actual use of visitor permits in Eindhoven per postcode zone. Using regression analysis, this data was then linked to:

- geographical data (density, function, accessibility and housing types),
- demographic data of residents in the area (family composition, income and education level),
- parking facilities (on-street, off-street, tariffs).

Surprisingly, it transpired there was hardly any relationship between the number of visitor parking transactions and the number of residents or households. Areas in or near the city centre attract more visitor parking. Residents of larger, owner-occupied, dwellings attract more visitors and, finally, accessibility by car, measured by the number of parking spaces available and proximity to the main road network, has a positive influence on the number of visitors wanting to park.

The study concludes that visitor parking demand is very complex and therefore visitor parking standards should be based on local conditions rather than defining a national uniform value per dwelling. In addition, limiting the number of visitor parking spaces may possibly lead to reduced demand from visitors. However, this needs further practical research to establish new, more specific guidelines.

LIVING WITHOUT A CAR

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Graduation year: 2022

Living without a car: an analysis of the car-sharing landscape in Belgium

This research is in two parts. The first part focuses on understanding the group of households without a car and the advantages and disadvantages they experience as a result of not owning a car.

In the context of this study, a zero-car household was viewed as not owning a car. However, zero-car households may still use a car. To understand the issues concerning not owning a car, a literature review was conducted. This revealed that the group of zero-car households is diverse. The group can be subdivided based on the underlying reasons for not owning a car:

- **car-free** households who do not own a car by choice.
- **car-less** households who do not own a car due to external factors.

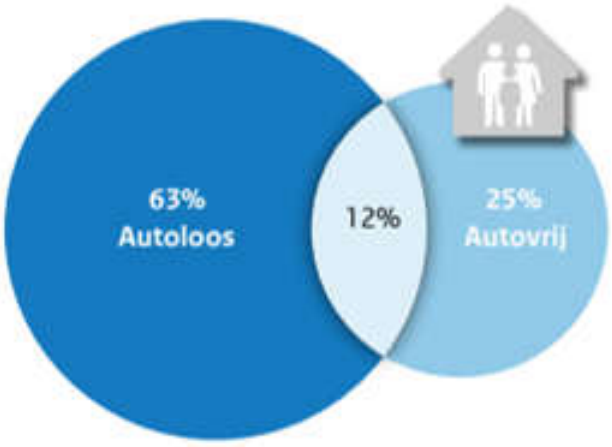
In this context, the label was applied according to the disadvantages experienced by the car-free and car-less households. Reasons for a household being car-less are mainly economic, however, depending on the residential location a household may be forced into car ownership to participate in economic, political, and social life of the community.

Car-free households are mainly located in more densely populated areas with better public transport coverage than car-less households. These car-less households therefore tend to experience more mobility disadvantages than car-free households.

The second part of this research focuses on the car-sharing landscape in Belgium as a possible solution for car-free and car-less households. This involved comparing the various organisations regarding general operation, geographical locations, additional facilities, and cost price.

The car-sharing industry is competitive and still developing, while the lack of standardisation makes comparison difficult. The car-sharing providers distinguish themselves mainly by the region in which they operate, the facilities offered and the conditions for users. Car-sharing organisations which specifically target sparsely populated areas may offer a solution for the group of car-less households.

Figure 4: Car-free versus car-less households



RESIDENTIAL URBANISM AND AGING

Student information
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Graduation year: 2022

The impact of residential urbanism and aging of young adults on car travel demand in the Netherlands

Travel demand in the Netherlands has been decreasing over the past two decades. This applies particularly to car travel by young adults and urban residents. Despite this, over 50% of all trips in the Netherlands are still made by car. The impact of urbanisation on car travel demand and the development of car travel by young adults in the longer term is still not clear.

This research examines the role of residential urbanism in car travel behaviour for different types of household composition in the Netherlands. It also explores the development of car travel behaviour among young adults.

Two waves of data from the Dutch Mobility Panel, from 2013 and 2019, were selected. Participants from waves, aged 18 and over, were asked to complete a three-day trip diary. This enabled changes in demographic characteristics together with changes in car travel behaviour within this group to be analysed.

The analysis revealed that residential urbanism is an important factor for determining car travel behaviour. However, residential urbanism does not affect all household types in the same way. It's clear that households with children travel by car more frequently whereas singles, especially in cities, are more inclined no to travel by car.

The results imply that urbanisation has the potential to decrease car travel demand among single person households and couples. However, as young adults age, they exhibit similar car travel behaviour to older adults.

