STUDENT AWARDS

QPARK Quality in parking

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.

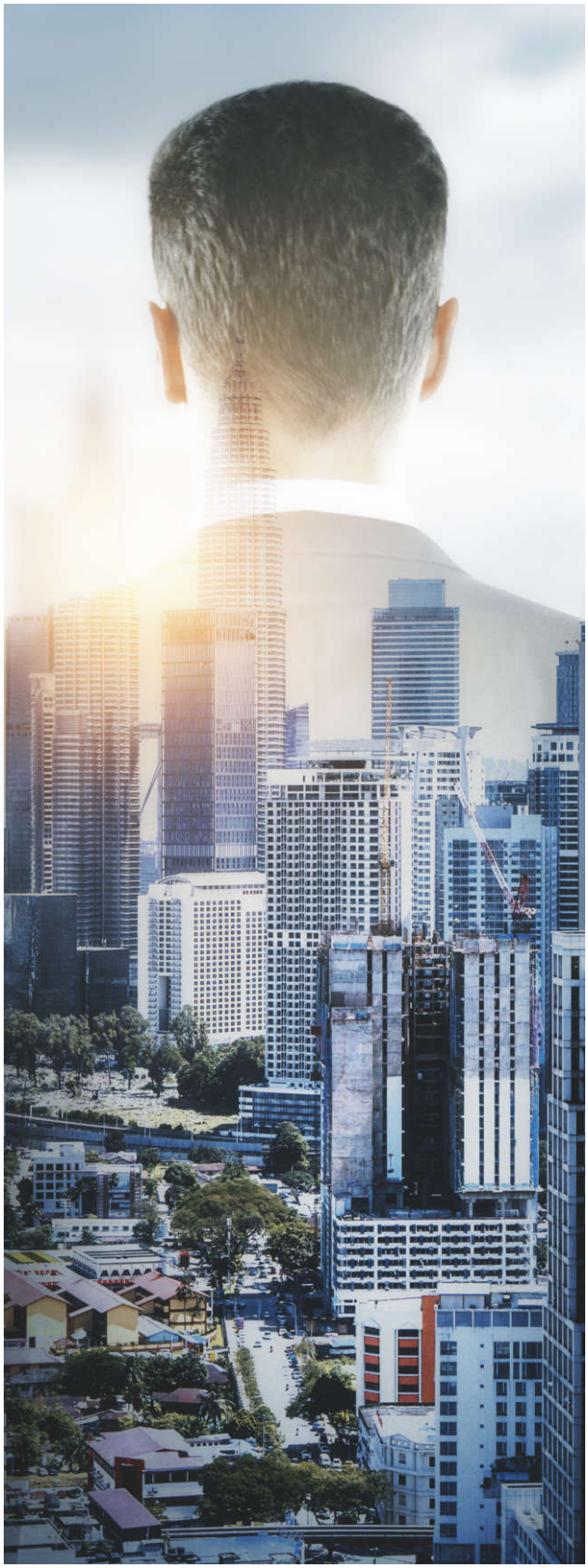
We show that the unpriced marginal externality is the key metric that parking authorities should use to inform their parking policies. We apply this methodology to the city centre of Melbourne, where strict time limits are combined with on-street parking prices that are below short-term off-street parking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

