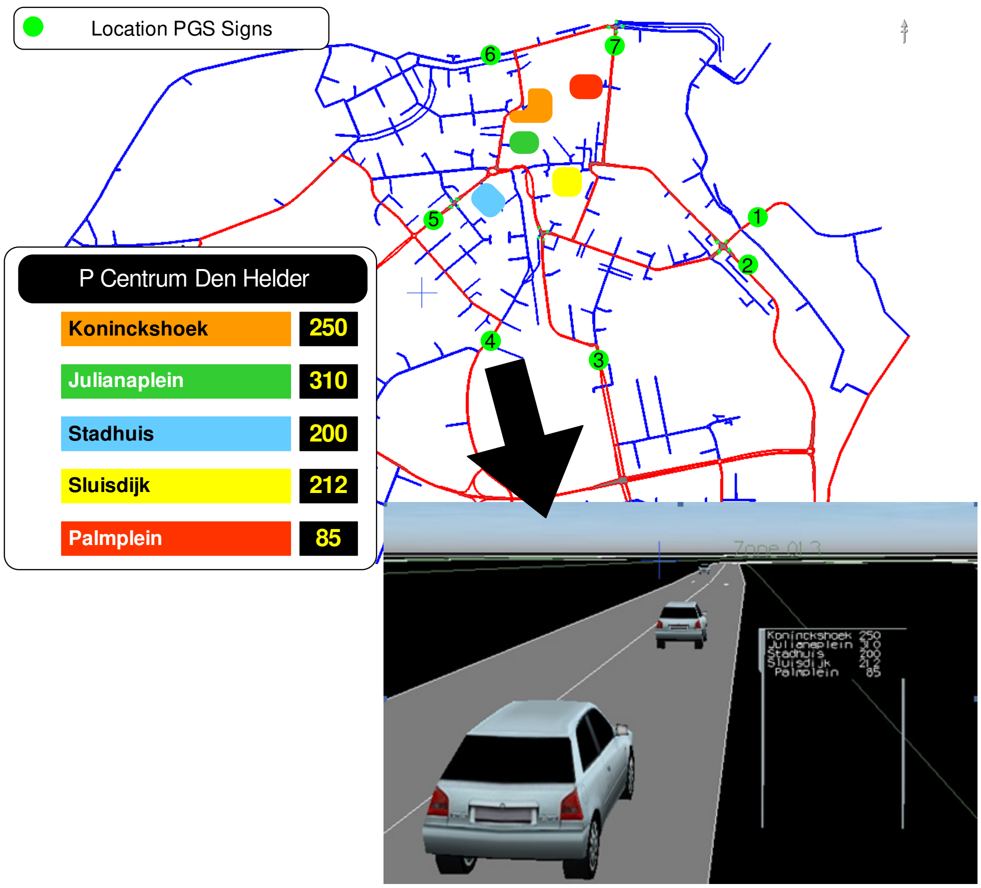
Modelling parking guidance systems in S-Paramics

Development of an S-Paramics tool to simulate parking guidance systems



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Authorisation

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Abstract

Parking problems in city centres, mainly on Saturdays, are a well-known phenomenon. The parking (capacity) problems are illustrated by full car parks, which result in long queues and unnecessary pollution. To reduce parking problems, parking guidance systems (PGS) have been implemented since the 1970s. At first mainly to inform the car drivers, but nowadays municipalities try to steer car drivers to gain a better distribution over the different car parks and to reduce 'searching' traffic.

The costs of implementing a PGS can however be relatively high. Most of the larger Dutch municipalities have implemented a PGS in the past, but have not carried out evaluation studies of the effects of PGS on the traffic performance. Medium-sized municipalities (60,000 – 100,000 inhabitants) find it hard to justify the high costs of the implementation of PGS, while the expected effects are not known.

Having a tool, which can estimate ex ante what the effects are of implementing PGS, can help municipalities in the decision on whether or not to implement a parking guidance system. The effects on the traffic performance can for instance be part of a cost-benefit analysis and municipalities can decide whether an increase in parking fees is justified to finance the implementation of PGS.

Aim of master thesis
Therefore the main objective of this master thesis is to develop an S-Paramics tool for modelling the effects of the implementation of parking guidance systems on the traffic performance. S-Paramics is a microsimulation traffic modelling software, which is used by many municipalities in the Netherlands for modelling their inner cities. Adding a tool to these models for modelling the effects of PGS can give municipalities a clear insight in the effects of implementing PGS.

Effects of PGS on car drivers
Although evaluation studies with regards to the implementation of PGS have barely taken place, field studies investigating the usage of the information displayed on PGS signs have been carried out in multiple cities. The field studies consist of surveys carried out among car drivers who parked at car parks, which were part of the information displayed on a PGS sign. The different studies show comparable results:

- On weekdays the amount of drivers changing their car park destination, because the PGS sign displayed that their 'original' car park destination was full, is ranging from 10% to 16%;
- On Sundays this percentage ranges from 15% to 18%;
- The information displayed on a PGS sign was mainly used by non frequent visiting, shopping traffic from nearby municipalities; habitual behaviour of car drivers was barely influenced by PGS signs;
- The higher share of non-frequent visiting traffic on Sundays causes the higher percentage of car drivers which change their parking location based on the information displayed on a PGS sign.

Development of PGS tool
Current microsimulation parking models in S-Paramics do not include PGS, but do include the different aspects and cost factors of parking. In the available S-Paramics models, which include parking, the parking fee and the (egress) walk time are part of the total trip costs. Car drivers in

the models try to minimize their total trip costs and chose a car park accordingly. Whether or not the car park has available spaces is an aspect which the car drivers in the model notice once they arrive at the car park. In case of a long queue in front of the car park, the car driver will re-route to another car park. With the addition of PGS to a model, information about the availability of parking spaces is retrieved at an earlier stage by the car drivers.

ITS controllers can be added to an S-Paramics model to represent PGS signs. Car driver behaviour in the model can be influenced at the locations of the ITS controllers. The influence of PGS on the car driver behaviour in the model is programmed and specified in the developed PGS tool. The outcomes of the earlier mentioned field studies are used as a basis for the development of the PGS tool and the response of car drivers to PGS signs in the S-Paramics models.

The PGS tool is triggered by S-Paramics once car parks are full and the tool starts rerouting a share of the car drivers to an alternative car park, once their ‘original’ car park destination is full in the model. The share of car drivers which is rerouted reflects the amount of car drivers which in reality change their car park destination, because the PGS sign displayed that their ‘original’ car park destination is full.

Case study PGS tool

Tests on small networks were carried out to verify the functionality of the PGS tool. The test were mainly performed to check whether the tool functioned as intended. Some small adjustments were made and finally the PGS tool was applied on a larger network: the model of Den Helder. The model of Den Helder was chosen, because the municipality of Den Helder is currently considering the implementation of PGS.

The developed PGS tool was applied to the model of Den Helder to simulate the difference in the future situation with and without an implemented PGS. The setup of the PGS tool (the locations of the ITS controllers and alternative car parks) was determined in consultation with the municipality of Den Helder. The amount of car drivers which would change their parking location, when the PGS signs indicate that their original parking location is full, was set to 18%.

Ten simulation runs were carried with and without the application of the PGS tool, by using the same set of ten random seeds. These ten random seeds release the same amount of vehicles per hour, but have a small randomness in the exact release time of vehicles on the network.

For the analysis of the outcomes several traffic performance indicators were analyzed. Significant differences were found in the traffic performance indicators of which the value is summed up over a time period. The duration of the ‘full time’ of the full car parks dropped with 19.8%, because a share of the car drivers rerouted to alternative car parks. The total travel time within a cordon around the city centre decreased with 4.3% as a result of the reduced waiting times at the full car parks. Significant differences in the traffic intensities were not found, mainly because there was no congestion on the road network in the situation without PGS.

Discussion and recommendations

The final product is a PGS tool which simulates the implementation of PGS on a network. The PGS tool is a simplification of reality and the known effects of PGS. The main strength of the current PGS tool is that is relatively easy to add to an existing S-Paramics model which includes parking.

The possibility to manually set the input of the PGS tool makes it a flexible tool with a clear structure, which can be used for multiple purposes. For instance different advised parking routes (by a PGS sign) to car parks can be evaluated. Or the effect of PGS in case a higher percentage of car drivers drives to an alternative car park based on the PGS information.

Another strength of the PGS tool is the fact that is added to a microsimulation model, which gives the opportunity to investigate the effects on multiple traffic performance indicators. Not just the car park occupancies can be analyzed, but also the traffic intensities and travel times for instance.

The main weakness of the tool is that the tool does not model the effect on 'searching' traffic realistically. 'Searching traffic' exists of car drivers who are looking for a parking space, might not be familiar with the road network and are sometimes driving around 'clueless'. The implementation of PGS helps to steer these car drivers towards an available parking space. 'Search traffic' is however very hard to model and to measure within the S-Paramics environment. Car drivers in S-Paramics are 'intelligent', know the road network and always drive towards their destination. Therefore the modelled effect of PGS on the 'search' traffic might be underestimated compared to reality.

The developed PGS tool is a product which can still be further developed. For this master thesis the focus was on the development of a PGS tool, which can be used to predict the effects of implementing PGS. The modelled effect of PGS is based on surveys, which investigated the use of the information on PGS signs. This means that the modelled effects of the PGS tool, can be used to make predictions about the implementation of PGS.

The PGS tool can however be calibrated for an existing PGS situation in case municipalities have available of the parking situation before and after the implementation of PGS. Therefore it is recommended to look at the possibilities for calibrating the PGS tool. The setup of the tool remains the same. The additional variables for calibration are then the amount of vehicles responding to the PGS 're-routing advice' and the alternative car parks which are set as 'advice'. This also opens the possibility to see what the expected effects are, in case the setup of a PGS a the city is changed.

Future developments also offer opportunities for the PGS tool. Dynamic route instructions, based on the traffic situation on the network, are a new development for PGS signs. This is one of the features which can also be incorporated in the PGS tool. The PGS tool can retrieve traffic performance indicators (e.g. traffic intensities, travel times) from S-Paramics and base the route instructions on these indicators.

Another promising development is the addition of PGS to in-car navigation systems. Based on the car park occupancies, the navigation system sets the closest car park with available parking spaces as final destination for the car driver. This means that the in-car systems 'overwrite' the first car park choice of a car driver with an alternative car park, just as now happens with the PGS tool in S-Paramics. In case the majority of cars have in-car systems and use this PGS function, the PGS tool can be used to determine the effects of different advice strategies of in-car systems.

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List of definitions

Different definitions for terms related to parking guidance systems and the use of the information of parking guidance systems can be found in literature. Therefore several terms and phrases, which are used multiple times in this master thesis, are defined below.

Parking guidance system (PGS)
The system of all the PGS signs implemented in a city to inform car drivers about the available number of parking spaces at the parking locations in a city.

Parking guidance system sign (PGS sign)
The single PGS sign, which can be found along roads. These signs show the availability of parking spaces at multiple car parks. In other literature the term ‘PGS sign’ is also used to refer to signs inside car parks to guide drivers towards a free parking space within the car park. In this master thesis solely the PGS signs along roads are subject of research and are therefore referred to when this term is used.

Car drivers notice the PGS sign
In case a car driver notices a PGS sign, the driver has seen the PGS sign along the road and the information displayed on the PGS sign.

Car drivers change their parking location based on PGS sign information
After a car driver notices a PGS sign, he or she uses or ignores the information. In this master thesis the following sentence is often used “a car driver changes parking location based on the PGS sign information”. This means the following: The car driver has car park destination P1, but notices on the PGS sign that car park P1 is full. The car driver therefore uses the PGS information to re-route to an alternative car park, which was not his or her ‘original’ destination.

Alternative car park
The new car park destination of a car driver, after he or she notices that the ‘original’ parking destination is full.

PGS advice (in model)
The developed PGS tool in this master thesis gives ‘advices’. In reality a PGS signs displays information and does not give a real advice. The PGS advice of the PGS tool is an alternative car park, to which the car driver will drive in the model.

Response rate to PGS advice (in model)
In the PGS tool a ‘response rate’ can be set. This respond rate sets the amount of car drivers who will ‘follow the advice’ and thus change their parking location.

Preface

This document presents my master thesis report, which is the final project for receiving the Master of Science degree in Traffic Engineering and Management at the University of Twente. The master thesis was carried out at Grontmij from September 2010 till March 2011.

At the start of my master thesis I expected that switching from the ‘student life’ to a ’40 hours per week office job’ would be hard. The nice working environment provided by my colleagues at Grontmij however ensured that spending 40 hours per week at the office was not that hard after all. Therefore I would like to thank all my colleagues of the division ‘Mobiliteit’ at Grontmij and some of them I would like to thank in particular.

First of all I would like to thank Erik Versteegt, my supervisor at Grontmij. He gave me constructive criticism on my working documents and was always available to give advices for the problems I ran into during my master thesis.
I would like to thank my ‘office roommates’ Arie Pols and Thomas Rook which had a large share in the nice working environment at Grontmij. I also really appreciate the help of Arie, who helped me to gain more acquainted with the S-Paramics software.
Other colleagues I would like to thank are Jeroen de Wit, Wouter Mieras, Hans Drolenga, Wim Husen and Falco de Jong for their help and time to answer my questions during my master thesis.

Finally I would like to thank Jing Bie and Eric van Berkum, my supervisors at the University of Twente. Their critical questions and remarks during our meetings helped me to improve my research.

1 Introduction and research setup

1.1 Introduction and problem description

The Netherlands has 16.5 million parking spaces, which is more than twice as much as the total number of cars possessed (7.6 million) by the Dutch population (CBS, 2010).Six out of ten Dutch car drivers however think, that finding a car space will be a major problem in 2020 (Goudkade and Snel, 2010).
Field studies support that finding a parking space will not only be a problem in 2020, but currently already is the case in many occasions. In extreme situations it was found that up to 74% of the traffic on the road was ‘search traffic’ and thus driving around and looking for a parking place (Shoup, 2007).

An answer to this problem was the introduction of parking guidance systems (PGS). These systems consist of multiple PGS signs placed along the roads. These signs show whether any parking spaces are available or the number of available parking spaces in car parks. The signs also show the route towards the car parks.

Figure 1-1: Parking guidance system

In the Netherlands most larger municipalities have implemented PGS and often state in their traffic and transport policies that these systems ‘help improving the traffic circulation in the city centres, but that the exact effects are unknown/unclear’. The main reason why municipalities state that it does improve the traffic circulation, is because a PGS guides drivers who are not familiar with the neighbourhood and prevents drivers from driving to full parking lots. Evaluation studies of the effects of the implementation of parking guidance systems however barely take place in The Netherlands (Dijkshoorn, 2002).

The unclear effects and high costs of the implementation of parking guidance systems is also reason for Dutch municipalities for not implementing the system (Gemeente Ede, 2004). Dijkshoorn (2002) carried out a survey in The Hague and Rotterdam. This survey showed that about 15% of the car drivers used the information displayed on the PGS signs to reroute to another car park, in case their ‘original’ car park was full. This however does not give a clear indication of what the effect on the traffic performance is.

To gain more insight in the effect of parking guidance systems on drivers, road traffic microsimulation software can be a useful tool. In road traffic microsimulation software, the driver behaviour of single vehicles is modelled and visualized in a road networks (see Figure 1-2). The cumulative effect of these single vehicles represents traffic flows on a physical road network. (SIAS Limited, 2009). Simulation runs can show the consequences of changes in the traffic operation (e.g. a change from an unsignalised to a signalised intersection) on the traffic flows. These consequences can be analyzed with the outcome data of the simulation runs, which is shown on the right pictures of Figure 1-2. The pictures and figures shown in Figure 1-2 are screenshots of the microsimulation software S-Paramics.

Figure 1-2: Visualisation of microsimulation models (source: www.sias.com)

Microsimulation traffic models are able to cope with intelligent transport systems and thus parking guidance systems, which makes them a useful tool for modelling the effect of parking guidance systems on parking traffic.
Currently a few microsimulation studies have been carried out, which deal with parking traffic. These studies investigated the effects of parking planning policies, because parking policies can have multiple effects on the transport chain, such as:

- the final choice of destination: can be influenced by the costs and availability of parking spaces;
- route choice: in case of a limited amount of available parking spaces, car users will start looking for parking spaces at the destination;
- travel mode; in some cities parking policies for the inner city aim to keep out the cars of the inner city and to stimulate the use of public transport (Tamminga, de Jong and Zee, 2005).

In case a microsimulation model is developed without parking spaces and lots, the cars will ‘disappear’ from the network once they have arrived in their destination zone. When car parks are added or linked to the destination zones, arriving traffic will park in the car parks. Once a car park is full, car traffic can either wait at the entrance or re-route and try to find a new parking place.

1.2 Study motive

Larger municipalities in The Netherlands claim that PGS helps improving the traffic circulation and reducing the parking problems in inner cities, but that the exact effects are unclear. A better insight in the effects of parking guidance systems can help medium-sized municipalities in the decision on whether or not to implement PGS.

Microsimulation traffic models are able to cope with parking guidance systems and parking traffic. Currently there is however little to no attention for parking guidance systems in microsimulation traffic models. When the effects of PGS are modelled in microsimulation traffic models a better insight in the effects on the traffic performance of these systems can be gain.

1.3 Research objective

Having a tool, which can estimate ex ante what the effects are of implementing PGS, can help municipalities in the decision on whether or not to implement a parking guidance system. Therefore the objective of this master thesis is:

> *"Developing an S-Paramics tool for modelling the effects of the implementation of parking guidance systems on the traffic performance"*

1.4 Research questions

The main research question of this master thesis is:
How can the effects of implementing a parking guidance system on the traffic performance be modelled in an S-Paramics environment?

To gain an answer on the main research question, the following seven research questions are formulated:

- What aspects of parking policies influence the parking behaviour of car drivers?
- What is the influence of PGS on driver and parking behaviour?
- Which S-Paramics models including parking behaviour are available?
- What are the possibilities for modelling the influence of PGS on driver behaviour in these microsimulation models?
- How can the effects of PGS on driver behaviour be modelled, taking into account the possibilities and limitations of S-Paramics?
- Which traffic performance indicators can be used to get an insight in the effects of PGS?

Figure 1-3 illustrates the research model which is related to these research questions. It is an overview in which the following different steps can be distinguished:

- A desk study: The aspects of parking, parking guidance systems and transport models will be investigated to gain insight in the aspects which are of importance for developing the PGS tool;
- PGS tool development: Based on the desk study and knowing the limitations and possibilities of S-Paramics, the setup for the PGS tool is developed;
- PGS tool verification testing: The developed PGS tool is verified; test are performed to check whether the tool functions as intended;
- Case study: The PGS tool will be applied to a case study to gain an insight in the applicability of the PGS and discuss the possibilities for evaluating the effects of PGS.