	Residents of the most urban areas (2500 or more inhabitants/km^2)			**Residents of the least urban areas (1000 or less inhabitants/km^2)**		
Household type	Singles, N = 251	Couple, N = 154	Couple + children, N = 57	Singles, N = 123	Couple, N = 303	Couple + children, N = 202
License holding	205 (82%)	134 (87%)	53 (93%)	109 (89%)	276 (91%)	195 (97%)
Car ownership	122 (49%)	133 (86%)	53 (93%)	93 (76%)	288 (95%)	190 (94%)
Preferred transport mode to work						
Bike	73 (29%)	38 (25%)	12 (21%)	21 (17%)	46 (15%)	39 (19%)
Car	50 (20%)	36 (23%)	30 (53%)	38 (31%)	88 (29%)	122 (60%)
Not applicable	75 (30%)	48 (31%)	9 (16%)	43 (35%)	157 (52%)	26 (13%)
Public transport	19 (7.6%)	12 (7.8%)	2 (3.5%)	5 (4.1%)	1 (0.3%)	3 (1.5%)
Walking	6 (2.4%)	0 (0%)	0 (0%)	0 (0%)	1 (0.3%)	0 (0%)
Preferred transport for groceries						
Bike	73 (29%)	38 (25%)	8 (14%)	44 (36%)	103 (34%)	41 (20%)
Car	41 (16%)	42 (27%)	26 (46%)	32 (26%)	108 (36%)	109 (54%)
Not applicable	29 (12%)	20 (13%)	4 (7.0%)	11 (8.9%)	21 (6.9%)	11 (5.4%)
Public transport	1 (0.4%)	0 (0%)	0 (0%)	0 (0%)	1 (0.3%)	0 (0%)
Walking	52 (21%)	19 (12%)	4 (7.0%)	7 (5.7%)	16 (5.3%)	5 (2.5%)
Home to work travel by car	64 (25%)	43 (28%)	31 (54%)	45 (37%)	93 (31%)	129 (64%)
Average number of trips	13.0 (7.1)	12.2 (7.1)	11.9 (6.2)	10.7 (5.6)	10.1 (4.8)	11.2 (5.2)
Average distance travelled (km)	229.8 (346.2)	149.8 (248.4)	217.1 (282.9)	142.2 (211.3)	107.1 (144.1)	147.6 (172.8)
Average number of trips by car	3.1 (3.9)	4.4 (4.1)	6.9 (5.4)	4.8 (3.9)	5.2 (4.0)	6.8 (4.8)
Average number of PT trips	3.9 (6.8)	3.0 (7.1)	1.4 (4.0)	1.2 (3.4)	0.2 (1.3)	0.1 (0.8)

INTENTION TO USE MAAS

Student information
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Vehicle-owners' intention to use Mobility-as-a-Service

A latent class cluster analysis identifying factors behind the intention to use MaaS in the Netherlands

Increasing urbanisation and challenges regarding global sustainability mean that restructuring of current mobility and transportation systems is inescapable. One concept regarded as an answer to the changes needed is Mobility-as-a-Service (MaaS): an online platform which enables users to put together their optimal trip from a variety of transport modes, conventional and shared. MaaS only requires a single payment and provides up-to-date information about the desired trip. MaaS increases flexibility and ease of travelling, which is expected to have a positive effect on contemporary (urban) mobility.

As a relatively novel concept, MaaS has received considerable attention in academia as well as policy-making. In this body of literature, on the one hand MaaS is expected to improve the transport system, combat negative externalities of transportation, and positively impact social equity. On the other, the smart mobility solution is speculated to potentially be counterproductive by mostly replacing trips made by public transport and active transport modes. In this case, MaaS does not provide a solution to the changes needed in the current mobility and transportation systems, but contributes to the increasing number of vehicles on the road and related negative externalities.