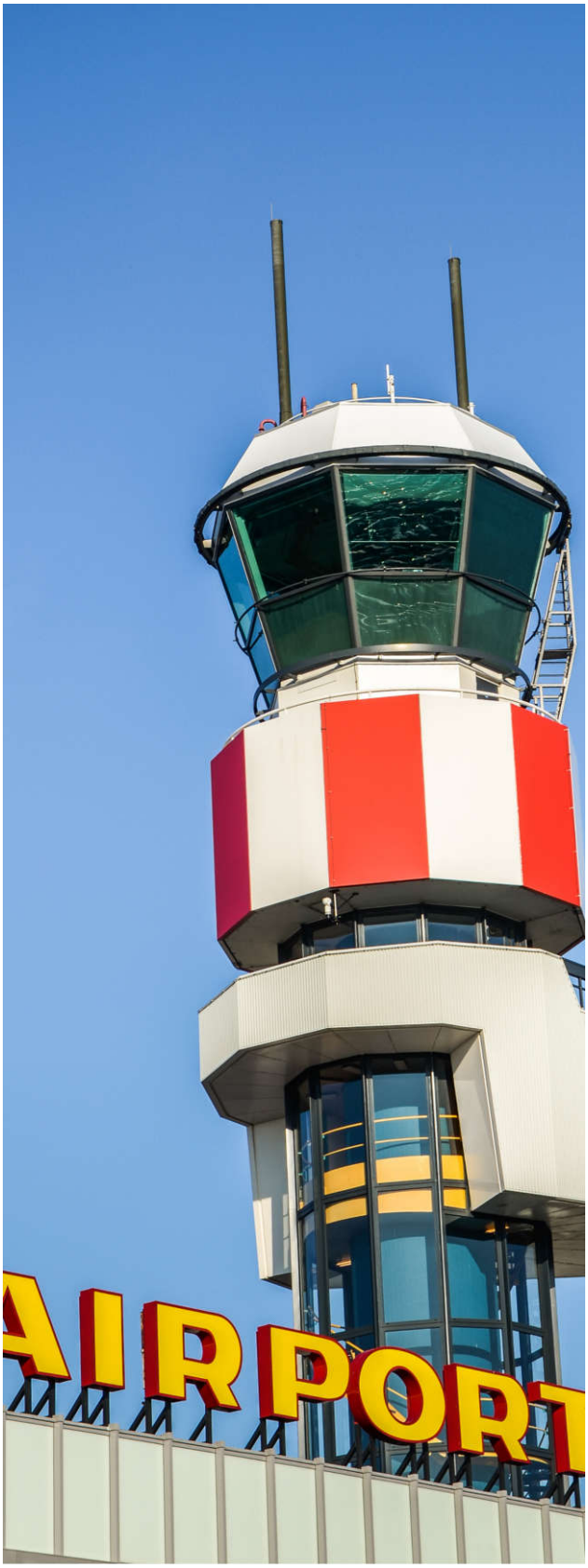
This study examines the possibilities of optimising non-aeronautical revenues of Rotterdam The Hague Airport. This is done by assessing the price elasticities for all different segments over the years 2013 -2017.

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.

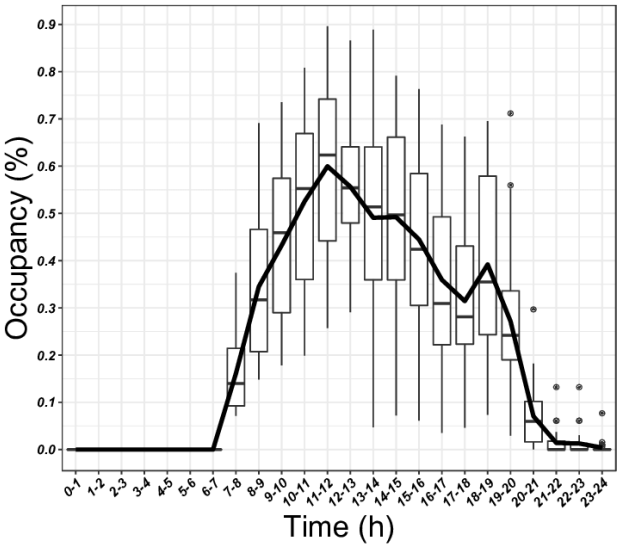
Data was collected for 1,037 existing Q-Park parking facilities in seven different countries. For these car parks, data including the number of hours parked, access and exit times, average length of stay, average occupancy and parking turnover per day were entered into the system. In addition, distinctions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