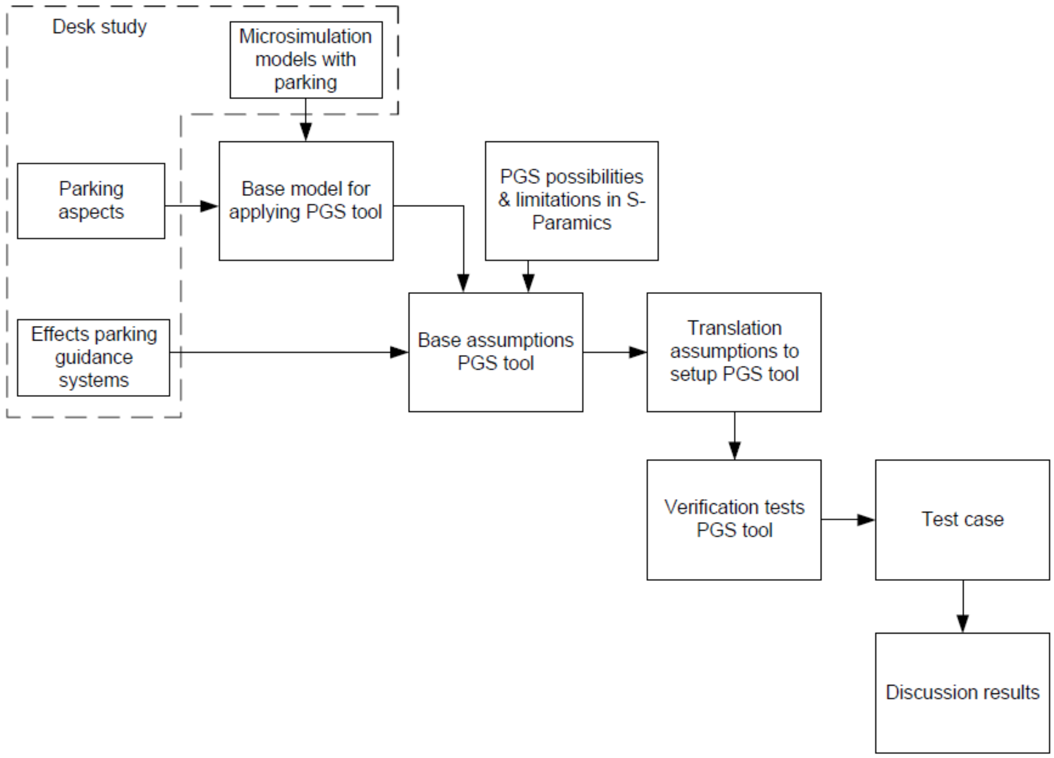


Figure 1-3: Research setup

1.5 Report outline

The different steps of this master thesis are discussed in 6 chapters

- Chapter 2: Parking and parking guidance systems. This chapter discusses the important aspects related to parking and parking guidance systems.
- Chapter 3: Parking traffic in microsimulation traffic models. This chapter discusses the structure of microsimulation models which currently include parking traffic.
- Chapter 4: Development of the PGS tool for S-Paramics. This chapter discusses the input which leads to the base assumptions for the PGS. These assumptions are then translated to the setup of the PGS tool, taking into account the possibilities and limitations of S-Paramics.
- Chapter 5: Verification and testing PGS tool. This chapter describes the verification tests of the PGS tool and tests whether the tool functions as intended.
- Chapter 6: Case study Den Helder. In this chapter the PGS tool is applied to the the model of Den Helder. It is a demonstration of the application of the PGS tool and the possibilities for analyzing the effects are discussed.
- Chapter 7: Discussion and recommendations: In this chapter the final product is discussed and recommendations about the further use of the PGS tool are given.

2 Parking and Parking guidance systems

This chapter discusses the aspects related to parking and PGS and gives an answer to the two research questions:

- *What aspects of parking policies influence the parking behaviour of car drivers?*
- *What is the influence of PGS on driver and parking behaviour?*

It is a summary of a desk study carried out for this master thesis. This chapter contains three subjects which are interlinked to each other as is shown in Figure 2-1.

The three subjects are described in the three sections of this chapter:

- Section 1: gives a brief introduction about parking and the start of parking problems in the past century. Secondly the policy measures of municipalities to reduce the parking problems in inner cities are described.
- Section 2: describes the effects is of measures taken by municipalities. First an overview is given of the car park choice process of car drivers and what aspects play a role in this choice process. These aspects are influenced by policies of municipalities and these influences are briefly described.
- Section 3: gives a brief description of the history of PGS is given. Secondly the reasons for implementing PGS and the setup of PGS's are described. Thirdly the known effects of PGS on the car park choice process of car drivers are discussed.

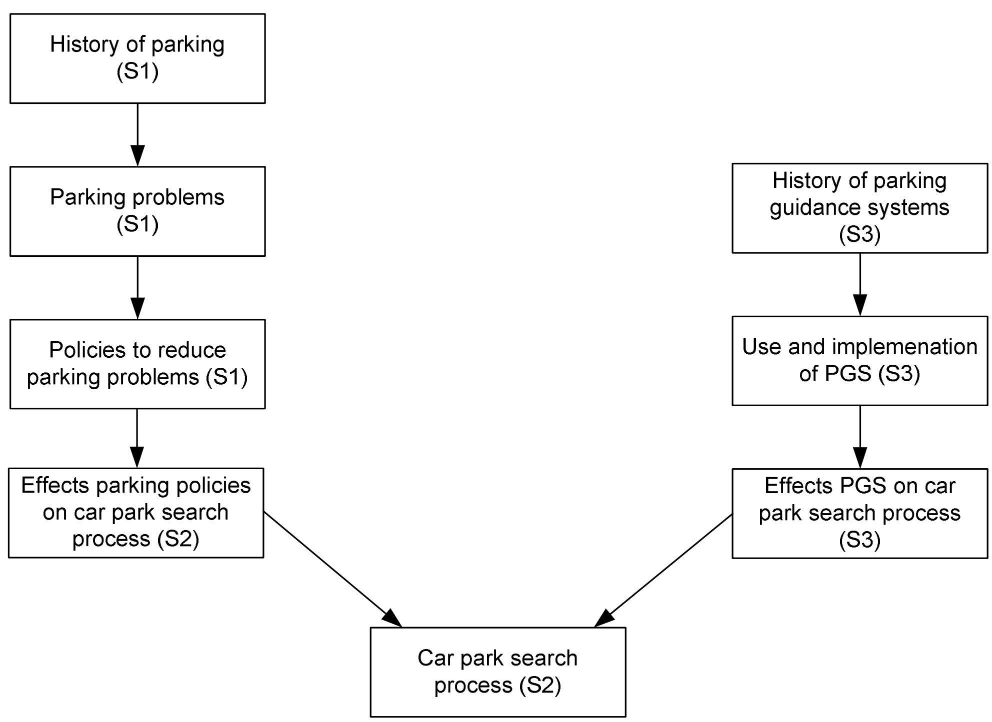


Figure 2-1: Overview structure chapter 2

The next chapter discusses the already available microsimulation models which include parking. Chapter three also describes which of the aspects related to the car park search process are included in these models.

2.1 History of parking and parking policies

Finding a parking space is not just a problem which is faced by car drivers nowadays, but has been a problem in the past century. "*Where shall they park?"* was already the title of United States Conference of Cities in 1928 after parking cars started to obstruct traffic flows. This was a consequence of the growth in car ownership (Holtz Kay, 2001).

The growth in car ownership increased significantly during the 20th century (CBS, 2010). In the 1970s attention rose for the pollution of the environment, as a consequence of population growth, industrialization and depletion of natural resources. Substantial public awareness was created when the Club of Rome published its report Limits to Growth in 1972. This report stated that economic growth could not continue indefinitely, because of the limited amount of resources.

Although the increase in car possession contributed to the depletion of natural resources, most cities expanded their parking infrastructure to facilitate car drivers in inner cities. This facilitation contributed to the increase of congestion in inner cities, which had a negative impact (such as smog) on liveability. During the nineties this was the reason for several cities to redevelop their inner cities (European Commission, 2001).

As a result several Western and Northern European cities started redeveloping their inner cities, in order to regenerate the city centres and create a more sustainable transport system: the city centres were restricted for cars and space was created for pedestrians and cyclists to reduce the environmental impacts of car traffic.

Redeveloping an inner city is a rather radical approach, but since the seventies a switch in the Netherlands is noticed with regards to the facilitation of parking places in city centres. Two main policies for the distribution of parking places can be distinguished:

- A steering parking policy: a policy aiming to reduce car use, by minimizing the amount of parking places;
- A demand following parking policy: a policy aiming to provide the car users with parking spaces where needed, which means that the supply of parking places meets the demand (van Dijken, 2002).

Until the end of the seventies most of the Dutch Municipalities had demand following parking policies, to provide the car drivers with parking spaces. From the mid seventies Dutch municipalities started to apply steering parking policies. This was part of the overall car and mobility policy, which was aiming to minimize the growth in car possession (van Dijken, 2002).

Nowadays municipalities often apply a policy in which a balance between the demand and supply is found. The municipalities try to meet the parking demand and to find an ideal combination between the accessibility and liveability of an area (CROW, 2003).

In the Netherlands the guidelines of the CROW are used to determine the amount of parking spaces, which meets the demand. These guidelines take into account the function of the area and/or building and the location. With these guidelines, municipalities often calculate the minimum and maximum needed amount of parking places. The municipality can then determine the exact number of parking spaces, which is dependable on the available space, parking policy and the revenue generation (Van der Heijde, 2010).

The location and amount of parking spaces are important for the accessibility and liveability of an area, which plays a role for car drivers in determining their final car park and destination area. Parking fees are another important aspect in determining the car park destination and are therefore a powerful policy measure. Nowadays there is still a lot of criticism on paying for parking, since the costs are already high enough for using and driving a car and car users see free parking as a ‘right’. According to a case study of Shoup (1997) parking spaces constructed cost at least $124 per space per month. These costs consist of construction, maintenance and monitoring and are included in this price and are distributed over the whole life cycle of the parking place.

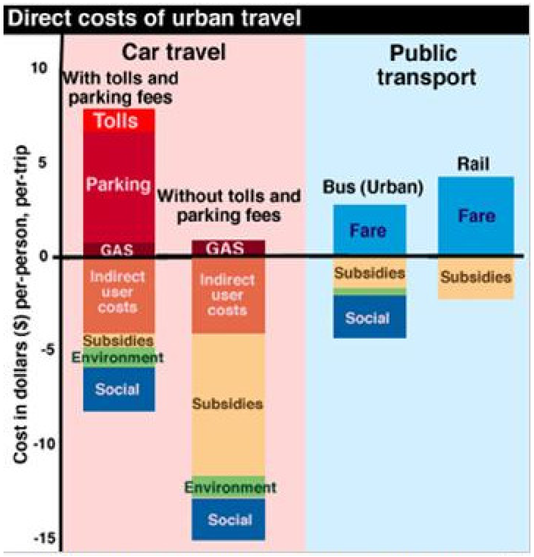


Figure 2-2: The costs of parking (Vuchic, 1999)

Figure 2-2 shows the costs of a car trip compared to a public transport (PT) trip in the United states. The ‘negative costs’ show the costs that are made, but for which the car driver or PT user does not pay. These costs for instance include environmental damage as a consequence of the car trip made. The costs for the parking place are also part of the total trip costs. This figure states that in case parking is free, it is actually subsidized by the government. Van Dijken (2002) concluded that the ‘Dutch taxpayers’ subsidise parking places with 500 Euros per year per parking place.

Parking fees can be a powerful policy measure for municipalities in discouraging car drivers to park at certain location or travel by car at all. In the Netherlands parking tariffs are part of the parking policy and are also influenced by the political ideas of a city council. For instance Amsterdam has the highest tariffs of the Netherlands, because the city aims to reduce the amount of cars in the inner city. The final tariff is also determined by the revenue which it generates. Often municipalities try to find a balance between the occupancy level and the revenue generated for the parking tariff. Ideally the parking lots have occupancy levels close to 90%, so they generate sufficient revenue and there is still space for car drivers searching for a parking place (van der Heijde, 2010).

2.2 Car park search process

Section 1 gives a short introduction to parking policies and how municipalities try to steer the parking demand by determining the location and number of parking places and applying parking fees. This raises the question if and how it influences car drivers in their car park choice. Therefore this section describes the car drivers search process and how different elements influence this search process.

2.2.1 Choices in car park search process

Parking is the final part of a car trip. Several choices have to be made by a car driver to finally chose the parking location. Thompson and Richardson (1996) developed a behavioural search model to investigate driver behaviour and the factors influencing decisions made by drivers searching for a parking place. A simple representation for the search behaviour, as developed by Thompson and Richardson (1996) is shown in Figure 2-3.

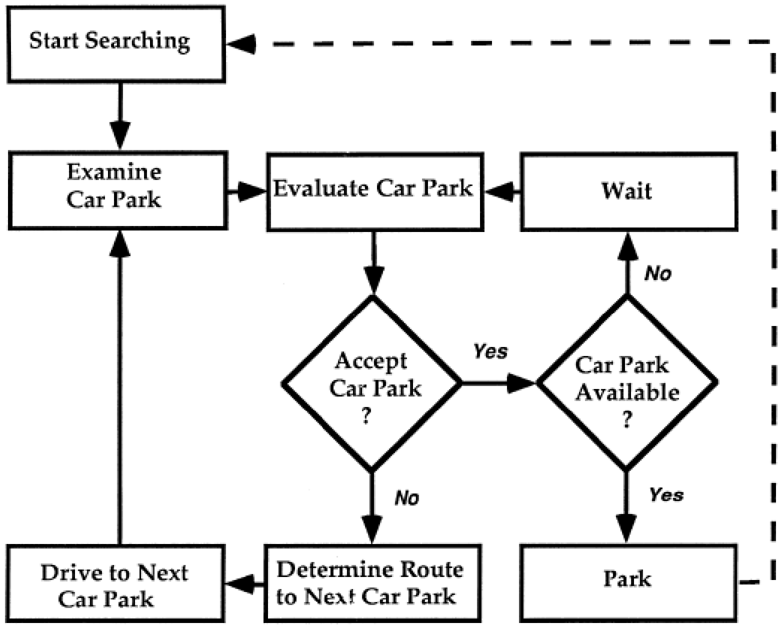


Figure 2-3: behavioural car park search model by Thompson and Richardson (1996)

The factors influencing search and parking behaviour are categorized in three dimensions by Thompson and Richardson (1996) and illustrated in Figure 2-4. The first dimension is 'Access', which contains the two parameters 'In-Vehicle Travel Time' and 'In-Car Park Search Time'. These parameters take into account the time spent travelling to a car park and the time searching for a parking space in a car park. The second dimension 'Waiting' contains the waiting time, which is the queuing time of a vehicle in front of a parking lot or parking space. The third dimension 'Native' contains the parameters related to the usage costs and contains the parking fee, expected fine and the egress (walk) time.

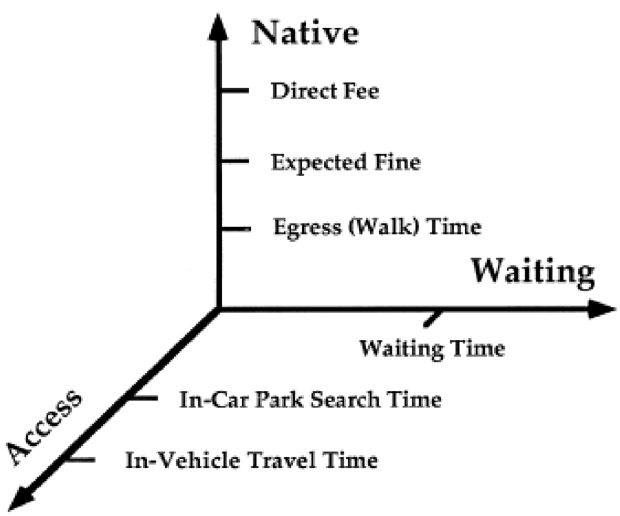


Figure 2-4: Parameters and attributes associated with car parks (Thompson and Richardson, 1996)

In this behavioural model, drivers try to minimize the disutility of using a car park by minimizing the cost factors of Figure 2-4. This means that a trade-off is made between the different cost factors:

- Direct parking fee;
- Expected fine;
- Egress (walk) time;
- Waiting time (queuing time);
- In- car park search time;
- In-vehicle time to car park.

Not much research is carried out to the driver behaviour towards the aspects: expected fine, queuing time and in-car park search time. These aspects are therefore left out of this literature study. The 'in-vehicle time' to the car park is part of the total trip costs and therefore not included in this literature study with regards to parking. This means that the following costs aspects related to parking are summarized in this section:

- Parking fees;
- (Egress) walk time;

2.2.2 Influence of parking fee

Parking fees are an importing factor in managing travel demand, since it can change the parking location and mode selection (Feeney, 1989 and Young 1990). An increase of 10% in parking fees regionally decreases the car usage by 3%, according to Goudappel Coffeng (2001). According to the CROW (2001) there is however a difference per trip motive, for example the car usage for the trip motive shopping barely decreases, in case of an increase in the parking fee.

This is also supported by Vaca and Kuzmyak (2005) who compared several case studies and concluded that the price elasticity of vehicle travel with respect to parking price ranges from –0.1 to –0.3. This means that a 10% increase in parking charges, reduces the amount of vehicle trips by 1% to 3%. The price elasticity however depends on demographic, geographic, travel choice and trip characteristics. If for instance pricing is applied to commuter parking, it is especially effective at reducing peak-period travel.

Besides raising the parking fee, a parking fee can also be introduced. This means that the parking situation shifts from free parking to cost-recovery parking. In case of cost-recovery parking the parking prices reflect the full costs of providing parking facilities. This shift reduces commuter traffic by 10% to 30% (Comsis Corp., 1993 & Hess, 2001).

Hensher and King (2001) however state that priced parking in just one area may simply shift vehicle trips to other locations with little reduction in overall vehicle travel. This was also supported by Gillen (1978) who stated that an increase in parking fees in a central business district (CBD) would lead to a relocation effect to the fringe of the central business district (CBD).

2.2.3 Influence parking location and egress walk time

The location of a car park also has an influence on the car park search behaviour. Drivers try to minimize their travel costs, which means they make a trade-off between the parking fees and the walking distance from the parking place to the destination. Gillen (1978) determined the full price elasticities of parking including the walking distance for a case study. The elasticities are shown in Table 2-1.