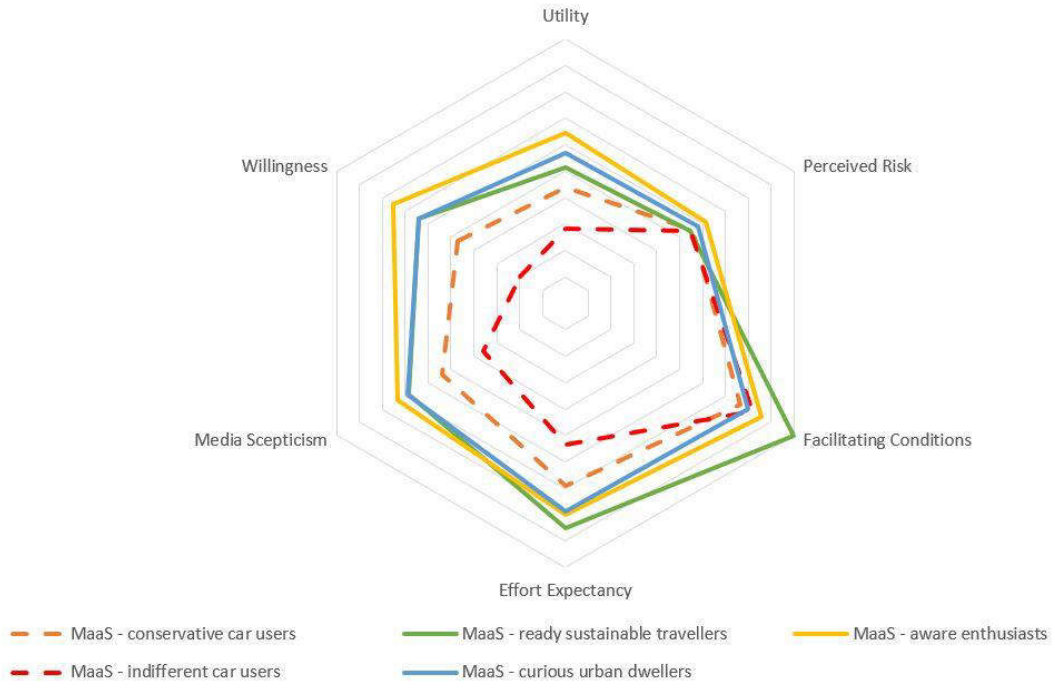
Previous studies on the adoption potential of MaaS in the Netherlands have identified private vehicle owners as unlikely to adopt MaaS while individuals using environmentally-friendly transport modes are likely to adopt. In that case, MaaS might be more likely to negatively affect the Dutch transport system and society. Despite the discussions on the expected potential impacts of MaaS, uncertainties still remain about the impact on the transport sector and on the potential for individuals to adopt MaaS.

Successful implementation of MaaS, where the concept positively impacts the transport system and society as a whole, relies on public acceptance. As vehicle owners are currently identified as unlikely to use MaaS, insight into their motives which could influence their intention to use MaaS and contribute to its successful implementation were examined.

For this, a conceptual model was created in this research to provide an overview of potentially influential factors. Data was collected using a self-administered questionnaire which was distributed among individuals living in the Netherlands and owning or jointly owning a car. The constructs and relationships of the conceptual model were analysed and resulted in five factors, plus a sixth factor representing the vehicle owners' willingness to use MaaS.

The research findings indicate that the overall willingness to use MaaS among vehicle owners is relatively low. The factor scores per cluster (see figure) show that clusters with a higher Willingness value also have a higher perceived utility and effort expectancy of MaaS. These clusters are consequently identified as intending to use MaaS. The perceived benefits in terms of convenience, travel time and travel costs of MaaS over current modes of travelling, similarities between MaaS and individuals' habits as well as the perceived ease of using MaaS thus indeed influence the intention to use MaaS.

The results also show that vehicle owners intending to use MaaS have a higher concern about potential risks and more scepticism of external evaluations.



Cluster factor scores

The factors identified, as well as personal characteristics which influence vehicle owners' intention to use MaaS, are mainly in line with previous research on the adoption potential of MaaS. Namely, clusters with a higher Willingness value have more younger vehicle owners, whereas clusters with a lower Willingness value have more vehicle owners aged 45 years or older.

An individual's main mode of transport affects their intention to use MaaS. Vehicle owners whose main mode of transport is public transport, walking or cycling are better represented in the clusters intending to use MaaS. As also shown in previous studies, those with a higher level of education and living in a larger municipality also indicate a higher intention to use MaaS.

From the findings, it can be distilled that vehicle owners might not be the first in line to use MaaS once introduced, but this does not mean that vehicle owners will completely disregard the option of MaaS. The cluster profiles show that personal characteristics, such as the age, education level or experience with MaaS(-like) services also play a role.

Recommendations from this research include increasing individual familiarity with MaaS, for example with car-sharing services, as positive experiences with such services have a positive influence on intentions to use MaaS. Efforts in less densely populated areas have the most potential as the research results show that clusters not intending to use MaaS contain a large share of vehicle owners living in smaller municipalities, those inexperienced with vehicle-sharing schemes and who are unfamiliar with MaaS.