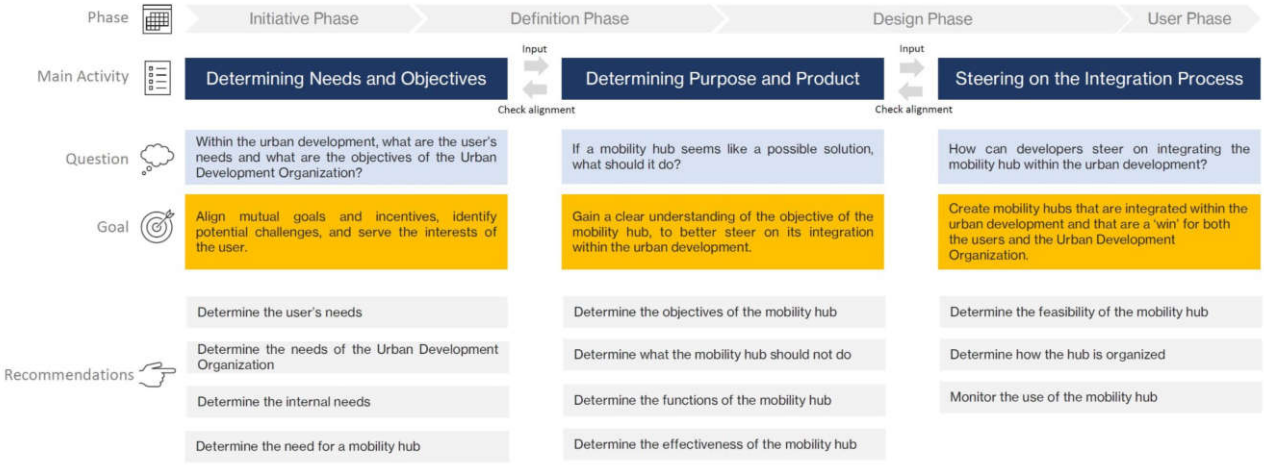
- **mobility hub concepts**: design and adaptability, digital integration and mobility as a service (MaaS), users and behaviour, including demand, transport modalities and operations, and energy;
- **urban development organisations**: organisation and management, business case, business-to-customer (B2C),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

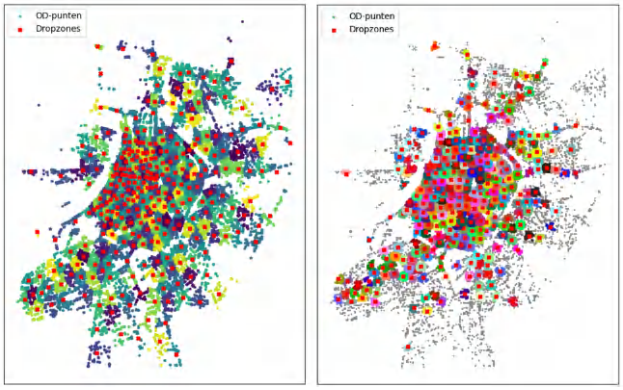
Evaluation of mobility hubs

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.

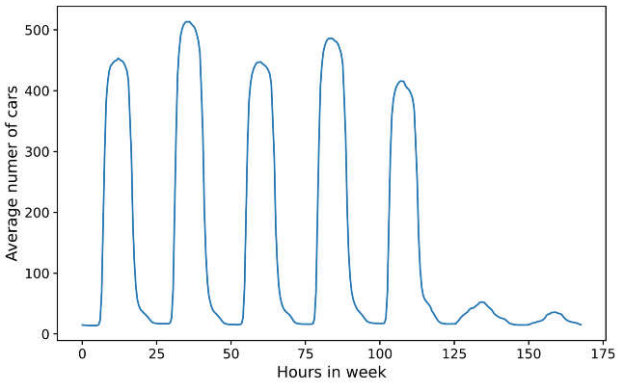
Although, Q-Park faces capacity management issues in several facilities, it was decided to apply the methodology to only one. Parking facility 'Zuidplein 1' in Rotterdam was selected for this project due to its importance and the reliability of data available.

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.