Table 2-1: Parking choice elasticities (Gillen, 1978)

Distance from destination	**Elasticity**		
	parking fee	**egress time**	**full costs**
< 1 block	-0.24	-0.53	-0.75
< 2 blocks	-0.35	-0.44	-0.78
< 3 blocks	-0.42	-0.38	-0.80

The table shows that the full costs elasticities are nearly stable. The different elasticities however state that drivers parking close to the destination (< 1 block) are less sensitive to an increase in the parking fee and more sensitive to an increase in the walking distance. While drivers parking further away are more sensitive to an increase in parking fees and less sensitive to an increase in walking distance.

A stated preference survey carried out by Goudkade and Snel (2010) shows that 80% of the car drivers are willing to walk 15 minutes from an alternative parking place, in case the total parking costs are increased by €5. This price difference is only achieved, when car drivers park for a longer period. Car drivers with the trip motive shopping, in general, park for a shorter period. Car drivers with the trip motive work, in general, park for a longer period and seem therefore more likely to reach this price difference of €5. The CROW (1996) also concluded that car drivers are also willing to walk a longer distance, in case their total parking duration increases.

The same stated preference survey of Goudkade and Snel (2010) looked at the willingness to pay for parking for different trip motives. The survey outcomes show that the willingness to pay for parking at more frequent trips, such as shopping at the supermarket, is lower than less frequent trips such as 'going out'.

2.2.4 Trade-off in car park search process

Thompson and Richardson (1996) state that car drivers try to minimize the total disutility of using a car park. The previous sub-sections show that minimizing the disutility in this case, often exists of making a trade-off between the different parking costs.

Based on the maximum distance car drivers are willing to walk, a number of car parks close to their destination can be selected. Subsequently the trade-off is made between the parking fee and the walking distance for the choice in the final parking location.

For the selection of possible car parks the in-vehicle time is also a cost factor in the model of Thomspson and Richardson. Car drivers try to minimize their total travel time and will therefore in the selection process of car parks mainly pick the car parks which they consider as car parks within a reasonable travel time.

The exact trade-off and choice of car park is also determined by the characteristics of a car driver. As shown in the previous sub-sections some drivers are more willing to pay than others. The characteristics which are of importance are the trip motive, trip frequency and parking duration.

2.3 Parking guidance systems

Not only did municipalities use the supply in parking places and parking fees to influence the parking behaviour. Since the seventies also dynamic traffic management measures were implemented. Dynamic route information panels were implemented to provide road users with 'live' information about the situation on the roads and in the parking lots. To inform car drivers about the available parking spaces PGS signs were implemented.

This section describes the several aspects of PGS. First a brief summary of the history of PGS is given. Secondly the reasons for implementing PGS and the setup of the PGS are described. Finally the effects of the implementation of PGS are discussed in the final sub-section.

2.3.1 History of PGS

In The Netherlands the first static PGS's were traffic signs indicating where the nearest parking places are located. Because these 'systems' were static traffic signs, they did not include any information about the available empty parking spaces (Jogems and Spittje, 2005).

In the seventies of the past century the first dynamic PGS's were placed in The Netherlands. These systems were indicating whether the parking spaces were either 'fully occupied' or 'available'. These systems were not used to steer car users, but mainly to inform them (Jogems and Spittje, 2005).

During the nineties a second generation of PGS's was introduced in The Netherlands. Because of a better algorithm and an increase in the calculation capacity of computers, these systems did now show the number of available parking spaces. Besides the number of available parking spaces, also additional information can be displayed on this second generation of parking guidance systems. This can be information such as the opening hours of parking lots and information about the possibilities of public transport from park and ride locations (Jogems and Spittje, 2005).

Figure 2-5 shows the difference between the PGS signs in the seventies and the nineties in Zwolle. The PGS sign shown on the left only shows whether places are available in the car park and where the car park is located. On the right the PGS sign is shown, which also shows the amount of parking places available.

Figure 2-5: PGS signs: left 1970s, right 1990s (sources: Insta.nl & ANWB.nl)

2.3.2 Implementation and setup of PGS by municipalities

Currently most of the larger Dutch Municipalities have parking guidance and information systems in their municipality. Municipalities often distinguish different reasons for implementing the PGS.

Dijkshoorn (2000) interviewed several Dutch municipalities and distinguished five main different reasons for installing parking guidance systems. Below the reasons are mentioned and the percentages show the percentages of municipalities which mentioned the reason:

- More efficient use of parking lots (73%);
- Prevent/reduce the queuing line at the parking lots (33%);
- Reduce amount of 'searching' traffic (20%);
- Steering and guiding traffic (20%);
- Possibility to stimulate the use of public transport (13%).

For instance the municipality of Amsterdam started in 2002 with the 'Integrated Dynamic Parking Guidance systems' (IDP). The aims of these systems were to:

- Steer car drivers who are less familiar with (the infrastructure of) Amsterdam;
- Helping all car drivers in finding an empty car space.

This should overall lead to a reduction of car drivers searching for parking space, which can create dangerous situations on the roads and causes more (unnecessary) emissions.

Part of the IDP are 180 parking guidance panels, showing route information and information about the price and number of available parking spaces. Hereby the Municipality of Amsterdam tries to stimulate car users to park at the Park + Ride facilities at the edges of the city centre. At all the three ring roads (outer ring road A10, city centre ring road S100 and the inner ring road) parking guidance systems guide and try to steer car users to the most nearby parking places. By already doing this on the outer ring road the municipality of Amsterdam tries to encourage car drivers to use the Park + Ride facility and thus let these car drivers use the public transport to the city centre (Sources: Amsterdam.nl and Dienst Infrastructuur Verkeer en Vervoer (2006)).

A slightly different approach is taken by the Municipality of Rotterdam, a city which is known as a more 'car-friendly' city. Their aim is to let car drivers themselves decide where to park and to prevent rat-runs. (Gilbers and Deckers, 2008).

The displays of the newest PGS show the expected numbers of free parking spaces, which the car driver will observe once he/she arrives at the car park (Dijkshoorn, 2000). Lately a new development in the PGS is the use of dynamic route panels. These panels can show different routes to a parking lot, in case roads on other routes are either congested or closed (Gilbers and Deckers, 2008).

Besides the amount of available parking places and the route to the parking lots, also additional information is sometimes displayed. This is shown at the PGS sign in Figure 2-6. This sign also shows the bus frequency (3 times per hour) at the Park + Ride location ("Parkeerbus elke 20m"). Displaying this information could possibly stimulate the use of public transport, which was also one of the reasons mentioned by 13% of the interviewed municipalities by Dijkshoorn (2000).

Figure 2-6: Example of additional information displayed on PGS

One of the reasons mentioned by municipalities for implementing parking guidance systems is to reduce 'searching traffic'. The amount of 'searching traffic' can be substantial; studies however show big differences in this amount. Shoup (2007) made an overview of studies in the past which showed that the percentages of drivers driving around and looking for a parking space could add up to 74%.

Policy documents often state that PGS helps in reducing this amount of searching traffic, but that it unclear what the exact effect is on the traffic performance (Gemeente Gorinchem(2004), Gemeente Ede (2004)). The high costs and the unknown effects of a PGS on the traffic performance is also a reason for smaller municipalities for not installing a parking guidance system. For instance the municipality Ede, a Dutch city with approximately 68.000 inhabitants, decided not to implement a parking guidance system. The costs of the system were estimated at 525.000 Euros, which meant that the parking fees had to be increased to generate more revenues for financing the system (Gemeente Ede, 2004).

2.3.3 Effects of parking guidance systems on drivers car park choice

Although several studies with regards to the response of drivers to parking guidance systems are available, evaluation studies with respect to the effects of parking guidance systems on the traffic performance are limited. Mcdonald and Chatterjee (2000) state that the effect of parking guidance systems is more significant in places where the parking demand is higher. The surveys held in Southampton showed that the average search time for a parking place was reduced from 2.2 minutes to 1.1 minute as a consequence of the parking guidance system.

Similar studies with regards to Dutch municipalities are not found. Dijkshoorn (2000) already concluded that there barely had been any evaluations of the implementation of parking guidance systems, regardless of the high costs of the implementation.
Evaluating the effect of parking guidance systems is however hard. It is hard to proof that changes in the traffic performance are the result of just the parking guidance systems, while multiple factors can contribute to this improvement of the traffic performance.

Therefore this sub-section focuses on the results of field studies, which interviewed car drivers and asked them about their response to the displayed information on the PGS signs.

<u>Influence of PGS on car park choice process</u>
Thompson and Richardson (1996) state that the estimation of the parameters is in some cases subjective and based on perceptions formed by drivers. The perception is formed by the initial perception, observations during previous trips and observations made during the current trip.

The perception during the current trip is influenced by the PGS signs. As shown in Figure 2-7, the PGS sign influences the information about the available parking places at an earlier time, than at the entrance of the car park.

Using this model the car drivers still has two options in case he or she notices the PGS and his/her car park is full. The question now is:

- Will the car driver drive to the full car park?; or
- Will the car driver drive to an alternative car park?.

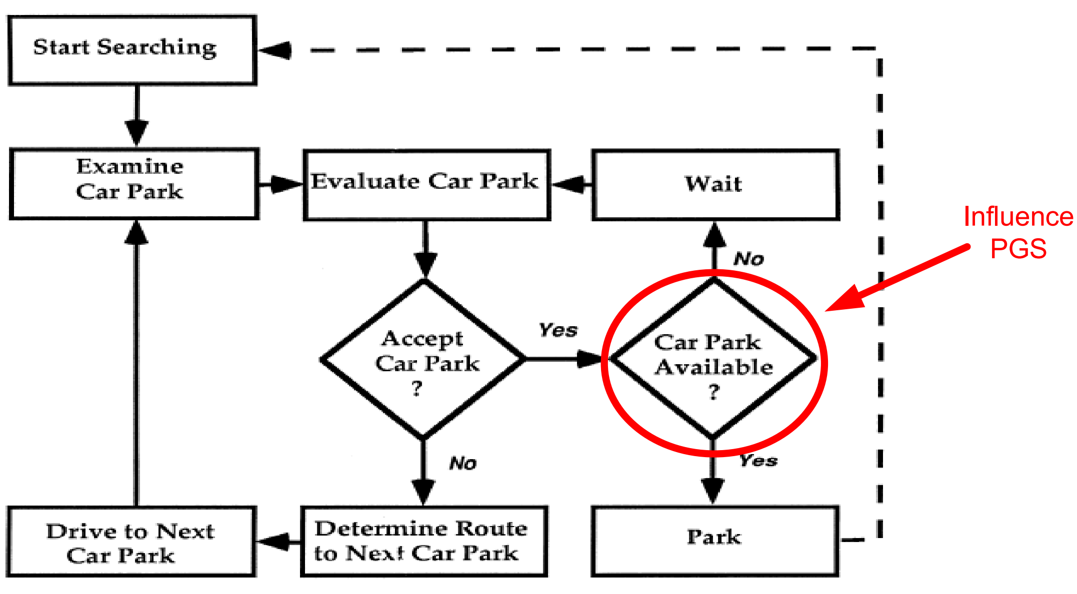


Figure 2-7: behavioural car park search model by Thompson and Richardson (1996)

<u>Field study results: Effects of PGS on car park choice</u>
The extent to which PGS influences driver behaviour was subject of several field studies. Figure 2-8 and Figure 2-9 show an overview of the outcomes of five different field studies with regards to parking guidance systems and the amount of drivers using the systems. For these field studies surveys were held among car drivers, who parked at car park which were linked to a PGS. The figures show an overview of:

- the percentage of car drivers noticing the PGS sign;
- the percentage of car drivers changing their car park destination, because the PGS sign displayed that their 'original' car park destination was full.

These percentages are the percentages of the total amount of car drivers. E.g. in the case of Rotterdam and The Hague 71% of the total amount of car drivers noticed the PGS sign and 15% of the total amount of car drivers changed their parking location, because the PGS sign displayed that their 'original' car park destination was full.

Five field studies of two Japanese and three European cities are compared. These are the cities:

- Frankfurt (Germany – Europe; Axhausen, Polak, Boltze and Puzicha (1994));
- Utsunomiya (Japan – Asia; Thompson, Takada and Kobayakawa (1999));
- Southampton (England – Europe; Mcdonald and Chatterjee (2000));
- Shinjuku (Japan – Asia; Thompson, Takada and Kobayakawa (1999));
- The Hague and Rotterdam (The Netherlands – Europe; Dijkshoorn (2000)).

The outcomes of the five different studies show comparable results. For weekdays the amount of drivers changing their parking location, based on the PGS information (which displayed that their 'original' car park was full) is ranging from 10% to 16% and on Sundays from 15% to 18%.

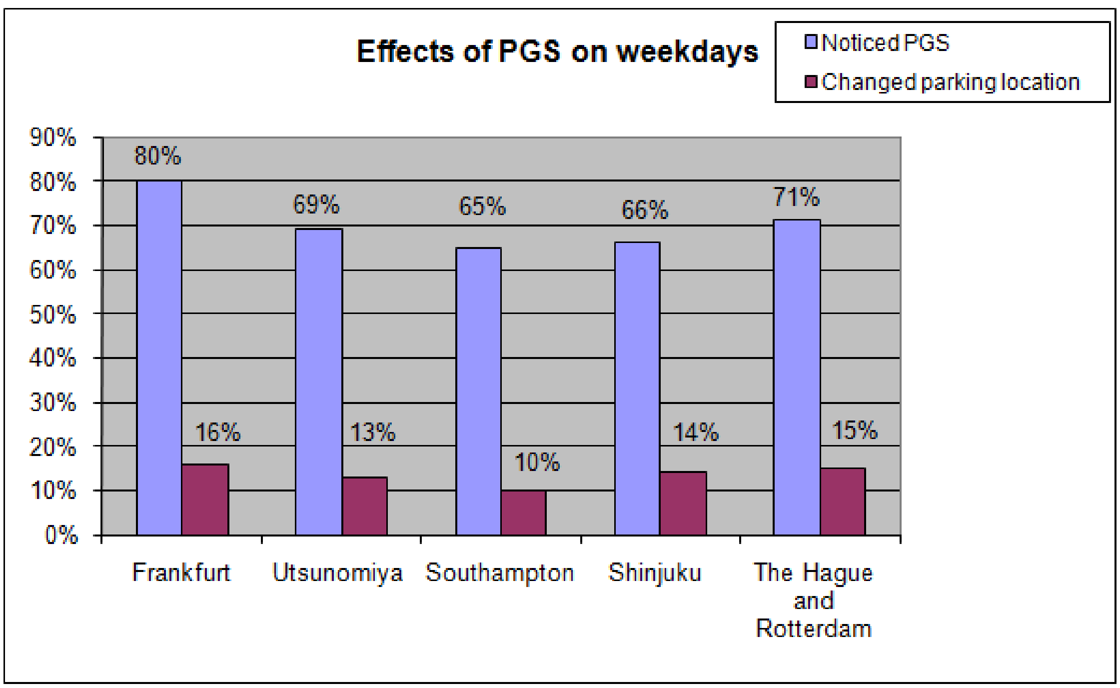


Figure 2-8: Effects of PGS on weekdays

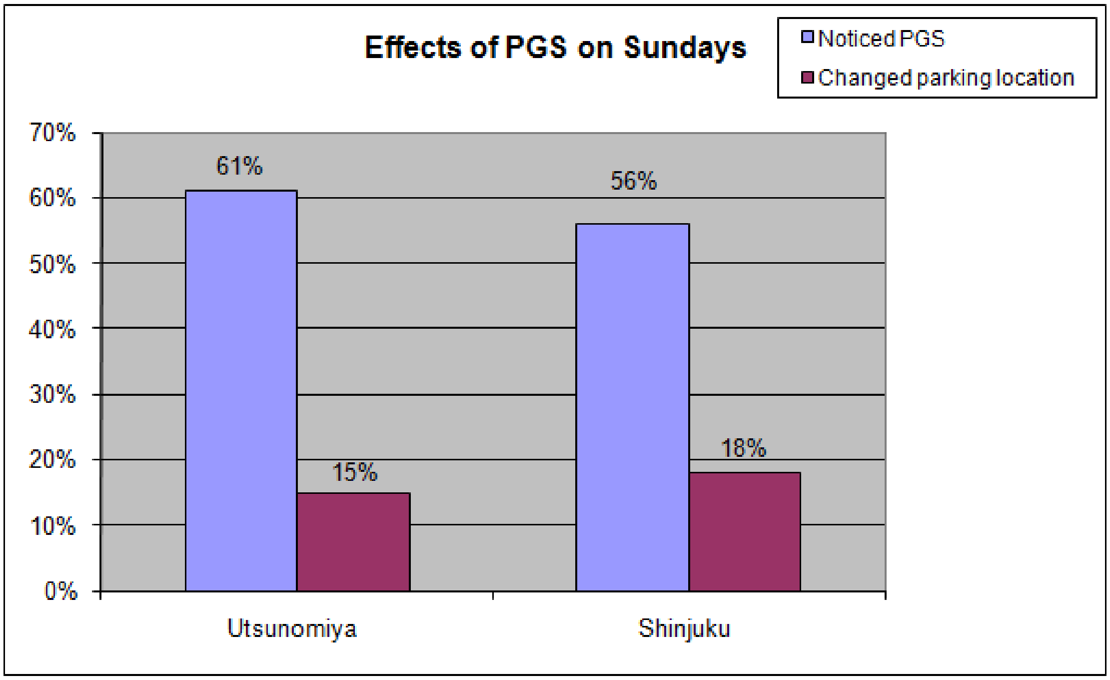


Figure 2-9: Effects of PGS on Sundays

This difference between the effect on weekdays and Sundays can be explained by the composition of the traffic of both days. Different researches (Mcdonald and Chatterjee (2000), Thompson et al. (1999), Dijkshoorn (2000)) investigated the relationship between car driver characteristics and the use of PGS. It was found that:

- Car drivers who make the trip on a low frequent basis notice the PGS signs less often, than car drivers who make the trip on a frequent basis;
- Car drivers who make the trip on a low frequent basis change their parking location based on the PGS information more often, than car drivers who make the trip on a frequent basis;
- Car drivers who are less familiar with the destination area are more likely to use the PGS information displayed, than car drivers who are familiar with the destination area.