RESIDENTIAL SELF-SELECTION AND TRAVEL BEHAVIOUR AND ATTITUDES

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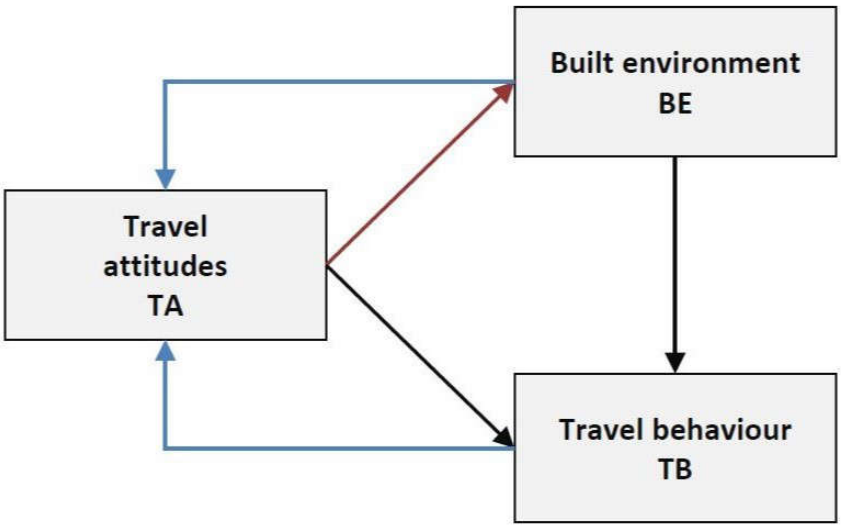
Institution: Delft University of Technology
Graduation year: 2023

With the transition to more sustainable transport systems, many different concepts and innovations have arisen. One of these is the car-free neighbourhood, which discourages car use through an urban design that favours active modes of transport, and leaves less space for private cars.

Developers aim to create urban and rural environments that encourage sustainable transport, in line with the wider objectives of reducing transport emissions and improving urban liveability. Achieving this transition requires a nuanced understanding of the complex urban planning relationships between the built environment (BE), travel attitudes (TA) and travel behaviour (TB).

Research in this area has consistently shown that the built environment has a significant impact on travel behaviour. The consensus is that mixed-use neighbourhoods equipped with sustainable transport options encourage residents to travel less by car and more by public transport or active modes of transport such as walking and cycling. However, the impact of the built environment on travel behaviour is intertwined with individuals' travel attitudes (TA). This relationship introduces the concept of residential self-selection (RSS), where people not only adapt to their environment but also select an environment which is consistent with their travel preferences and attitudes.

This study focuses on the relationship between the built environment (BE), travel behaviour (TB), and travel attitudes (TA) of people who move home. Using data from the Netherlands Mobility Panel(MPN), the study uses a basic cross-lagged panel model (CLPM) and a random intercept cross-lagged panel model (RI-CLPM) to identify the causal relationships between BE, TA, and TB and public and private transport before and after moving home.



Relationship between TA, TB and BE

The three-day travel diary extracted from the MPN data was used to specify travel behaviour through a variable derived from the total car kilometres driven. Questions on mode of transport preference for different travel purposes were used to identify travel attitudes. The built environment was defined by an urbanisation indicator provided by Statistics Netherlands. The data sample was created from MPN respondents with complete data points in three consecutive waves between 2014 and 2019, and who had moved home between their first and second data wave. This resulted in a data sample consisting of 347 respondents.

Both models showed that residential self-selection (RSS) is a significant factor. It suggests that people tend to move to environments that match their pre-existing travel attitudes. The RI-CLPM introduces a reverse causality effect, suggesting that the built environment after moving can influence travel attitudes one year later. However, there is also a reciprocal effect from travel attitudes after moving to the built environment.

Surprisingly, the RI-CLPM does not identify any effects on changes in travel behaviour, such as changes in car kilometres driven, that can be attributed to the built environment or travel attitudes. On the other hand, the CLPM does find relationships between travel attitudes and behaviour, suggesting these are influenced by stable, time-invariant third variables that the RI-CLPM most likely factors out.

Despite its valuable findings, the study acknowledges limitations related to the operationalisation of variables and the sample size. Further research into more reliable specifications of travel behaviour, exploring different types of relocation, and considering the influence of time-varying third variables is recommended.

In particular, the study highlights the theoretical advantage of the RI-CLPM and recommends its use in future research. It emphasises that conclusions drawn from CLPM studies may lead to erroneous conclusions about causal mechanisms.

Policy implications are highlighted in the context of limited evidence to explain changes in travel behaviour. The study suggests that facilitating opportunities for people with a lower preference for travel by car to relocate to dense neighbourhoods with reliable alternative transport options, may encourage more sustainable travel behaviour. However, the need for more robust evidence poses a challenge in translating these findings into concrete policy recommendations.

The lack of evidence to explain changes in travel behaviour makes it difficult to translate the findings into policy recommendations. One recommendation is to encourage people with a lower car preference to relocate to densely populated neighbourhoods with reliable alternatives, so they can self-select and practice more sustainable travel behaviour.

If future research confirms that changes in travel attitudes after relocating do lead to changes in behaviour, policymakers should target recent movers to dense areas, and inform them about sustainable travel options. This approach aims to reduce car preference by encouraging residents to seek and adopt alternative modes and change their travel behaviour.

PARKING AS MOBILITY TOOL

THE EFFECT OF PARKING MEASURES


P

Student information
Author: Johannes Martens
Institution: Hasselt University
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
Author: Ines Eline Ferrier
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Graduation year: 2016

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.

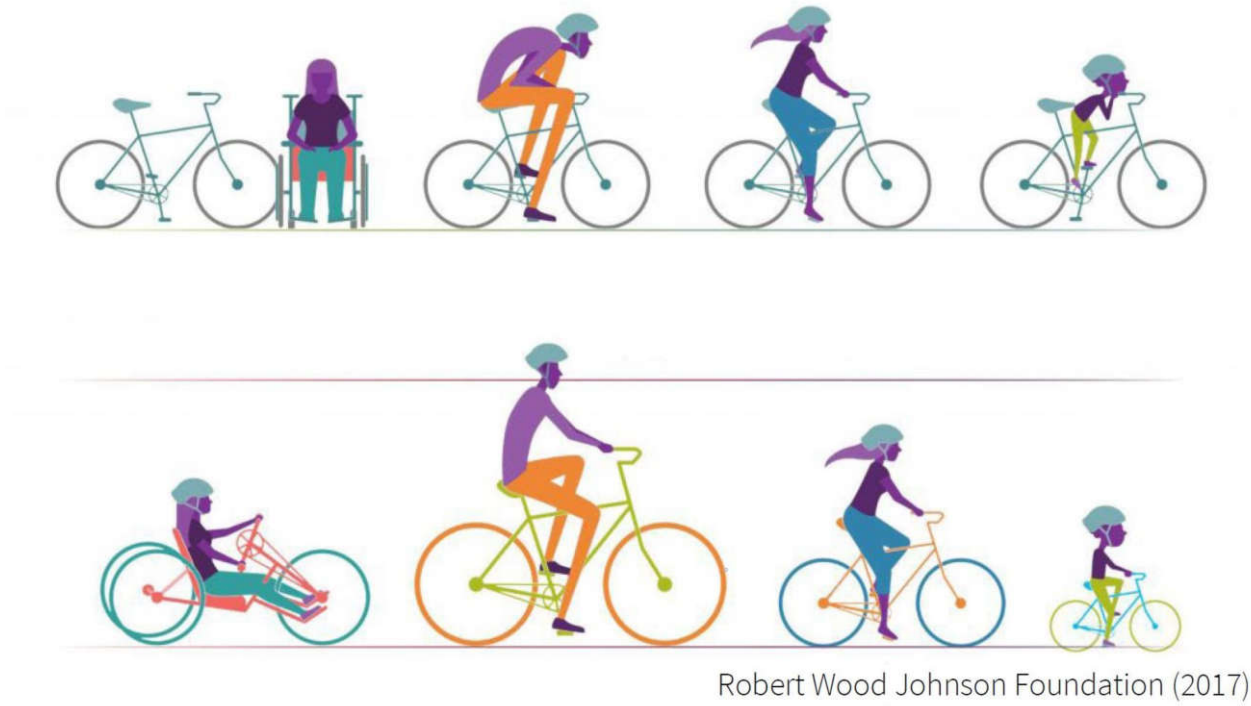
The effect of smart mobility on the road network was set outside the boundaries of this research, however it is expected that it will affect the public space.

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.

MOBILITY INJUSTICE: INDIVIDUALS' EVERYDAY MOBILITY EXPERIENCES

Student information
Author: Jolien Meulepas
Institution: Delft University of Technology
Graduation year: 2023



Robert Wood Johnson Foundation (2017)

To plan for accessibility (...) is to focus on the ends rather than the means and to focus on the traveller rather than the system: do people have access to the activities that they need or want to participate in?' (Handy, 2002, p. 4)

In many countries, there is growing evidence of transport related social exclusion. This is considered to have a significant impact on people's subjective well-being as it limits their participation in activities outside the home.
Various studies have identified groups at risk of transport poverty. These include people living in peri-urban areas (where the distances to travel are greater), people on lower incomes (where transport costs take up a greater proportion of their income) as well as people with low literacy or who do not understand the local language.

Arguably, transport poverty only occurs when transport disadvantage (not having access to a car) and social disadvantage (low income) overlap. Therefore, in areas where these two disadvantages are more likely to overlap, the risk of transport poverty is expected to be greater. In the Netherlands concerns have been raised about the high cost and length of journeys to work, school or hospital for several peri-urban neighbourhoods.

Other factors exacerbating transport poverty include a lower density of facilities and a poorer public transport network which can make people more dependent on private car use to access key activities. One of the peri-urban areas where signs of transport poverty have been observed is The Hague Southwest.

The research included a literature review, desk research as well as interviews with experts and residents.

The Capabilities Approach was adopted as a technical tool which is gaining attention when considering issues related to mobility injustice. This approach focuses on individuals' opportunities to access valued activities (capabilities) rather than focusing on realised behaviour.