This can be illustrated by some of the outcomes of these studies:

- Southampton: 2% of regular visitors changed parking location, while 28% of irregular visitors changed parking location after they saw that their original parking destination was full (Mcdonald and Chatterjee, 2000);
- Shinjuku: The percentage of drivers changing their parking location based on the PGS information on Sundays was related to trip motive, frequency and origin. PGS was more used by non frequent visiting, shopping traffic from nearby municipalities (Thompson et al. 1999);
- The Hague and Rotterdam: The PGS information is mainly used by non-frequent visitors of the area. The habitual behaviour of frequent visitors was barely influenced by the PGS (Dijkshoorn, 2000).

The studies which compared Sundays with weekdays concluded that:

- On Sundays there is a higher share in the traffic composition of car drivers who make their trip on a non-frequent basis and are less familiar with the neighbourhood;
- This difference in traffic composition leads to:
    - A higher percentage of the car drivers on weekdays notices the PGS signs, than on Sundays;

- ° A higher percentage of the car drivers changes their parking location based on the displayed PGS information on Sundays, than on weekdays.

One study which found significant different numbers, is a survey carried out in Valencia (Spain). The survey was carried out among 600 car users and found that 89% of the drivers noticed the parking guidance systems in Valencia and about 30% used the information (Mcdonald and Chatterjee, 2000). The survey questions were however formulated different for this particular survey. The percentage of 30% 'using' the information also includes the car drivers who 'use' the information as a confirmation of their car park choice. E.g. a car driver has car park A as destination and sees that car park A still has enough spaces free on the PGS sign.

<u>Reasons for not using the displayed information by car drivers</u>
What might be surprising is the high amount of car drivers who do change their car park location, once it shows that their 'original' destination car park is full. Three main reasons can be distinguished for car drivers not using the displayed information.

- The first reason is already shown in the percentages and is the fact that 20% to 35% of the car drivers do not notice the PGS signs.
- Secondly not all drivers attach high credibility to the information displayed. For instance Dijkshoorn (2000) concluded that for one of the parking lots, the displayed information on the PGS did not match the reality for a high percentage of the car drivers (49%). In most cases the PGS stated that the parking lot was full, while there were still parking places available when the drivers arrived. This experience can withhold car drivers in future situations to use the information of parking guidance systems.
- Thirdly car parks in shopping areas (especially with supermarkets) have high turnovers. Car drivers who are familiar with the parking facility know that due to the high turnover the queuing time is relatively short. The car drivers are willing to wait this short time to finally park at their first choice location.

<u>The way the information is used by the car drivers</u>
How the information displayed on the PGS signs is used by the car drivers is location specific. The different researches mentioned in this section state that the car drivers use the information to drive to an alternative car park.
There is however not much found in the field studies about this exact choice of this alternative car park. The research of Thompson et al. (1999) states that the alternative car park is in most cases a car park in the same destination zone close to their original car park.

<u>Increase in use of PGS information in future?</u>
A new development is the addition of parking guidance systems to in-car navigation systems. Q-park is one of the private operators of car parks in The Netherlands, which currently developed applications for (smart phone) navigation systems for parking guidance. Currently the Municipality of Maastricht is carrying out a pilot, providing the PGS data to the navigation systems. The in-car system then automatically changes the parking destination, once the original car park destination is full (Verkeersnet, 2010).
This might increase the PGS following percentage, since drivers are more likely to follow in-car navigation systems. In The Netherlands about 20% to 25% of the cars have a navigation system installed in 2009. 95% of the car drivers use the navigations for trips to destinations with which the drivers are unfamiliar. About 60% used the navigation system to destination with which they were familiar (SWOV, 2009). In case the parking guidance system application is linked to this navigation system, the overall follow up percentage of PGS is likely to increase.

2.4 Summary

This chapter briefly summarizes the desk study carried out for this master thesis. First it gives a brief introduction to parking, how parking problems started and how municipalities try to reduce these problems.
The effect of the policy measures implemented by municipalities is described in the second section. In this section the car park choice by car drivers is also described. The final choice in a car park is mainly determined by the travel time to the car park, the egress walk time from the car park to the destination and the parking fee. The location of car parks and the parking fees can be influenced by municipalities. Car drivers finally make the trade-off between the different aspects in choosing a parking destination.

Whether or not a car park is available also plays a role in choosing a car park. Car drivers however only know this once they arrive at a car park or when they pass a PGS sign. Therefore the third section focuses on the effects of PGS. It was concluded that about 15% to 18% of the car drivers change their car park destination, in case they see that their first car park choice is full on a PGS sign. The information displayed on a PGS sign was mainly used to change the parking location by non frequent visiting, shopping traffic from nearby municipalities.

Now that an insight is gain in the car park choice process of car drivers, the next chapter discusses the available microsimulation models, which include parking.

3 Parking traffic in microsimulation traffic models

Chapter 2 discussed the aspects of parking and parking guidance systems. Different microsimulation models have implemented the aspects of parking. This chapter gives a short overview of microsimulation models which include parking and answers the question:

- *Which S-Paramics models including parking behaviour are available?*

To reach answer this question three steps can be distinguished in this chapter.

- Section 1: gives a brief summary of the structure of traffic and transport models and in particular microsimulation models.
- Section 2: analyses the available microsimulation models which include parking.
- Section 3: compares parking microsimulation models with 'regular' microsimulation models. This leads to an overview of the additional elements of microsimulation models which include parking.

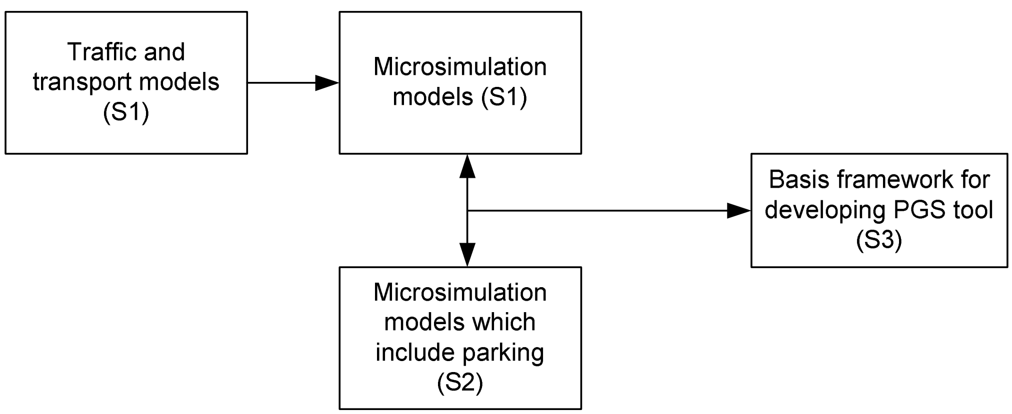


Figure 3-1: Overview structure chapter 3

The final objective of this master thesis is to develop a PGS tool which can be applied to microsimulation models which include parking. To develop the PGS tool, it is of importance to gain an insight in the basis which already exists for microsimulation models including parking. Therefore this chapter results in an overview (framework) which is used as the basis for the development of the PGS tool in the chapter 4.

3.1 Microsimulation traffic and transport models

Transport models are used to predict the future traffic situation, or the expected traffic situation in case infrastructural changes are made. The first transport modelling techniques originate from the 1960s. The structure used for transport models in the 1960s is however still used nowadays. Many transport models are derived from the classic four-stage model, which is shown in Figure 3-2 (Ortúzar & Willumsen, 2002).

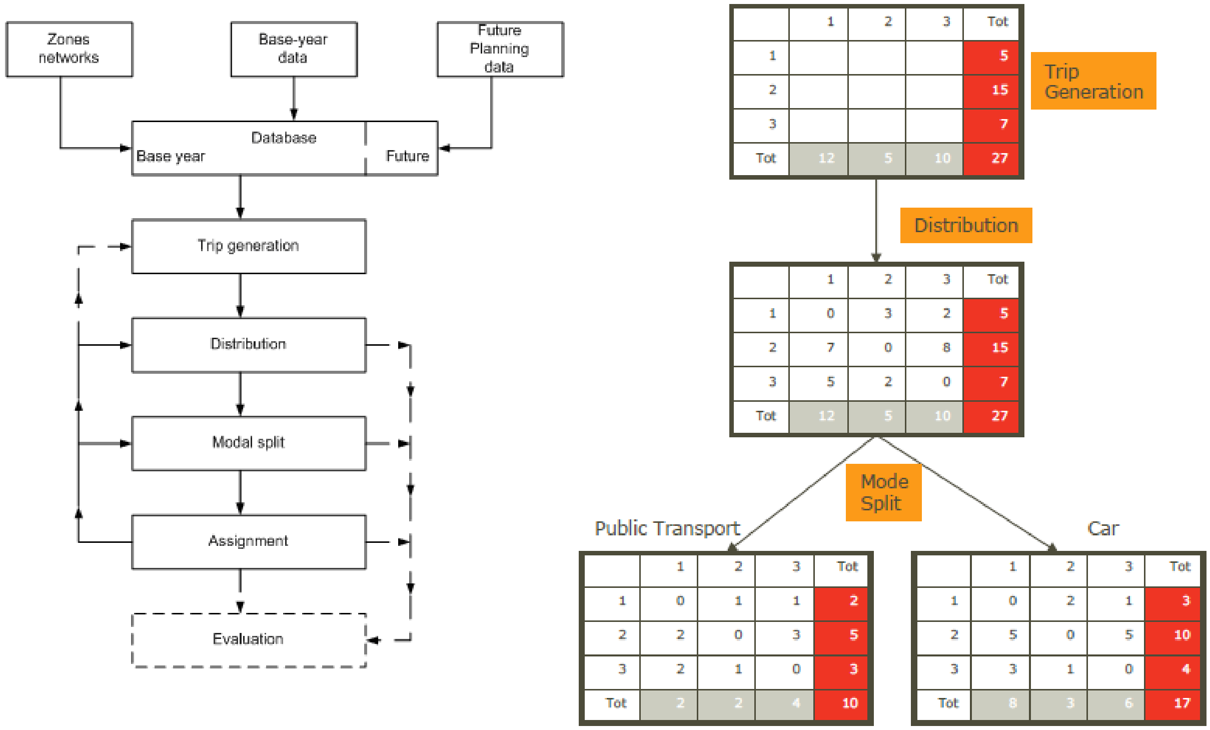


Figure 3-2: Classic four-stage model (Ortúzar & Willumsen, 2002; Allen, J. 2009)

The first step in this four-stage model is to collect data and the networks of an area. The network is divided in zones, which represent a smaller part of the area. The gathered data includes population numbers, economical activities (employment, shopping space, educational and recreational facilities). Once this data is gathered four steps are undertaken:

- Trip generation: the data gathered is used to determine the total number of trips generated and attracted by each zone in the network;
- Trip distribution: the allocation of the trips to particular destinations to produce a trip matrix;
- Modal split: the allocation of the trip matrix to different transport modes;
- Assignment: The assignment of each trip to the corresponding networks (Ortúzar & Willumsen, 2002).

When these steps are carried out an overview is gain of the expected traffic flows on a network. The scope of the model and the level of detail can however differ. Three scales for traffic and transport modelling are often distinguished:

- Microscopic simulation: Microsimulation is the dynamic and stochastic modelling of individual vehicle movements. Within a transport network each vehicle is moved according to the physical characteristics of the vehicle (e.g. length, max speed, etc.), the fundamental rules of motion (e.g. velocity times time equals distance, etc.) and the rules of driver behaviour (lane changing, etc.). The cumulative effect of these single vehicles represent the flows on a network.
- Macroscopic simulation models: Macroscopic models simulate traffic flows, instead of single vehicles. The flows are simulated taking into consideration cumulative traffic stream characteristics (speed, flow and density) and their relationships to each

other. In contrary to microsimulation models, macroscopic models cannot model the interactions of vehicles on alternative design configurations.

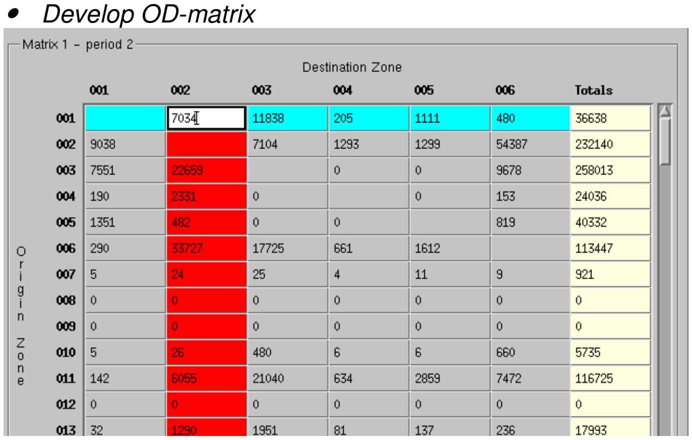
- Mesoscopic simulation models: Mesoscopic models combine the properties of both microscopic and macroscopic simulation models. Individual vehicles are modelled, but describe their activities and interactions based on aggregate macroscopic relationships (SIAS (2009) and Caltrans (2008)).

This master thesis focuses on the use of dynamic microscopic road traffic simulation software, In a microsimulation model roughly three different phases can be distinguished:

- *Model network setup*

In a microsimulation model the network of an area is built. The network consists of the road network and includes the roads which are considered of importance for the study area. Part of the building of the network is also the allocation of the cost factors to the roads. Zones are added to the road network and function as origin and destination zones. The zones represent a smaller area of the total modelled area.

- *Develop OD-matrix*



Matrix 1 – period 2

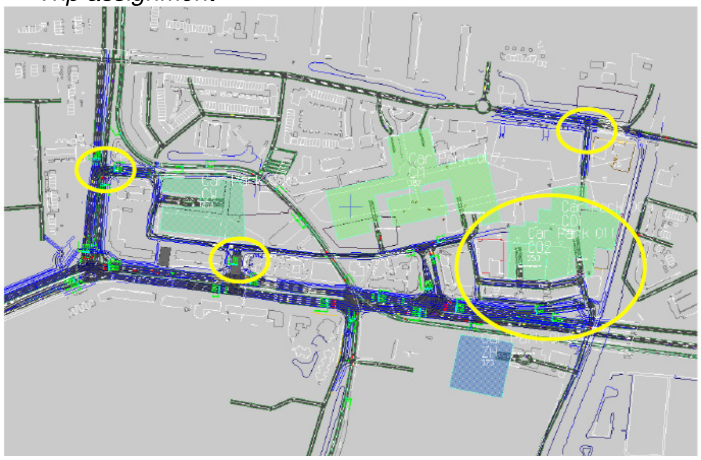
Destination Zone

Origin Zone

	001	002	003	004	005	006	Totals
001		7034	11838	205	1111	480	36638
002	9038		7104	1293	1299	54387	232140
003	7551	22659		0	0	9678	258013
004	190	2331	0		0	153	24036
005	1351	482	0	0		819	40332
006	290	33727	17725	661	1612		113447
007	5	24	25	4	11	9	921
008	0	0	0	0	0	0	0
009	0	0	0	0	0	0	0
010	5	26	480	6	6	660	5735
011	142	6055	21040	634	2859	7472	116725
012	0	0	0	0	0	0	0
013	32	1290	1951	81	137	236	17993

The macroscopic models use the classic four stage model to develop an OD-matrix and assign the trips to the network. Microsimulation models do however not include all the four stages of this classic four stage model. The OD-matrix of a microsimulation model is often derived from an OD-matrix of a macroscopic traffic model and adjusted in the calibration process.

- *Trip assignment*



In road traffic microsimulation software single vehicles are released onto the network. The cumulative effect of these vehicles represent the traffic flows on the network. The number of vehicles released on the network is determined in the OD-matrix. In the assignment stage it is determined how vehicles route through the network. The route chosen is based on the lowest costs for the single vehicle, taking various costs into account (SIAS, 2009).

3.2 Microsimulation models with parking traffic

The majority of microsimulation models do not include parking traffic. In these models vehicles 'disappear' from the network once they have reached the destination zone. In case car parks are added to a modelled network, drivers park in a car park linked to their destination zone. Still the vehicle will 'disappear' in the car park, but will however not be able to enter ('disappear" in) the car park once it is full. There are several examples of microsimulation models which include car parks and the car park choice.

This section discusses one example of a VISSIM model which included parking and parking guidance systems and three examples of S-Paramics models which included parking. Examples of these cases are the models developed for the municipalities of Rochdale, Takapuna and Nieuwegein.

3.2.1 Parking and parking guidance systems modelled in VISSIM

Schipper (2001) investigated the possibilities and options for modelling parking traffic and parking guidance systems for the road traffic microsimulation software VISSIM. Schipper used a case study to test several options of modelling the parking behaviour. In this case study a differentiation was made per trip motive in the OD-matrix. A different search profile was attached to every trip motive. For instance commuter traffic had already determined their parking location pre-trip, while cars making leisure trips would travel to the destination zone and chose the car park while they were close to the location. The outcomes of the model showed significant differences with the actual data. The major shortcomings of VISSIM (in version 3.50) were:

- There was no possibility of setting an entrance capacity (maximum of cars that can enter the car park per hour). Car parks with a barrier at the entrance have a lower entrance capacity, but this could not be set. Therefore the modelled queue could be lower, than the actual queue;
- VISSIM first determined which car park would be used per car driver, based on the car park costs, and then determined the route to the car park. VISSIM did not include the car park choice as a part of the total trip choice;
- There was no possibility for displaying information of multiple car parks on one variable message signs.

Not only did VISSIM have shortcomings, but also assumptions made about the behaviour of car drivers lead to significant differences in the modelled outcomes and reality, according to Schipper (2001). Besides the limitations of VISSIM, the structural the errors between the model and the reality were caused by:

- The ‘return trip’ of parking traffic was not based on the arrival time and parking duration;
- The influence of PGS on drivers was not known exactly and an assumption was used.

Based on the differences between the model results and the reality Schipper (2001) stated that the model could not be used to estimate the amount of search traffic and the queues in front of car parks. To improve the model predictions Schipper (2001) formulated the following recommendations:

- Include the cost factors of car parks within the total trip cost equation for the car park choice in the model;
- Change the settings of the variable message signs (VMS): link the VMS to destination zone, show information of different car parks on one VMS;
- Gain more insight in the effect and response to parking guidance systems, to model the effect properly.

This research was carried out in 2001 and the software of VISSIM has been updated. Therefore not all shortcomings are still the case in the current VISSIM software. The car park choice however still is not part of the total trip costs equation, but is determined pre-trip.

3.2.2 Parking traffic modelled in S-Paramics

Examples of S-Paramics models which include car parks are the models developed for the municipalities of Rochdale, Takapuna and Nieuwegein.

The microsimulation models of Rochdale, Takapuna and Nieuwegein focus on the effects of the urban planning and development of the next years. The cities are expanding and the microsimulation models were used to study the effect of the different locations of the car parks (Sykes et al, 2010).