Everyday mobility experiences can be used as an analytical tool to describe the relationship between mobilities and capabilities. In other words, the tool creates an understanding of how mobility contributes to or impedes individuals' opportunities to access valued activities outside the home, and thereby affects their well-being.

The focus on everyday mobility experiences and capabilities contributes to a deeper understanding of the nature of the problem from the perspective of a group for which very little is currently known. This is considered to be essential information for designing effective solutions and policy instruments to address mobility injustice relevant to accessibility.

Recommendations for urban planners include:

- a top-down approach to ensure a basic minimum level of accessibility;
- a bottom-up approach, including consultation with residents and experts, to make use of existing local knowledge and experience.

STORIES OF AGING AND ACCESS

Student information
Author: Laura Drechsel
Institution: Delft University of Technology
Graduation year: 2024

Stories of aging and access: exploring capabilities and challenges of accessibility for urban elderly through microstories

By 2040, one in four Dutch residents will be 65 or older, underscoring the need to address mobility and accessibility for this growing demographic. Despite the size of this group, transport planning often marginalises the elderly, treating them as a uniform group and ignoring their diverse needs. Elderly populations, particularly women, are vulnerable to transport poverty, with mobility being strongly linked to independence and well-being. However, the current accessibility studies available, conducted by the Planbureau voor de Leefomgeving, rely on oversimplified, time- or distance-based measures, and mostly to healthcare destinations. These simplifications challenge transport justice and fail to reflect the complex realities of perceived accessibility, and the complex realities of the 65+ demographic's experiences and preferences.

Research framework: Capabilities Approach and microstories

This research uses the Capabilities Approach, which focuses directly on the quality of life that individuals are actually able to achieve, as a conceptual framework. The research focuses on the interplay between resources, personal abilities, and individual circumstances to analyse accessibility for older people. To provide detailed insights, it uses *microstories* – personal narratives of mobility – collected through interviews with elderly residents in Rotterdam. This approach highlights the factors shaping accessibility, including health, income, gender, and local infrastructure.

Findings: mobility profiles and accessibility patterns

One of the most significant findings is that there is no single, uniform category of 'the elderly' associated with a specific set of skills for achieving access.

The study identifies three distinct mobility profiles which describe different levels of accessibility. These profiles were not necessarily defined by age, but more by factors such as individual health, ongoing commitment and proximity to important facilities.

For example, 'shut-in' residents adapted to their circumstances by limiting their activities to a small, local radius. On the other hand, residents who were 'forcedly mobile' faced the greatest accessibility challenges, as they were unable to limit their activities and instead had to contend with the difficulties of using public transport to reach important destinations.

Other microstories showed very active older adults who moved freely around the city and pursued numerous activities without encountering any significant mobility problems, categorised as 'local beneficiaries' or 'spinning citizens'. This highlights the vast diversity in actual mobility among older people, demonstrating that old does not necessarily equate to infirm or immobile.

Therefore, grouping elderly people into such mobility profiles has a much greater potential for creating policy that takes the mobility barriers into account and therefore meets needs, rather than simply sorting people into age groups.

Challenging traditional accessibility measures

The focus on the different resources and conversion factors encompassed in this research on urban accessibility for older people, also challenged the way we look at accessibility for older people in general.

Traditional time-based and distance-based accessibility measures often fail to capture the full scope of elderly experiences. The study advocates for effort-based thresholds, which take account of the physical and

mental exertion involved in travel, especially for those with mobility impairments. It also emphasises the importance of evaluating access to social and cultural activities, as well as access to healthcare, to support overall well-being.

Broader implications and future research

Microstories cannot replace aggregated accessibility studies but can certainly play a crucial role in refining and deepening these studies. They add a layer of lived experience to the – often abstract – data of aggregated accessibility assessments. They can also predict the choices and thresholds regarding which activities will be undertaken. In this research microstories proved to be a powerful tool for analysing and exploring the unique accessibility challenges and opportunities for particular groups.

Although focused on urban Rotterdam, the study's findings are more broadly applicable. This research shows that using microstories, mobility profiles, and the Capabilities Approach provide a useful framework for tailoring transport policies to the elderly population's varied needs.

Future research should explore rural settings and longitudinal studies to understand how aging affects mobility and accessibility over time. By addressing both functional and social dimensions, such research can inform policies that enable elderly individuals to lead dignified, independent lives.

PARKING AND ELECTRIFICATION

CAR PARK POWER PLANT

Student information
Author: Jurriaan Coomans
Institution: Delft University of Techonology
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:

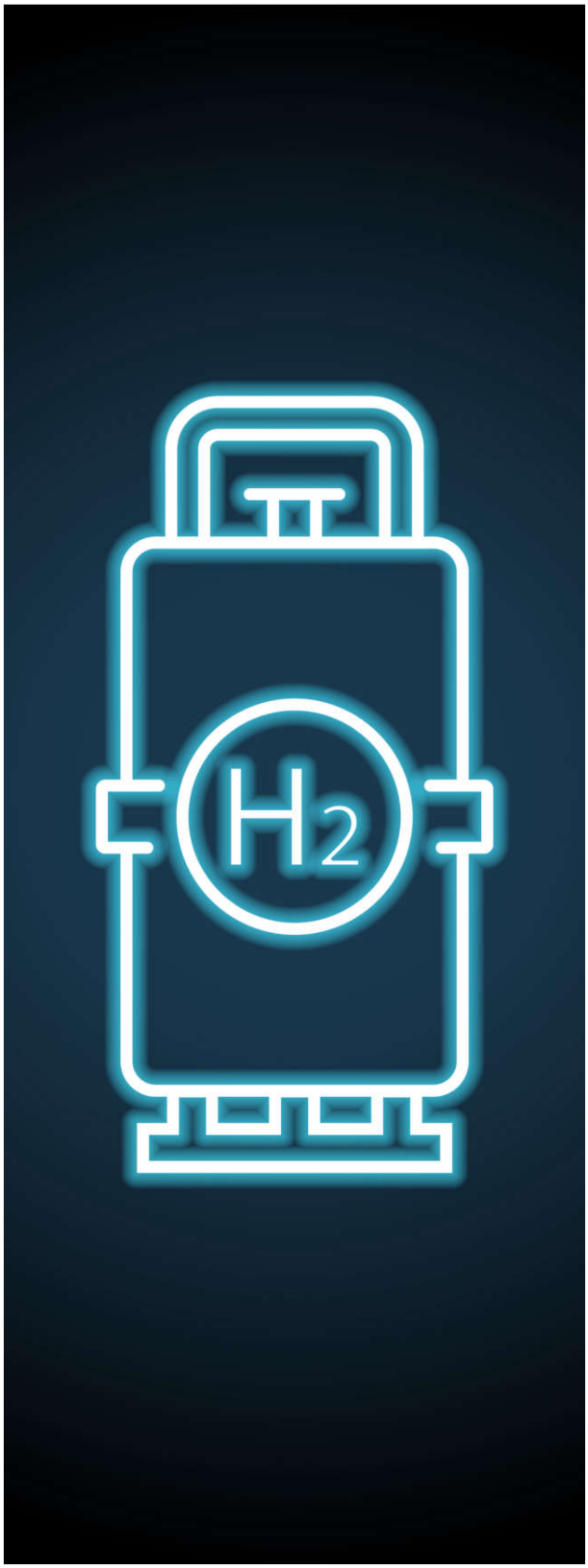
- The usage of simple CPPP operation tactics will result in CPPPs to produce electricity at all moments that satisfy the selected use-case. As a result the CPPP desires to produce electricity during many hours of the day.
- FCVs are expected to have production capacities of around 100 kW. If the conversion 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
Author: Dennis van der Meer
Institution: Delft University of Technology
Graduation year: 2016

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.

SOLAR CHARGING ELECTRIC VEHICLES

Student information
Author: Edward Heath
Institution: Delft University of Technology
Graduation year: 2020

Analysing the charging efficacy of an off-grid, solar powered electric vehicle charging system in long-stay parking applications

This thesis analyses the efficacy of off-grid solar powered EV charging systems, specifically for long-stay car parking at airports. The aim of such EV charging systems is to ensure that the EV is sufficiently charged for the return journey when the owner returns to retrieve their car.