In the case of Rochdale different OD-matrices were generated. Matrix segmentation per trip motive was used, because not all car drivers have the same preferences or behavioural aspects. Different matrices were derived for the car categories of commuters, non-commuters and work. The matrix segmentation was used to reflect parking policies, by applying parking prices and restrictions to a particular group of car drivers (Sykes et al. 2010).

In S-Paramics the ‘generalized cost equation’ (GCE) is used for the assignment of vehicles to the network. This cost equation includes the travel time, distance travelled and a toll coefficient. The model of Takapuna also included the car park charges and walk time from the car parks to the destination zones as a component of the generalized trip costs. In case a car park was full when a vehicle arrived, the vehicles would wait for a pre-defined time before assessing whether or not to drive to another car park (Sykes et al. 2010).

The parking durations and the modelling of the ‘return-trip’ is something which was modelled differently in the three models. For Takapuna the release profile of the ‘return-trips’ of car parks was derived from the morning peak occupancy numbers. For Nieuwegein an external controller was used to detect parking cars and assigned a release time to the cars. The ‘return-trips’ were therefore removed from the OD-matrix. The model of Rochdale influenced the choice of car park for departure by adding an exit cost of the car parks.

The model of Rochdale also dealt with the driver perception. The driver perception in real life is influenced by experiences during previous trips. For instance: The trip costs to a smaller car park might be lower, but experiences from the past could teach drivers that this car park is almost always full. In a model car drivers will first drive to this smaller car park to minimize their travel costs and then reroute when the driver finds out the car park is full. In reality drivers often know this car park is often full and will automatically drive to the car park of second choice. The developers of this model used two solutions for this problem. The first solution was using a car park availability controller to overwrite the driver's first choice. Secondly they grouped smaller car parks into one car park, to avoid this problem (Sykes et al. 2010).

3.2.3 Elements of car park search process in microsimulation models

When the car park search model of Thompson and Richardson (1996) is compared to the S-Paramics models discussed in this section the following similarities are found:

- The additional cost factors included in the microsimulation model are 'egress walk time', the 'parking fee' and the ' waiting time';
- The 'in-vehicle time' is included in the GCE of the microsimulation models;
- The microsimulation models include the different cost aspects and drivers in the model try to minimize the total trip costs;
- Different sensitivities and parking durations for different trip motives are used in the microsimulation models.

Therefore it is concluded that the S-Paramics models cover the most important aspects of the car park search process and can function as the basis for developing the PGS tool.

3.3 Base for developing the PGS tool

This chapter described several microsimulation models which include parking traffic. The models discussed in this chapter show comparable structures. Several aspects are added to a 'regular' microsimulation model without car parks.

By the developers of the different models it was stated that in order to model parking behaviour, a lot of input data are needed. As the setup shows the modelling is more in-depth and detailed, than 'regular' microsimulation models. For the calibration of these models car park data was necessary.

Using the simplified three phases of the S-Paramics microsimulation models, the additional elements can be put in the following phases:

- Model setup: the additional infrastructure (car parks) and the additional cost factors of this infrastructure (parking fee, queuing time and egress walk time);
- OD-matrix development: Segmentated OD-matrices based on trip motive with different sensitivities to cost factors;
- Trip assignment: the influence of additional cost factors on the route choice.

This is illustrated in Figure 3-3.

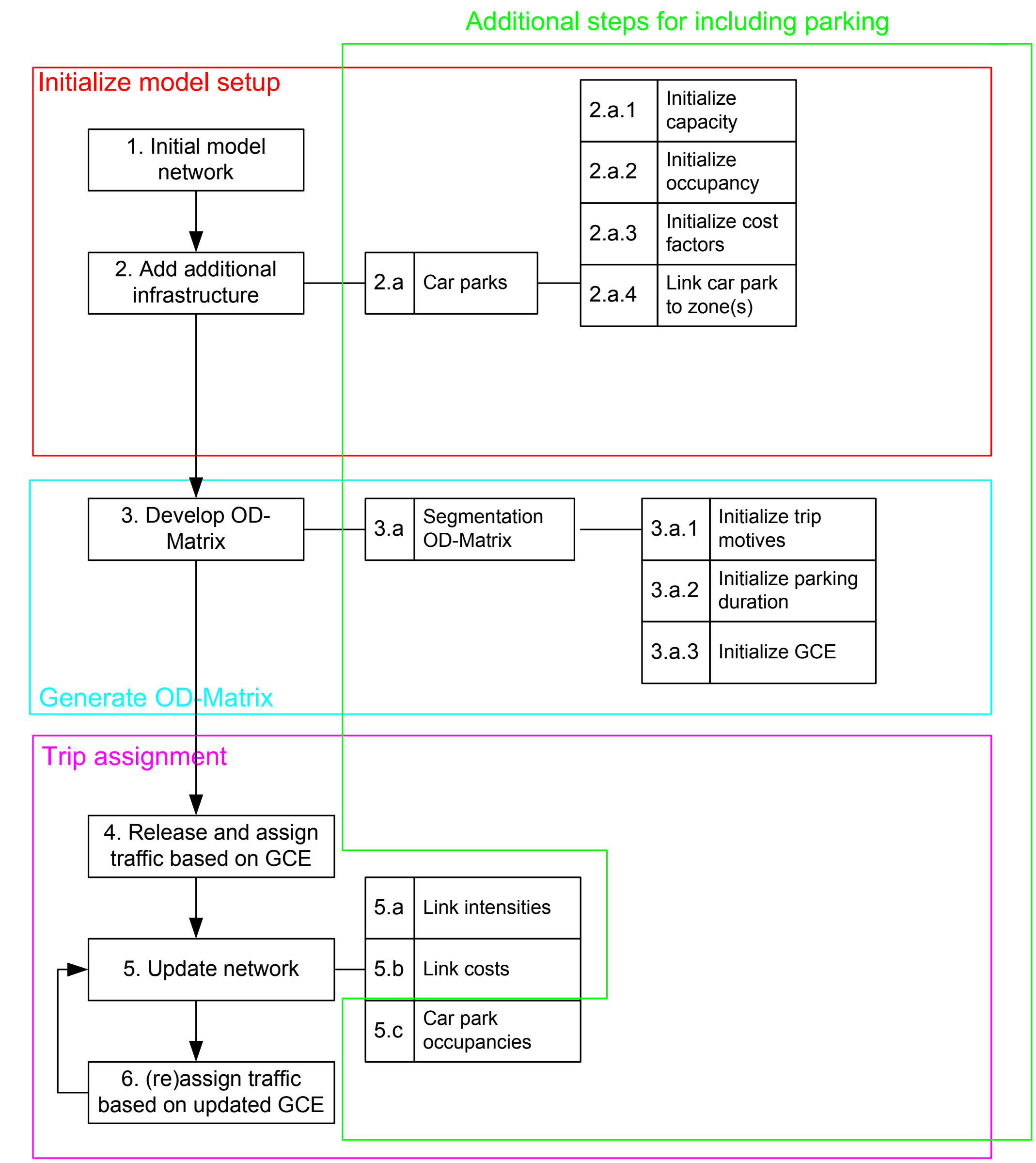


Figure 3-3: Overview additional steps including parking in microsimulation models

3.4 Summary

This chapter discussed the available traffic and transport models and particularly microsimulation models which include parking. Case studies with regards to parking are carried out with the microsimulation software VISSIM and S-Paramics. The VISSIM software showed several shortcomings, while the S-Paramics was used successfully to model parking behaviour. The elements included in these S-Paramics models match well with the car park search model of Thompson et al. (1998), which is discussed in chapter 2.

Therefore the S-Paramics models are taken as a basis for the development of the PGS tool. This basis is illustrated in a simple framework as is shown in Figure 3-3. This figure gives an overview of the additional steps which are undertaken in models which include parking. For the development of the PGS tool it is important to fit the tool within the framework.

The next chapter will discuss the development of the PGS tool.

4 Development of the PGS tool for S-Paramics

Chapter 3 gives an overview of the microsimulation models which include parking. This chapter describes the process of developing the PGS tool and deals with the research questions:

- *What are the possibilities for modelling the effects of PGS to microsimulation models?*
- *What are the possibilities and limitations of S-Paramics with regards to modelling PGS?*
- *How can the effects of PGS on driver behaviour be modelled, taking into account the possibilities and limitations of S-Paramics?*

The development of the PGS tool is carried out in five steps, which are described in different sections:

- Section 1: describes with the possibilities for the addition of a PGS tool in the current S-Paramics microsimulation models with parking.
- Section 2: describes the possibilities and limitations with regards to modelling PGS in S-Paramics.
- Section 3: describes the outcomes of the literature study with regards to effects of PGS. The outcomes of the literature study and the possibilities and limitations of S-paramics are used to define the base assumptions of the PGS tool.
- Section 4: describes the translation of these base assumptions to a functional PGS tool.
- Section 5: describes the location specific input which is needed for the PGS tool.

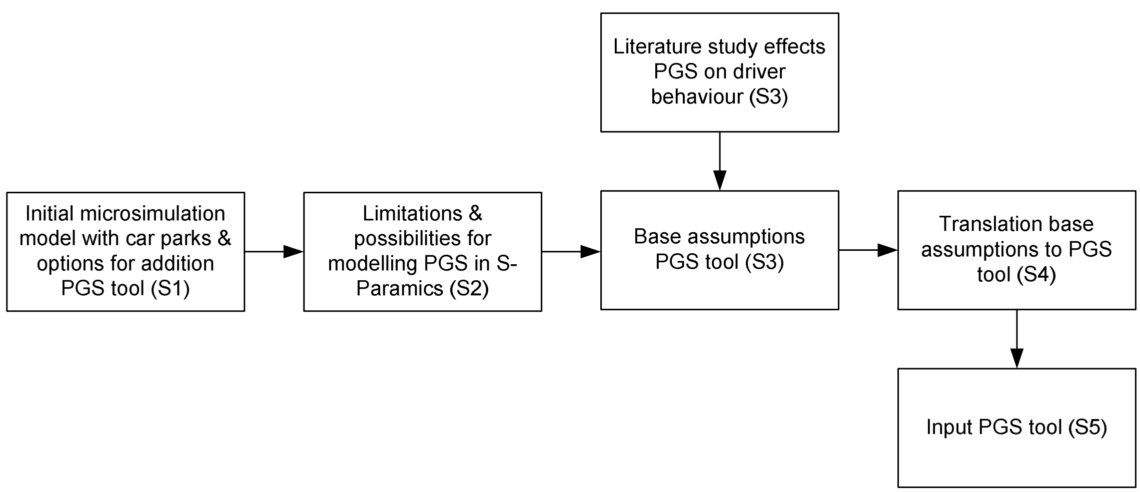


Figure 4-1: Overview structure chapter 4

The final outcome of this chapter is an overview of the intended functioning of the PGS tool. Chapter 5 verifies the functioning of the developed PGS tool by carrying out verification test runs.

4.1 Basis for developing the PGS tool

To model the effect of PGS on driver behaviour and thus eventually the traffic performance, different modelling approaches can be used.

For this master thesis the choice is to use the microsimulation software S-Paramics to model the effect of parking guidance systems. Microsimulation software is a network-based approach. The main reasons for choosing S-Paramics microsimulation software to model this effect are:

- A substantial amount of municipalities have S-Paramics traffic models available, so the PGS tool can be easily implemented;
- Grontmij does have extensive experience with S-Paramics, which can be used for developing the tool;
- It is relatively easy to edit parameters and write codes with regards to parking guidance systems in S-Paramics and the additional software.

The choice for using S-Paramics also brings some limitations, which will be discussed in section 2.

The PGS tool is an addition to the current microsimulation models which include car parks. The previous chapter described available models which include car parks. These microsimulation models serve as a basis for the addition of the PGS tool. The options and possibilities for the addition of the PGS tool are shown in Figure 4-2. Two parts of the PGS tool can be distinguished:

- The infrastructural addition in a microsimulation model;
- The influence on the trip assignment by the PGS tool.

Both aspects will be discussed in section 3.

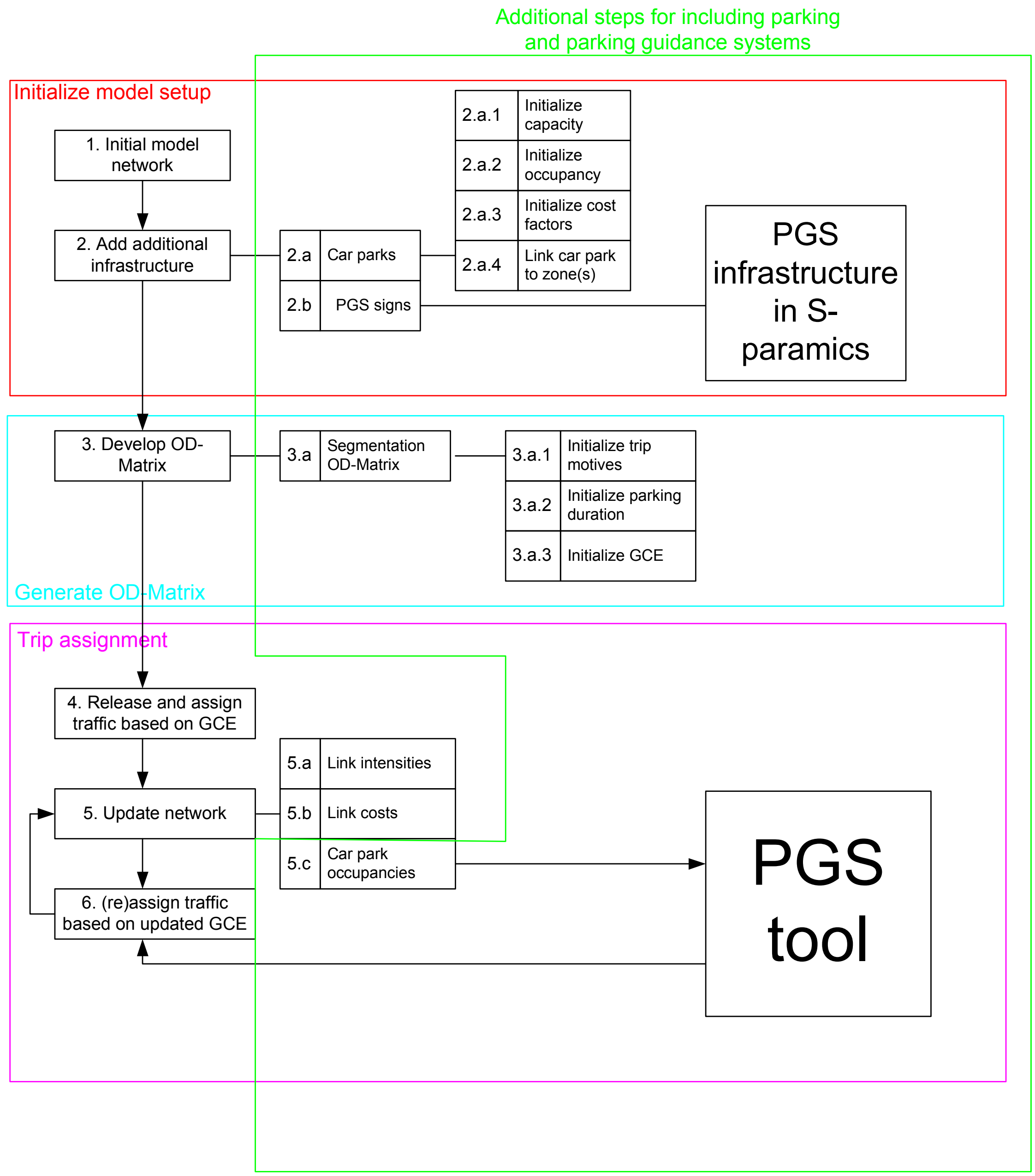


Figure 4-2: microsimulation models with car parks and the option for PGS

4.2 Possibilities and limitations for modelling PGS in S-Paramics

Two aspects of the addition of the PGS tool to a model network can be distinguished:

- The addition of pgs signs to an existing network;
- The effect of the PGS tool on trip assignment.

Both aspects are described in the two sub-sections.

4.2.1 Addition of PGS signs to an existing network

In S-Paramics there is no software yet for modelling PGS. The software does however have the possibility to add ITS controllers to an existing network. ITS controllers can represent different type of variable message signs (VMS). The location at which the ITS controllers are added to a network, are the locations at which behaviour is influenced within the model. This ‘influence’ has to be defined in external software.

4.2.2 Modelling influence PGS on trip assignment

In S-Paramics the car park choice is based on the total trip costs, which every car drivers tries to minimize. The total trip costs are determined by the GCE, in which the travel time, travel distance and possible toll costs are included. The number of available parking spaces is not part of this equation. This means that within standard S-Paramics software PGS cannot influence the car park choice based on the GCE.

In S-Paramics the ITS controller can change the behaviour of passing cars. The exact programming for this ITS controller has to be done in external software. S-Paramics has a limited amount of possibilities which can be programmed for the ITS controllers. These are:

- Change in behaviour: cars passing an ITS controller can be instructed to change their behaviour, this can be: change in maximum speed, lane changing, changing in route to destination and change in car park choice.
- Response settings: Which vehicles will comply with this change in behaviour? Vehicles which do follow the behaviour change instructions can be selected based on their destination zone, destination car park, vehicle type and a response percentage.

A time step can be set in the external software for ‘pausing-continuing’ a simulation run. While a simulation run is paused, it can be determined whether or not a change of behaviour in the model is desired. This is done by comparing traffic performance indicators with conditions for enabling/disabling a change in behaviour.
The following traffic performance indicators can be retrieved from a simulation run and compared to conditions:

- car park occupancies;
- queue times;
- journey times;
- pollutant levels.

This means that briefly the following steps can be programmed in external software:

- pause the simulation run;
- retrieve input (traffic performance indicators -TPI) from the simulation run;
- compare the TPI’s with the conditions of enabling/disabling a change in behaviour
- enable/disable change in behaviour
- communicate the change in behaviour back to the ITS controllers in the S-Paramics model.

This is illustrated schematically in Figure 4-3.

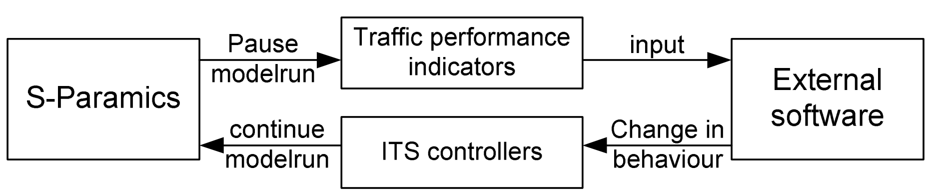


Figure 4-3: flow chart ITS in S-Paramics

This change in response and behaviour can be set for every single ITS controller added to a network in S-Paramics. The use of ITS controllers in S-Paramics brings the limitation that the only possible way of simulating the effect of PGS is ‘overwriting’ a car driver’s first car park choice with an alternative car park.

4.3 Basic assumptions for PGS tool setup

The evaluation studies of PGS (described in Section 2.3) serve as basis for the setup of the PGS tool. The outcomes are used to formulate the basic assumptions for the PGS tool. Although the exact effect of PGS is location specific, these outcomes can be used for making predictions as the outcomes are similar for different cities with different characteristics.

The different evaluation studies of PGS have investigated the following aspects of PGS:

- Amount of car drivers noticing the PGS signs;
- Amount of car drivers changing their parking location based on the information displayed on the PGS signs;
- Characteristics of car drivers who use the information displayed on the PGS signs;
- Reasons of car drivers for not using the information displayed on the PGS signs;

Different field studies show that the amount of car drivers noticing the PGS signs is in between 65% - 80%. During weekdays 10 to 16% of the car drivers changed their parking location based on the information displayed on PGS signs and 15 to 18% on weekend-days

Whether or not a car driver uses the information displayed on a PGS can be put in a simple choice model as is shown in Figure 4-4.

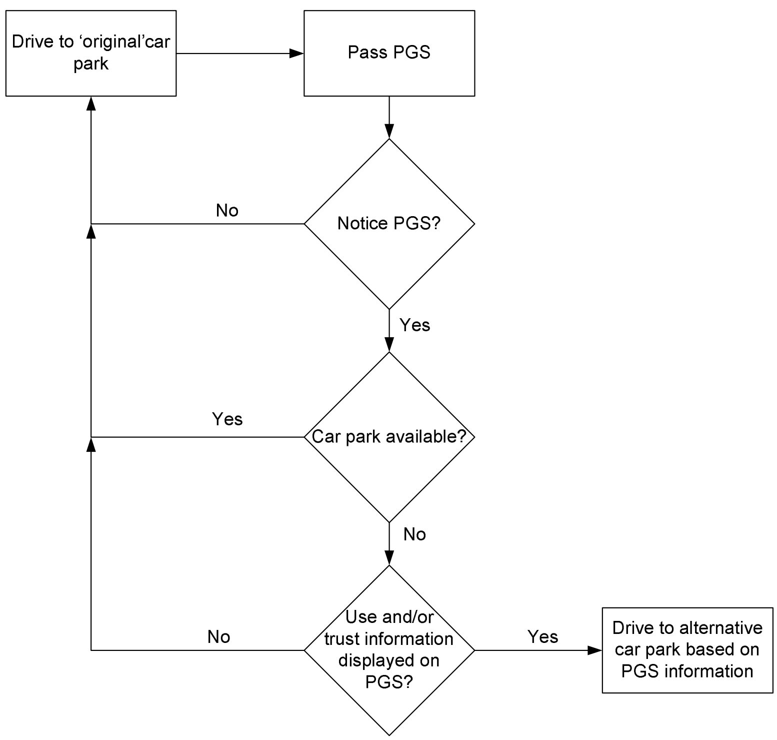


Figure 4-4:Choice process car drivers with PGS

Not all surveys, with regards to the use of PGS, investigate what the exact alternative car park choice is based on the displayed PGS information. Studies which investigated this aspect, came to the conclusion that the majority of the car drivers chose an alternative car park closest to their original destination (Thompson et al. 1999).

Once a car driver has selected its alternative car park destination, the route choice is the next step. The drivers who use the PGS information to drive to an alternative car park are mainly non-frequent visitors who are less familiar with the neighbourhood. Therefore the assumption is that these drivers follow the route instructions shown on a PGS.

For the car park choice and route choice also the location of where the driver receives the PGS information plays a role. A car driver entering a city centre from the west side can make another car park choice, than a car driver entering a city from the east side, based on the same PGS information. Therefore the assumption is that the car drivers will pick the car park closest to their original car park.

The PGS field studies also show that car drivers only re-route to another car park, once a car park shows ‘full’ on a PGS sign. Therefore the PGS tool should only be triggered, in case PGS signs show that a car park is full.

Knowing the possibilities and limitations of modelling PGS for S-Paramics, the following basic assumptions are formulated as input for the PGS tool:

- Car drivers use the information displayed on PGS signs to change their parking location, once their ‘original’ car park destination shows ‘full’ on the PGS sign;
- Using the PGS information and changing of parking location is translated in the PGS tool to an ‘advice’;
- This PGS ‘advice’ is an alternative car park closest to their original car park;
- The ‘advice’ also contains a route advice, which is the shortest route over the main roads;
- The ‘advice’ depends on the location in the model where it is given;
- 15 – 18% of the car drivers in the model follow the PGS ‘advice’.

4.4 Translation of the basic assumptions to setup of the PGS tool

Section 3 summarized the basic assumptions for the PGS tool, knowing the limitations for modelling the PGS within an S-Paramics environment. The translation of these base assumptions to the PGS tool is explained in this section. The five basic assumptions are explained in two sub-sections, because they cover two different aspects of the PGS tool:

- Sub-section 1: Activation of the PGS tool:
  - Car drivers use the information on PGS signs once their car park destination shows ‘full’ on the PGS sign;
- Sub-section 2: Influence of the PGS tool on the car park choice (trip assignment):
  - Using the PGS information is translated in the PGS tool to an ‘advice’;
  - The PGS ‘advice’ is an alternative car park closest to their original car park;
  - The ‘advice’ also contains a route advice, which is the shortest route over the main roads;
  - The ‘advice’ depends on the location in the model where it is given;
  - 15 – 18% of the car drivers in the model follows a PGS ‘advice’.

The external software in which the PGS tool is programmed is visual basic. The interface is an XML-code. The functionality of the XML-code interface is explained in this section.

4.4.1 Use of scenarios to represent the ‘car park – available/full’ condition

Car drivers use the information displayed on the PGS to change their parking location, in case they:

- Notice the PGS;
- See that their ‘original’ car park is not available; and
- Use and trust the information to select an alternative car park.

Whether or not a car driver will notice a PGS within an S-Paramics simulation is not possible. A condition for car drivers to change the parking location, based on the PGS information, is that the ‘original’ car park is full. For the PGS tool this means that the conditions for enabling/disabling behaviour and response changes should correspondent with this criterion. Therefore the car park occupancy is a condition for enabling a change in behaviour and response in the model.

These conditions are set in the XML-code as scenarios. The scenarios are used to represent the possible car park occupancy situations in a simulation run. During a simulation run the following two situations are possible:

- No scenario conditions are met (car parks are not full) and no ‘advices’ are enabled;
- The conditions of a scenario are met (one or more car parks are full) and ‘advices’ are enabled.

Multiple scenarios can be activated during a simulation run, because multiple car parks are full.

Car drivers will change their parking location once a car park is full, or in case the PGS sign displays that a car park is full. In reality these two options can differ. Two types of PGS’s in The Netherlands show that a car park is full in case:

- The car park is full (option 1);
- The car park is expected to be full, once the car driver passing the PGS arrives at the car park (option 2).

For the first option the scenario condition can be set to a car park occupancy rate of 100%, before car drivers start changing their parking locations. For the second option different scenarios have to be used. The scenario conditions should be set in such a way that ‘advices’ per PGS sign are enabled if the car park is expected to be full, for the car driver who passes the PGS sign. For this second option the exact scenario condition can be fine tuned and is location specific. Section 5 describes how this input for the PGS tool can be determined.

Not only the ‘full car park’ can be set as a scenario condition. Also the alternative car park which is the PGS ‘advice’ can be included in the scenario conditions, because this car park should still have parking places available.

In reality the information on a PGS sign is updated every minute. Therefore the S-Paramics model is paused every minute by the external controller to compare the car park occupancy with the scenario conditions.

An example of the scenario conditions in the XML-code is illustrated in Figure 4-5

XML- code:

“GE” = greater or equal
“LT” = lower than

```
- <scenario name="ToP2">
  - <measures>
      <measure controller="PGS" measurename="ToP2" />
    </measures>
  - <enable>
      <exp type="occupancyrate" target="P1" operator="GE">100</exp>
      <exp type="occupancyrate" target="P2" operator="LT">90</exp>
    </enable>
  - <disable>
      <exp type="occupancyrate" target="P1" operator="LT">100</exp>
      <exp type="occupancyrate" target="P2" operator="GE">90</exp>
    </disable>
  </scenario>
```

enable

disable

Figure 4-5: Scenario conditions in XML-code

4.4.2 Behaviour change and response to behaviour change

Not all drivers change their parking location, in case the PGS sign shows that their ‘original’ car park destination is full. Whether or not a car driver will change of car park destination can be defined in the driver response. Both aspects are defined within a ‘measure’. These measures are part of the scenarios and are activated and deactivated.

<u>Behavioural change: Change in car park destination and route to car park destination</u>

In the external software the change in car park destination is carried out by overwriting the car driver’s first car park choice. If no further instructions are given the car driver will calculate the shortest route to the new car park destination and drive accordingly.
A second aspect of the PGS tool is that it should also be possible to ‘steer’ the car drivers over a certain route to their car park. This is done by redirecting car drivers in the model via way-points. Waypoints can be added to a model network.

Summarized the PGS tool undertakes the following actions, once a scenario is enabled (and car drivers meet the response profile):

- Set car park destination x to car park destination y (“carparkadvice”);
- Drive via waypoint z (“diversion”).

An example of the XML-code is shown in Figure 4-6.

XML- code:

```
- <measure name="ToP2">
  - <behaviour type="carparkadvice" name="P2" target="P2">
      <response type="destinationcarpark" name="P1" target="P1" />
      <response type="vehicletype" name="1" target="1" />
      <response type="responsefactor" name="100" factor="100" />
    </behaviour>
  - <behaviour type="diversion" name="Wpt2" target="Wpt2">
      <response type="destinationcarpark" name="P2" target="P2" />
      <response type="vehicletype" name="1" target="1" />
      <response type="responsefactor" name="100" factor="100" />
    </behaviour>
  </measure>
```

Figure 4-6: XML-code: behavioural change

<u>Response to change in behaviour</u>

Whether or not a car driver will comply with this change in behaviour is defined in the ‘response profile’. The ‘response profile’ is the profile which a car driver has to ‘meet’ in order to be re-routed to an alternative car park in the model. To model reality at best with the S-Paramics software the selection of car drivers, which do change their car park destination after passing a PGS, is based on the criterion ‘destination car park’ and a response rate.
The first criterion ‘destination car park’ ensures that only the car drivers in the model who are driving to the ‘full car park’ are possible cars for re-routing. The second ‘selection criterion’ is the response rate. This response rate is a percentage of the cars, passing the PGS and meeting the criterions, which will change their parking location.
In case a segmentation of trip motives is used in the car park model, also the response criterion ‘vehicle type’ can be used. The vehicle types in S-Paramics then represent a certain trip motive.

The PGS tool can use the following filter conditions in the response profile, once a scenario is enabled:

- destination car park (“destinationcarpark”)
- vehicle type (“vehicletype”)
- response rate (“responsefactor”)

An example of the XML-code is shown in Figure 4-7.

XML- code:

```
- <measure name="ToP2">
  - <behaviour type="carparkadvice" name="P2" target="P2">
      <response type="destinationcarpark" name="P1" target="P1" />
      <response type="vehicletype" name="1" target="1" />
      <response type="responsefactor" name="100" factor="100" />
    </behaviour>
  - <behaviour type="diversion" name="Wpt2" target="Wpt2">
      <response type="destinationcarpark" name="P2" target="P2" />
      <response type="vehicletype" name="1" target="1" />
      <response type="responsefactor" name="100" factor="100" />
    </behaviour>
  </measure>
```

Figure 4-7: XML-code: response profile

<u>Location of the ‘parking advice’ in the model</u>

Multiple measures can be activated within one scenario. Every measure is linked to an ITS controller in the S-Paramics network. By using this setup, the location at which the ‘parking advice’ is given in the model also plays a role.

<u>Overview process PGS tool</u>

Figure 4-8 shows an overview of the whole process of the PGS tool for S-Paramics.

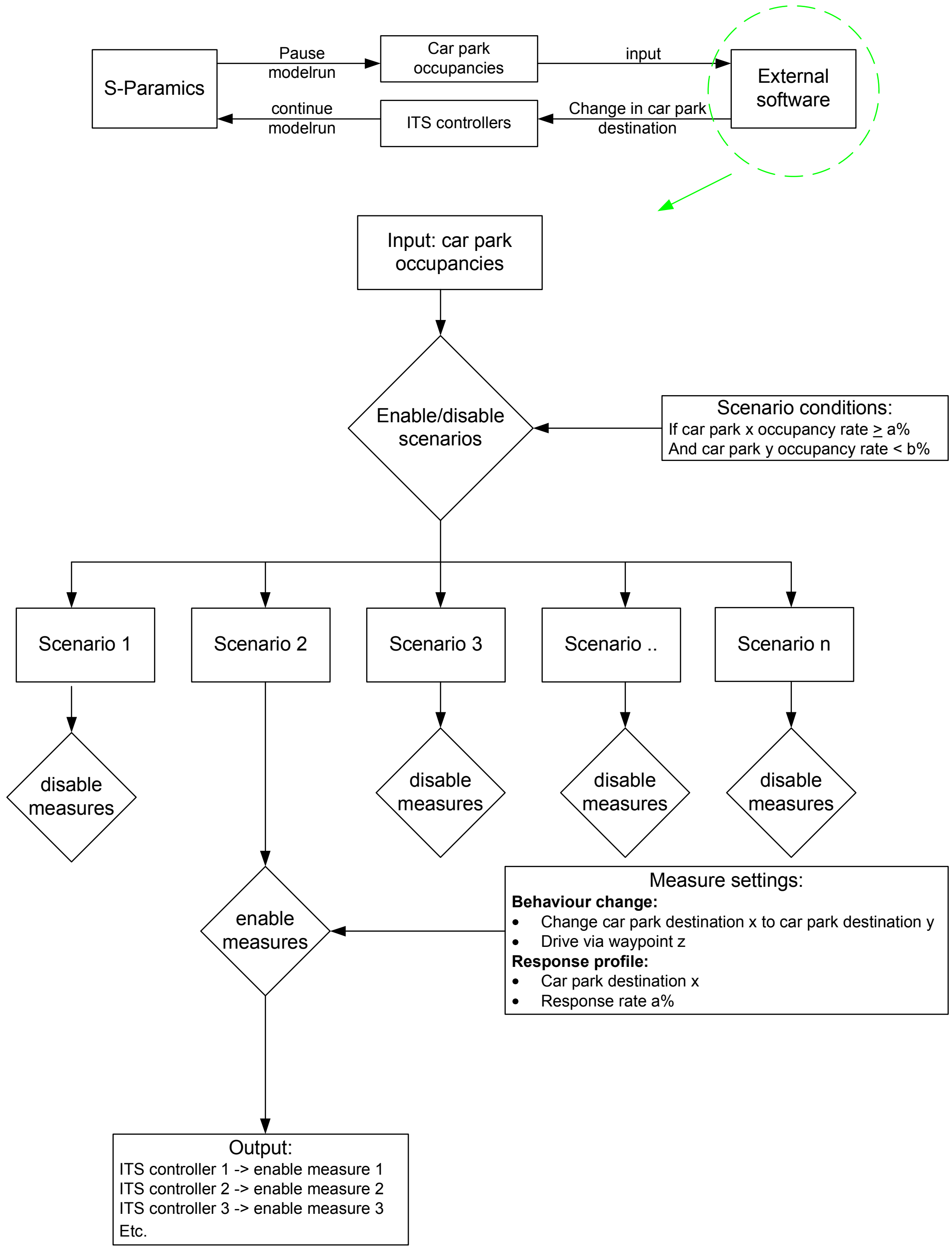


Figure 4-8: Overview process PGS tool

Within the model (the trip assignment) the behaviour of car drivers is influenced, once a scenario is enabled and measures are activated. The following happens for every car driver in S-Paramics which passes an ITS controller which represents the PGS sign.

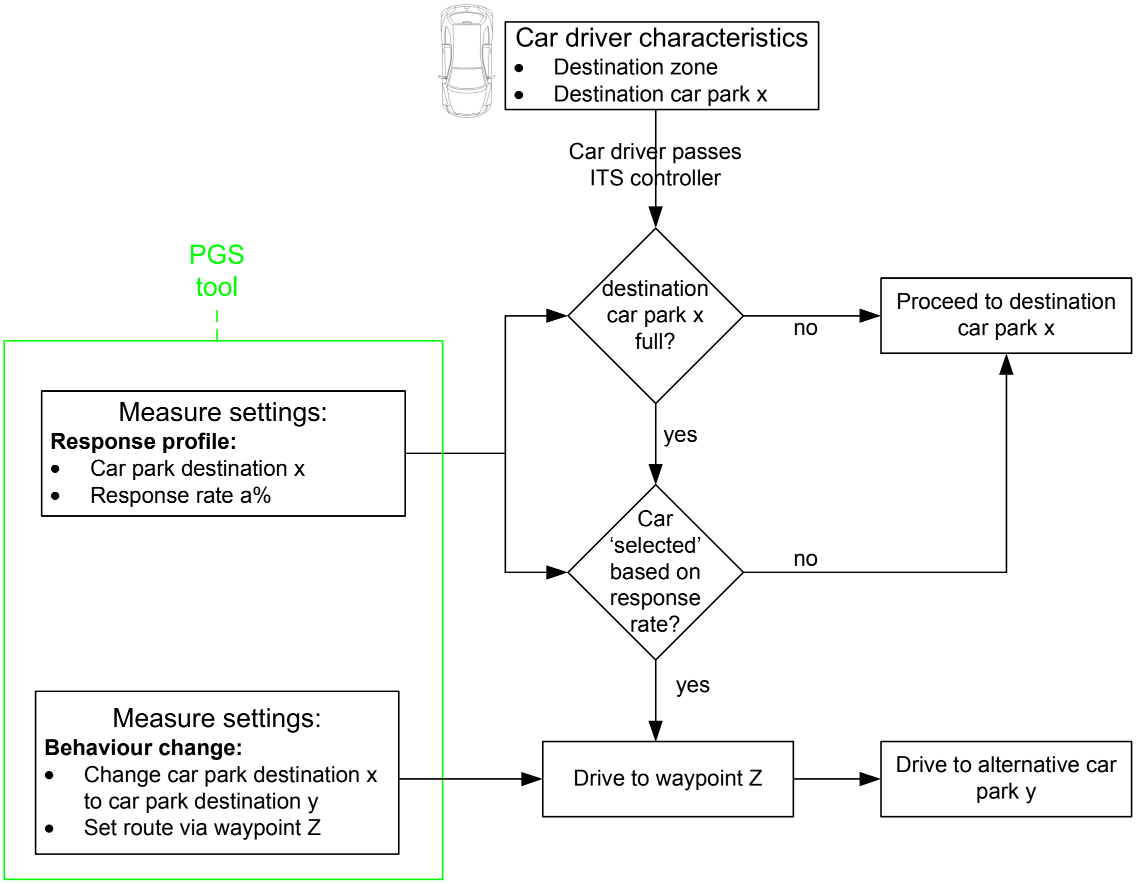


Figure 4-9: Overview response car driver in model

4.5 Input PGS tool

In the previous sections the technical functioning of the PGS tool is explained. Per specific model, specific input is required for the PGS tool. The specific input which is required for the PGS tool, and should be added to the existing model is:

- The location of the PGS signs in the model;
- The location of the waypoints in the model.