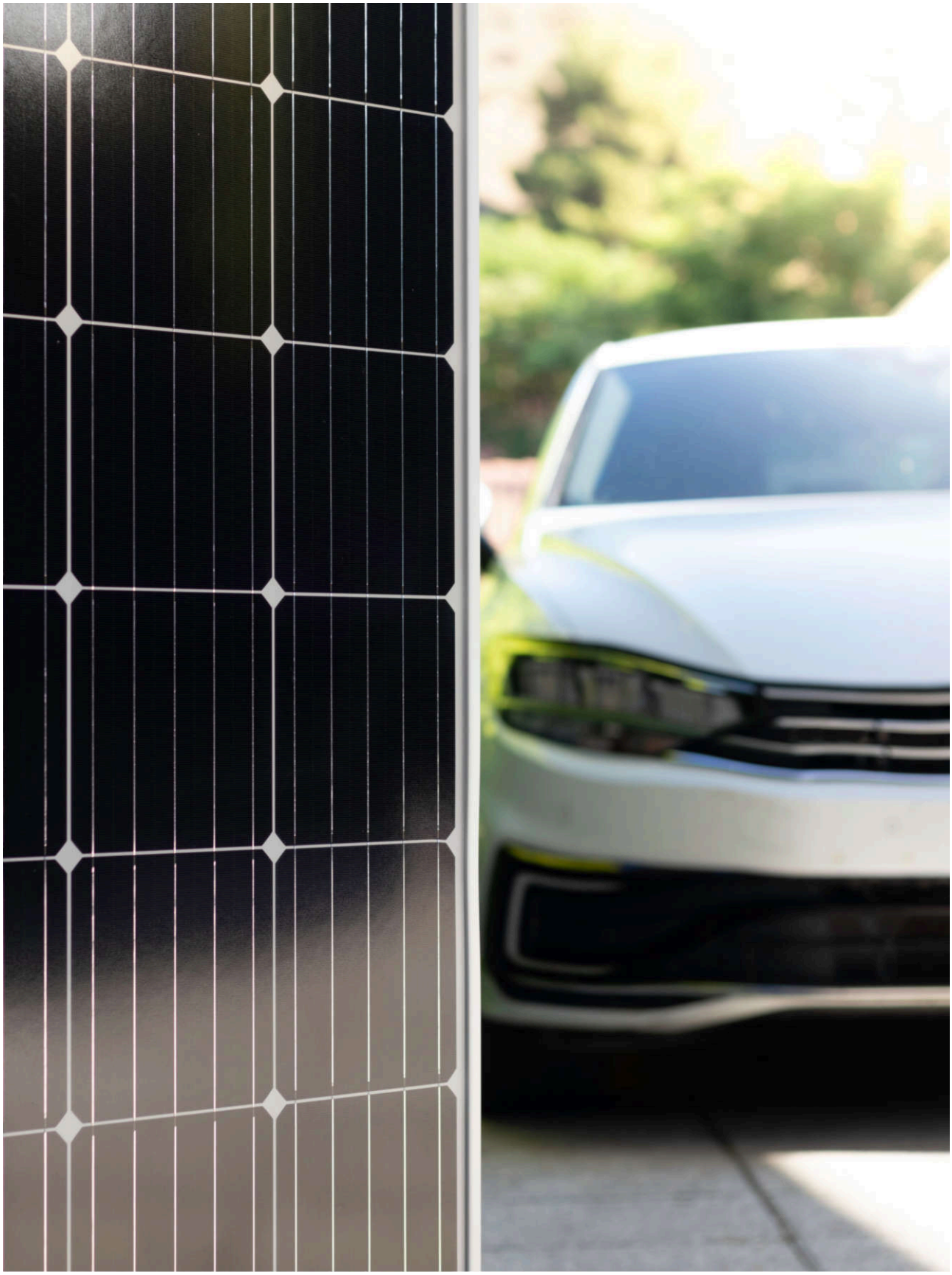
The research is based on a pilot study at Lelystad Airport long-stay car park. This facility includes 108 parking spaces for EVs under canopies fitted with solar panels. South-facing canopies covering four parking spaces, each with an EV charging point, are fitted with solar panels, 40 per canopy, 10 per parking space. Each parking space is equipped with a 3.7 kW charging point, which is powered only from the combined capacity of the solar panels. There is no top-up from the grid.

Arrival times were derived from information provided by Schiphol in November 2019, adjusted for the volume of the other months and assuming that flight arrival and departure times are comparable. The length of stay was derived from parking duration data provided by Boston Airport with a minimum of 48 hours, as the focus was on long-stay parking. The charging characteristics, including battery capacity and charging speed, of one of the ten most popular EVs sold in 2019 were then applied to each charging operation.

The simulations calculated that on departure, 85 percent of the cars would be sufficiently charged, in other words, with at least 75 percent of the battery capacity. Power generation was simulated based on weather conditions throughout the year: in the months April to August there was clearly overproduction. Throughout the winter months the charging efficacy dropped, to be expected for a location in the Netherlands at a latitude of 52°. In December and January, the simulation indicated that only 50 percent of the EVs leaving the car park had a sufficiently charged battery.

The underutilised generating capacity in the months April to August could be better used. A battery energy storage system is an obvious recommendation, and if sized and managed appropriately could offer reserve energy during the winter months and improve charging efficacy in the worst performing period.

Based on assumptions for installation costs and the price of electricity at € 0.36 per kWh, a payback period of 10 years was calculated. In the economic analysis, this basic case was compared with two alternatives: solar panels with top-up from the grid connection and powering the EV charging points only from the grid, without solar panels. The first alternative, solar panels with grid connection, requires the highest investment and has an estimated payback period of 15 years. The second alternative, where EV charging points powered from the grid without solar panels, has an estimated payback period of 9 years. However, there are disadvantages associated with the alternatives including grid connection, namely the capacity of the grid to incorporate new connections, and the associated risks regarding supply continuity.



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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