The specific input which is required as input in the XML-code of PGS tool are:

- The scenario conditions;
- Alternative car parks;
- Routes to alternative car parks;
- Response settings.

In this section the input is discussed and methods are described for determining the input. Figure 4-10 shows an overview of the input for the PGS tool.

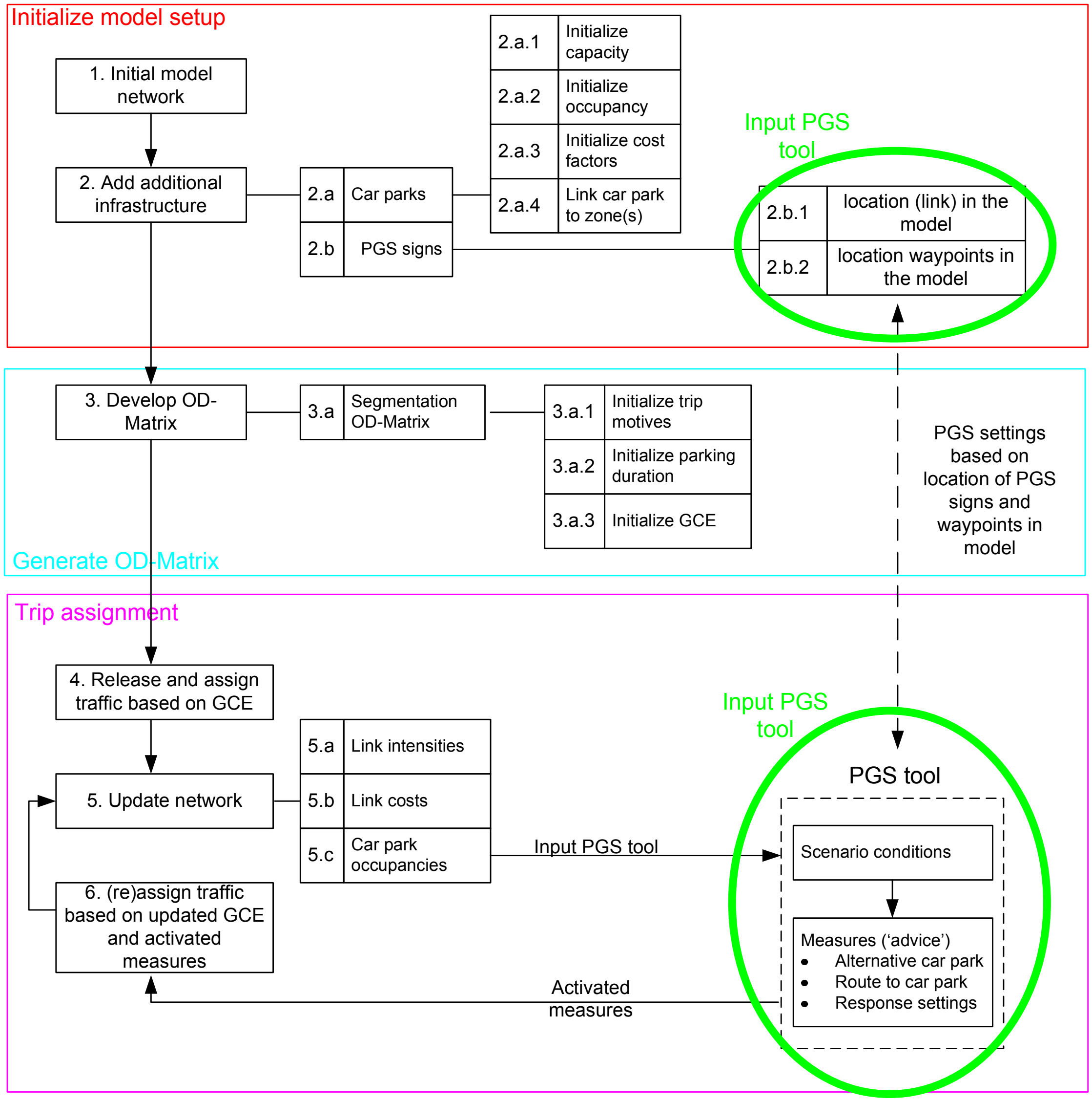


Figure 4-10: Input PGS tool

4.5.1 Model input

For every model to which the PGS tool is applied two components have to be added: ITS controllers (PGS signs) and waypoints.

The ITS controllers can be placed at the locations at which the PGS signs are placed in reality. In the model however it is not needed to place as many ITS controllers as PGS signs in reality. Car drivers in an S-Paramics model are 'intelligent', as they only need route instructions once. In reality PGS signs are often use to guide car drivers as well.

The location of the waypoints is dependent on the location of the PGS signs. Municipalities often try to guide car drivers over the major road network with a PGS. This means that the waypoints should be placed on locations of the major road network. Car drivers in the model can then be guided via these waypoints to their new car park destination.

4.5.2 XML-code Input for the PGS tool

The XML-code of the PGS tool needs specific input for four parts:

- The scenario conditions;
- Alternative car parks;
- Routes to alternative car parks;
- Response settings.

<u>Scenario conditions</u>
Car drivers will start re-routing once a car park is full, or in case the PGS sign displays that a car park is full. In reality these two options can differ. Two types of PGS's in The Netherlands show that a car park is full once:
- The car park is full (option 1);
- The car park is expected to be full, once the car driver passing the PGS arrives at the car park (option 2).

For the first option the capacity of a car park is set as a scenario condition. For the second example, the scenario condition can be calculated per car park and ITS controller in 5 steps:
1. Determine the average travel time from the PGS sign to the car park (TT_{pgs1});
2. Determine the time of day at which the car park is full for the first time (T_{full});
3. Subtract the travel time from the time of day ($T_{full} – TT_{pgs1}$);
4. Determine the occupancy (capacity – x) at ($T_{full} – TT_{pgs1}$);
5. Set occupancy as scenario condition.

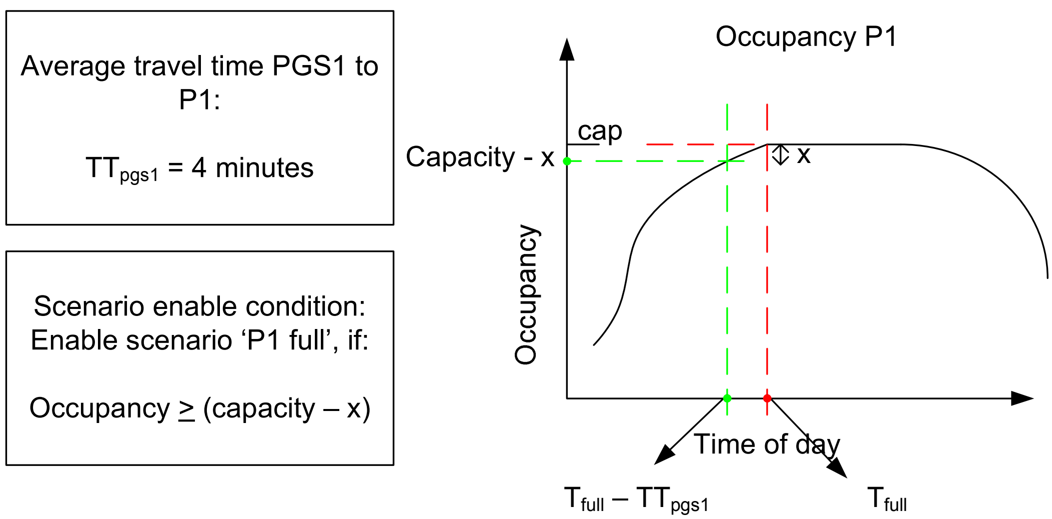


Figure 4-11: example determining scenario condition

The first condition for a scenario is the conditions which ensures that the car park destination is full. The other conditions should ensure that the alternative car parks still have spaces left. This means that the occupancy of the alternative car parks should be lower than (capacity – 2*x). In case all alternative car parks are full, no advice will be given by the PGS tool.

<u>(routes to) Alternative car parks</u>
The alternative car parks and routes to alternative car parks are also defined in the PGS tool. In case a car park is full (a part of the) car drivers in the model is re-routed to the alternative car park, possibly via a waypoint.

What the alternative car park should be, can be best determined in consultation with someone who has knowledge of the local situation. This can, for instance, be someone of the municipality which is implementing the PGS. This alternative car park should then be the most likely car park to which car drivers will drive, in case their 'original' destination car park is full. This alternative car park should be close to their original destination car park and destination zone.

For the PGS tool this means that for every car park, possible alternative car parks are defined.

The assumption is made, that car drivers follow the route instructions displayed on the PGS signs in reality. The route (via a waypoint) to the car park can therefore also be set in the PGS tool in consultation with for instance the municipality. As they often try to steer the cars over the major roads, to prevent rat-runs.

<u>Response profile</u>
The input of the response profile exists of the right destination car parks and the response percentage.

In case a car park is full in the model, only car drivers with this full car park as destination should possibly re-route in the model. Therefore the criterion 'destination car park' of the car drivers in the 'response profile' should be the full car park.

Of the car drivers, with the full car park destination, only a certain percentage will actually re-route in the model. The percentages of the field studies can be used as input.

Another option is to set different response percentages for different trip motive or frequencies. This creates however more (unnecessary) complexity in the model and it therefore seems better to set one overall follow-up percentage. Other reasons for choosing one overall 'follow-up' percentage in the PGS tool is, and not use a differentiation:

- Only a few field studies are available which investigated the 'PGS follow-up' percentages differentiated to trip motive/frequency. These percentages of these field studies differ too much, to set one average percentage for a certain trip motive or frequency;
- Not all microsimulation car park models have an OD-matrix segmentation in trip motives or frequencies.

4.6 Summary

This chapter describes the development of the PGS tool. As a basis for the PGS tool serves an existing microsimulation model with car parks. The PGS tool can be added to this model.

The PGS tool is based on the following five points:

- Car drivers use the information displayed on PGS signs to change their parking location, once their 'original' car park destination shows 'full' on the PGS sign;
- Using the PGS information to change the parking location is translated in the PGS tool to an 'advice';
- This PGS 'advice' is an alternative car park close to their original car park;
- The 'advice' also contains a route advice, which is the shortest route over the main roads;
- The 'advice' depends on the location in the model where it is given;
- 15 – 18% of the car drivers in the model follow the PGS 'advice'.

For the technical functioning of the PGS tool, this is translated to three steps which take place in the PGS tool:

- The input (car park occupancies) is retrieved from S-Paramics;
- Scenarios are activated/deactivated based on these car park occupancies;
- The activated scenarios contain measures, which start re-routing traffic in case car parks are full.

The application of the PGS tool is location specific and therefore needs input for every specific model to which it is added. The input consists of:

- The addition of ITS controllers (PGS signs) and waypoints to the model.
- The scenario conditions;
- Alternative car parks;

- Routes to alternative car parks;
- Response settings.

Section 4.5 explains how this input can be defined.

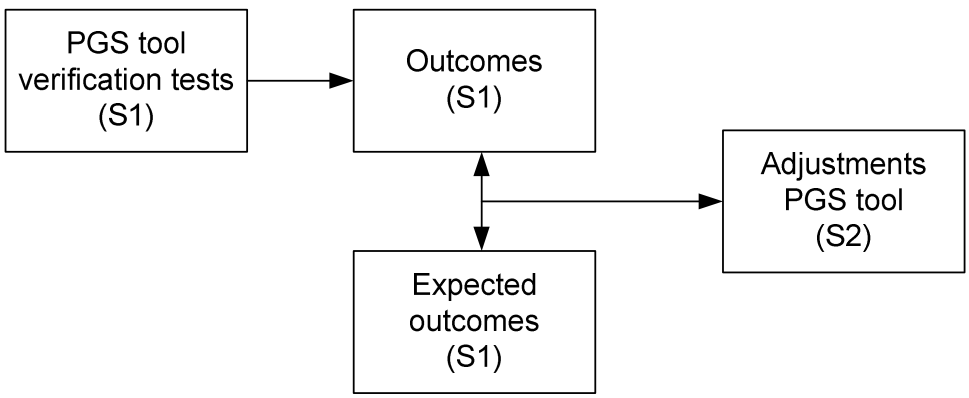
Now that the PGS tool is developed its functioning will be verified on small networks in the test phase. The test phase is meant for debugging the tool. The test phase should show that the tool functions as intended. The next chapter will discuss the testing of the PGS tool.

5 Verification and testing PGS tool

The development of the PGS tool is described in the previous chapter. In this chapter the testing of the PGS tool is described and therefore the objective of this chapter is to verify the PGS tool and make adjustments if necessary.

The verification process is done in two steps:

- Section 1: describes the verification process, for which several tests are performed, to check if the PGS tool functions as it is intended to do.
- Section 2: describes the necessary adjustments for the PGS tool, because it does not fully function as intended.



The outcome of this chapter is a PGS tool which functions as it is intended to do. This PGS tool will be applied to a case study in the next chapter.

5.1 Debugging tests and outcomes

The objective of verifying and debugging the PGS tool is to check whether the PGS tool functions as intended. The phases which can be distinguished in the PGS tool are:

1. Retrieving car park occupancy input from S-Paramics;
2. Enabling/disabling scenarios based on the input;
3. Activating measures.

All the three phases are tested for the PGS tool. The first and second phase are combined in one test and the third phase is tested by several tests.

5.1.1 Verification tests phase 1 and 2: Enabling/disabling scenarios

The PGS tool gives a log file as output, which describes at what time which scenario is activated. This is illustrated in Figure 5-1.

Simulation run log file:
[ITSManager] 12:08:00: scenario 'P2 full' enabled
[ITSManager] 12:40:00: scenario 'P2 full' disabled
[ITSManager] 13:43:00: scenario to 'P1 full' enabled
[ITSManager] 13:47:00: scenario to 'P1 full' disabled

Figure 5-1: Example of PGS tool logfile

The expected outcome of the scenario test runs, is that the 'right scenario' is activated at the 'right time'. To test whether the PGS tool activates the 'right scenario' at the 'right time', three tests are carried out.

- Test 1: testing whether 1 scenario enable condition functions:
  A test network with 2 car parks is used. Once the occupancy of car park A was at 50%, all traffic should be re-routed to the alternative car park B.

- Test 2: Testing whether multiple scenario enable conditions function:
  A test network with 3 car parks is used. Once car park A was full, all traffic should be re-routed to car park B. Once car park B reached 50% of its occupancy, all traffic should be re-routed to car park C.

- Test 3: Testing whether multiple scenario conditions function for enabling and disabling:
  Same test as test 2. However now at the end of the run cars are leaving car park A. Therefore the scenario should be disabled again, because traffic can park at car park A again.

The results of the tests can be found in Appendix I and show that the scenario conditions function as intended and thus also the retrieving of the car park occupancies from S-Paramics.

5.1.2 Verification tests phase 3

The previous tests were carried out with response rates of 100%. The tests for phase 3 contain different tests to test whether the measures function as intended. The measures in the external software contain:

- Change in behaviour
  - New car park destination
  - Route to car park destination

- Response profile
  - Destination car park
  - Vehicle type
  - Response rate

The expected outcomes are:

- For the tests with regards to the 'change in behaviour' that the 'right' change in behaviour' is the obtained;
- For the tests with regards to the response profile that the 'filter options' select the 'right' car drivers in the model for the 'change in behaviour'.

Whether or not cars re-route to the newly set car park destination is not tested, because it was part of the tests for phase 2. The following five tests are carried out, to check whether these elements of the PGS tool function as intended.

- Test 1: testing whether the new route to a car park functions
  A test network with 2 car parks was used. Due to the shortest route by far, all cars would drive to car park A at first. When car park A was full, all cars should be re-routed to car park B by the PGS tool. Two route options were possible to the new car park. Route X is the shortest and route Y the longest route to car park B. Without the route instruction all cars would chose route X. The waypoint was placed on the network on route Y, to check whether car drivers would follow the instructions and drive the route with largest travel time.

- Test 2: Testing whether the filter criterion 'destination car park' functions
  A test network with 2 car parks (A and B) linked to destination zone 1 and 1 car park (C) linked to destination zone 2 was used. 100% of the cars with car park destination A should be re-routed, once car park A was full, to car park B. Car drivers with car park C (other zone) should therefore not react to the re-routing instructions of the PGS tool.

- Test 3: Testing whether the filter criterion 'vehicle type' functions
  A test network with 2 car parks (A and B) and two vehicle types (1 and 2) in 50-50 proportions were used. Due to the shortest route by far, all cars would drive to car park A at first. Once car park A was full only vehicle type 1 should be re-routed to car park B. The other vehicle type (50%) should drive to their original car park choice, car park A.

- Test 4: Testing whether the response rate functions
  A test network with 2 car parks (A and B) was used. Due to the shortest route by far, all cars would drive to car park A at first and a response rate of 20% was set.

The results of the tests can be found in Appendix 1. The outcomes show that the different elements of the tool function as intended. One noticeable characteristic of the tool is however the response percentage. In case a response percentage of 20% is set, every 5th car (meeting the other criterions) is rerouted of a traffic flow. This means that the re-routing of cars does not happen 'random'.

5.1.3 Additional verification tests with multiple ITS controllers

Additional tests showed two limitations of the PGS tool:

- ITS controllers function independently;
- In case car park capacities are used as scenario conditions, scenarios can be disabled when they should not be disabled.

<u>ITS controllers function independently</u>

ITS controllers in an S-Paramics model function independently. Therefore the ITS controllers do not represent the system of the PGS signs as a whole, in case the ITS controllers are placed at the same locations as in reality.

This is caused by the 'response percentage' which represents the amount of car drivers changing their parking location based on the PGS information. In case a traffic flow passes more than one ITS controller, more car drivers than the intended percentage will change their parking location. The example below illustrates what happens, because the ITS controllers function independently.

The settings of the tool and model for this example are:

- 18% of the car drivers with destination car park P1 will their parking location to P2;
- In the model 100 cars with P1 as destination car park are released.

The following however happens in the model:

- The 100 cars pass the first ITS controller;
- The destination car park is changed to P2 for 18% (18 cars), 82 cars still have P1 as destination;
- The 100 cars pass a second ITS controller;
- The car park destination is changed again to P2 for 18% (15 cars) of the 82 cars with car park destination P1, 67 cars will still drive to P1;
- A total of 33 cars (33%) has P2 as new parking location and 67 cars will drive to their 'original' car park destination P1.

The intention was to change the parking location of 18 cars, but with multiple ITS controllers in the model the parking location of 33 cars was changed.

Another problem occurs with the PGS tool, when car drivers are re-routed via a waypoint. A test run used the following settings:

- 18% of the car drivers should be re-routed to the alternative car park, in case their original destination is full; and
- This 18% of the car drivers must drive via waypoint A.

The results show that 18% of the car drivers in the model is given the new car park destination. 18% Of the car drivers drives to waypoint A in the model and then drives to their parking location. These car drivers however do not have match. This means that 18% of the car drivers is rerouted to an alternative car park, while another 18% uses a route via waypoint A to their car park.

<u>Using car park capacities as scenario conditions</u>

Another limitation of the PGS tool appears once car park capacities are used as scenario conditions. Figure 5-2 shows an example. In S-Paramics a car has to leave a full car park, before a new car can enter the car park. When at this exact time of a car leaving the car park the occupancy is retrieved by the PGS tool, the retrieved occupancy is the (capacity-1). In this case the scenario is disabled while it should not be.

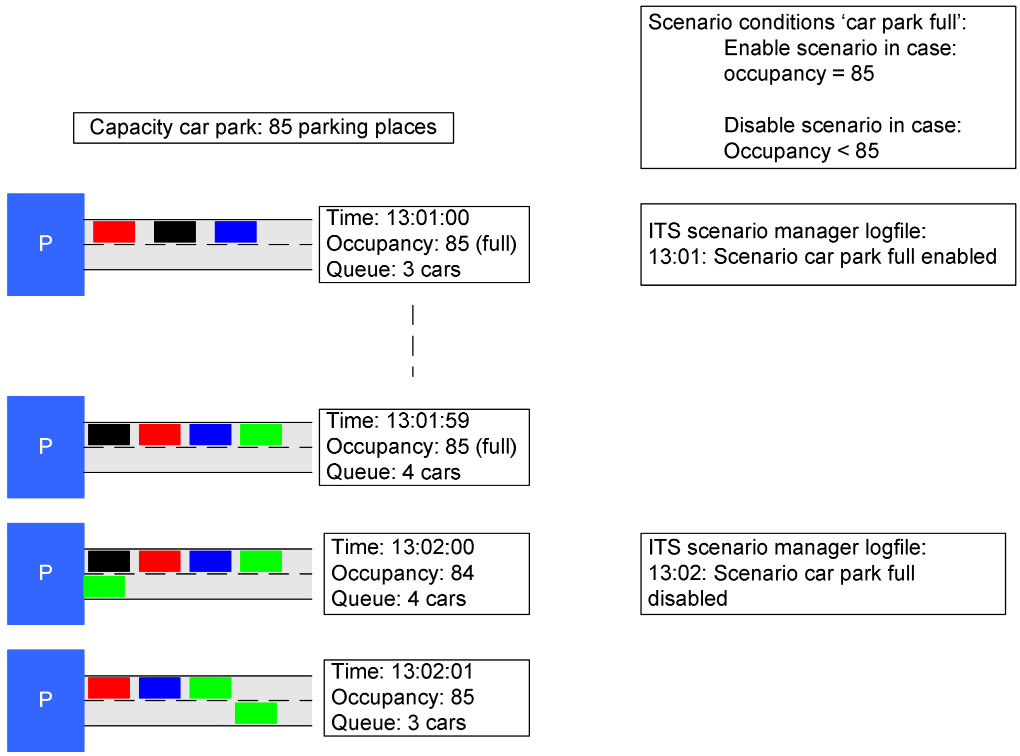


Figure 5-2: Example of a scenario which is disabled while it should not be

To prevent this from happening the scenario condition should not be set to a car parks capacity.

5.2 Changes in the PGS tool setup

The additional tests show that a change in the PGS tool is necessary to improve its functionality. Two problems are:

- Multiple ITS controllers enlarge the desired re-routing percentage;
- The drivers in the model who are given an alternative car park and route do not match.

A small adjustment in the setup of the tool can solve this problem. A vehicle type can be used as a selection criterion by the PGS tool. The vehicle type can be used, to ensure that just 18% of the car drivers in the model follow the PGS advice, once their 'original' car park is full.
In the OD-matrix a vehicle type proportion of 18% can be created. This vehicle type will then be the only vehicle type which is sensitive to the PGS tool.

The response rate for this particular vehicle type must then be set to 100%. This means that all cars with this vehicle type (a total of 18%) will change their parking location in case these cars meet the other response criterions (destination zone and car park).

This adjustment also solves the second problem, because the same cars are rerouted to a waypoint which is part of the route to their alternative car park.

The criterions for 'following the PGS advice' are the car park destination and a response rate. Now an additional criterion is the vehicle type and the response rate is set to 100%. This is illustrated in Figure 5-3.

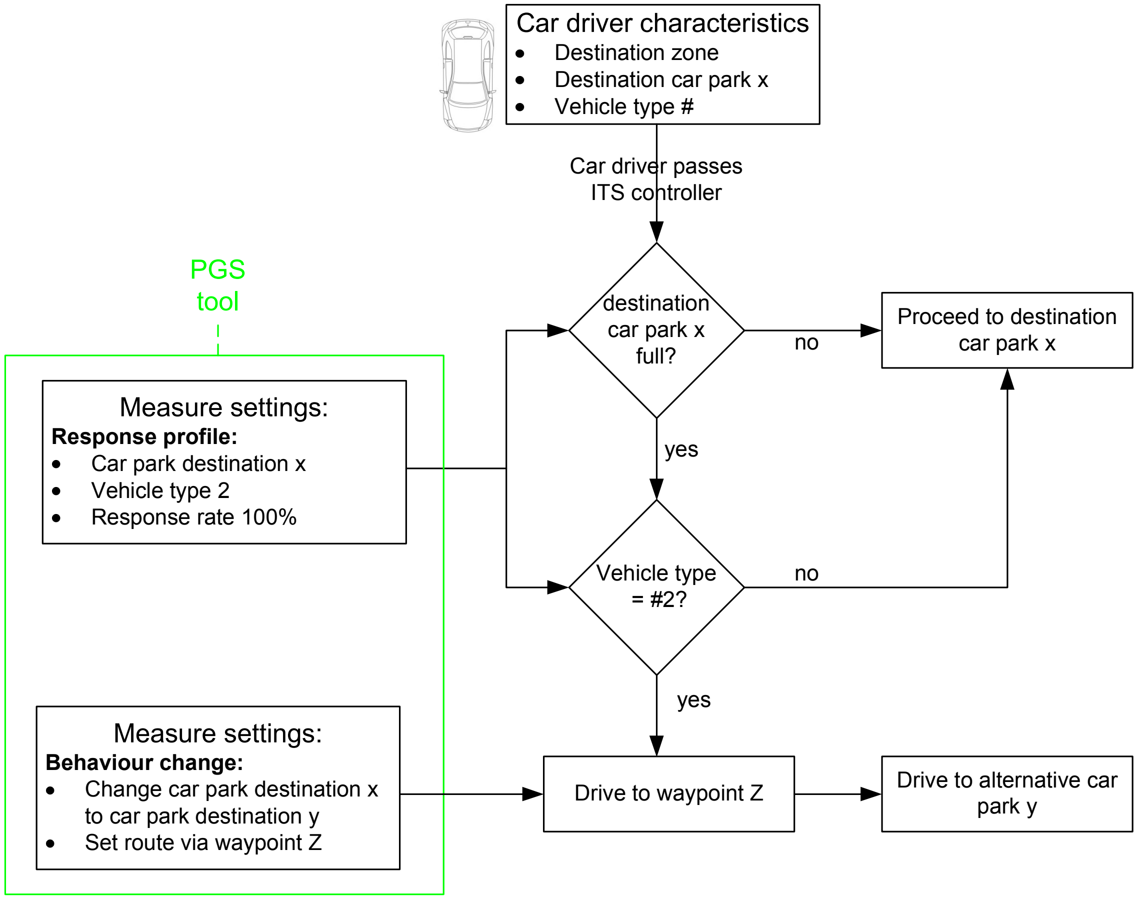


Figure 5-3: Overview adjustments PGS tool

This change has one consequence for the total model setup and is illustrated in Figure 5-4. The vehicle type proportion, which is sensitive to the PGS tool, is created in the OD-matrix.

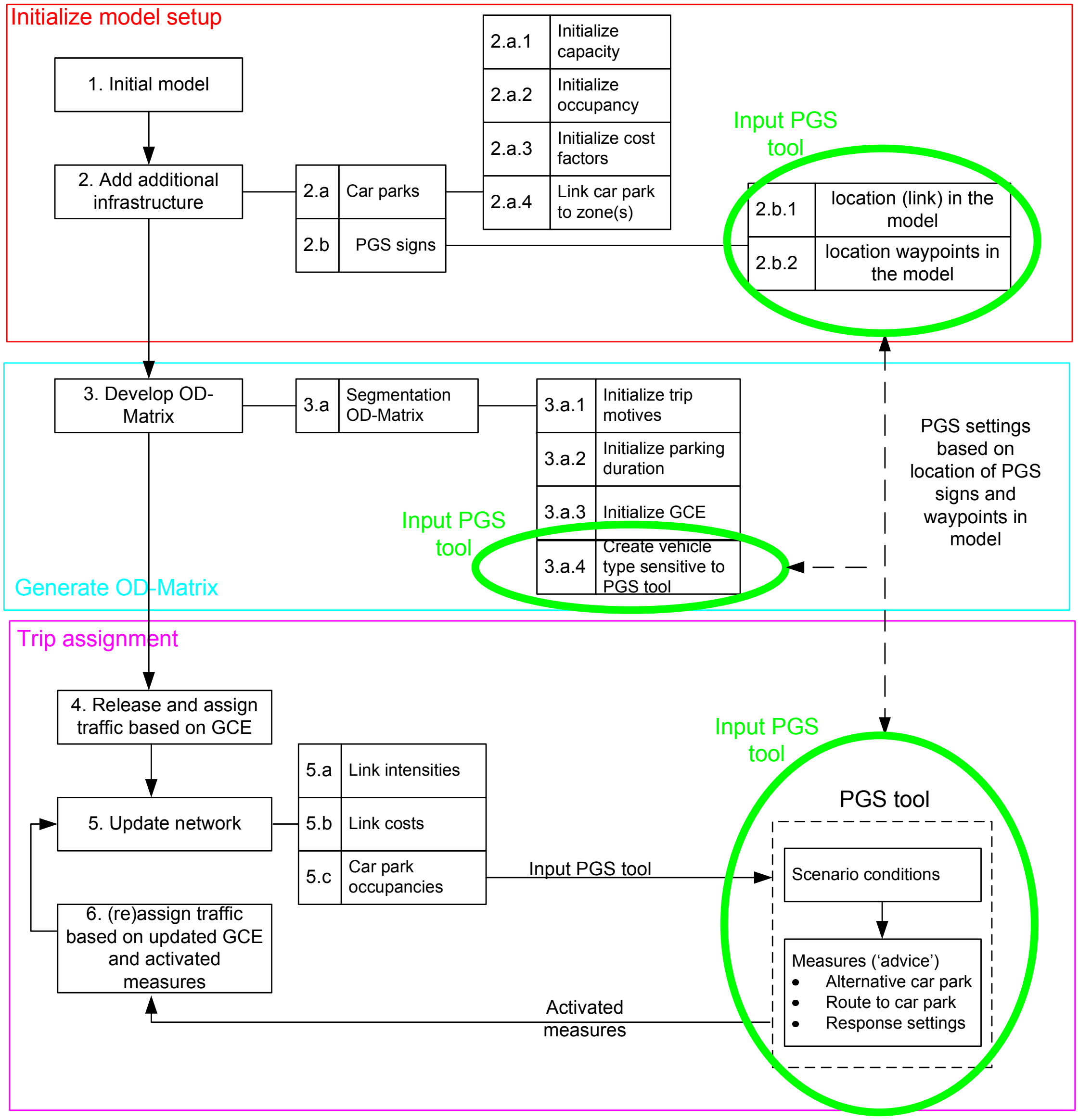


Figure 5-4: Adjusted PGS tool setup

5.3 Summary

In this chapter the tests performed with the PGS tool are described. The tests show that the tool functions as intended, but has however two limitations. These limitations are solved by one solution. The solution is to create an additional vehicle type in the OD-matrix, which is the only vehicle type which responds to the PGS tool. The proportion of the vehicle type is the same, as the desired percentage of car drivers which change their parking location based on the information displayed on a PGS sign.

This solution ensures that in all cases:

- The desired percentage of car drivers is re-routed; and
- These car drivers drive to the alternative car park via the instructed waypoint.

In the next chapter the PGS tool will be applied to an existing model.

6 Case study: Den Helder

In the previous chapter the functioning of the PGS tool is verified. The verification was carried out by applying the PGS tool on small test networks. Therefore the PGS tool is now applied to a larger test case: Den Helder. This chapter gives an answer to the research question:

- *Which traffic performance indicators can be used to get an insight in the effects of PGS?*

The application of the PGS tool for the Den Helder model is described in 7 sections:

- Section 1: describes the objectives of this case study;
- Section 2: describes the current and future parking situation of Den Helder;
- Section 3: describes how the parking situation in Den Helders is translated to the S-Paramics model of Den Helder;
- Section 4: describes all the different aspects of the setup and implementing the PGS tool on the Den Helder network.
- Section 5: analyses the outcomes of the simulation runs carried out with the PGS tool;
- Section 6: discusses the model outcomes;
- Section 7: concludes on this chapter.

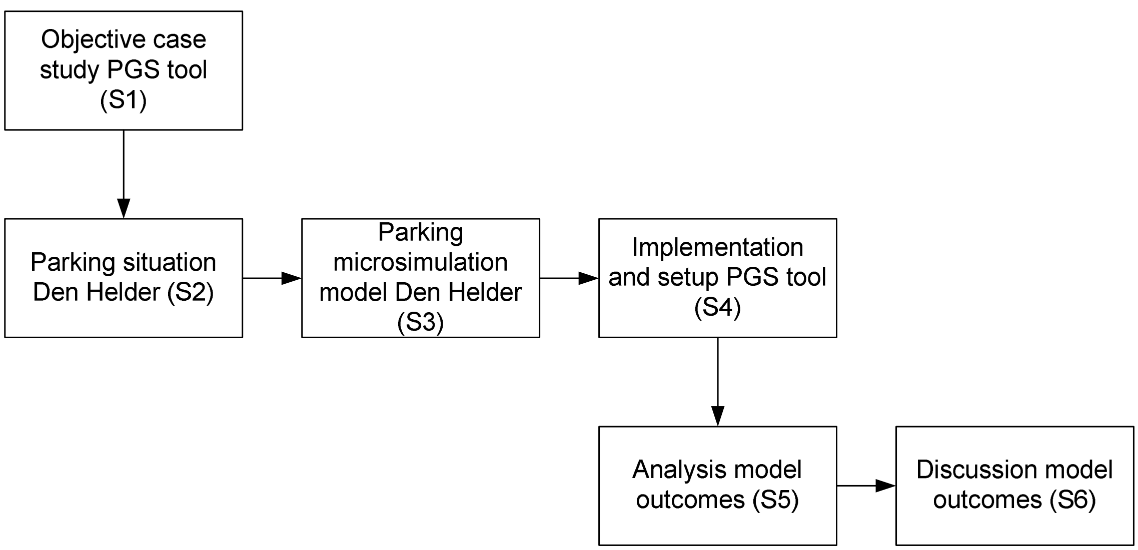


Figure 6-1: Overview structure chapter six

6.1 Objectives of the PGS tool case study

The PGS tool is developed, debugged and tested on smaller networks. Applying the PGS tool to the Den Helder model will be the first test case for a larger network. The objectives of this case study are:

- Demonstrate how to initiate the setup of the PGS tool for a larger network:
  This objective focuses on the implementation of the PGS tool on an existing S-Paramics model and how it reflects the actual ('ideal') setup of a PGS. The steps for implementing the PGS tool from the previous chapter are now applied to the Den Helder case.

- Analysis of the results:
  This objective consists of a number of steps. A first step in the analysis is to verify the functioning of the PGS tool on a larger network. This done by carrying out the same verification checks as in chapter 5.

  Secondly the outcomes are analyzed. The first analysis deals with the stability of the model outcomes using the PGS tool. The stability is important for using the outcomes to make predictions. If the outcomes of the model runs (using the same set of random seeds) with the PGS tool differ significantly from each other, the predictions of the PGS tool can be doubtful.

  Thirdly the possibilities are investigated for analysing traffic performance indicators, to gain insight in the effects of implementing the PGS tool. Hereby it is investigated which indicators can be used, to show the possible differences after PGS is implemented.

- Discussion of results:
  The setup of the PGS tool contains several assumptions. These assumptions have consequences for the outcomes of the model. Therefore the effects of these assumptions on the outcomes are discussed.

6.2 Parking and traffic situation in Den Helder

Den Helder is a municipality with 57.219 inhabitants (CBS, 31st of December 2010). The city centre of Den Helder is located at the north-east of Den Helder (Figure 6-2). Currently there are no congestion problems in and around Den Helder during the morning and evening peaks. On Saturdays, holidays and days of special events there are however parking problems.

The total amount of parking spaces in and around the city centre is sufficient for the parking demand. Currently there is mainly parking places shortage on the east side there, while there is enough parking capacity on the south and west side of the city centre. The municipality of Den Helder states this is mainly to a lack of information supply about available parking places in the city centre.

To cope with the city centre expansion, the municipality of Den Helder has plans to expand the car park facilities. As it looks now Den Helder will have six car parks in 2020 as is illustrated in Figure 6-2.

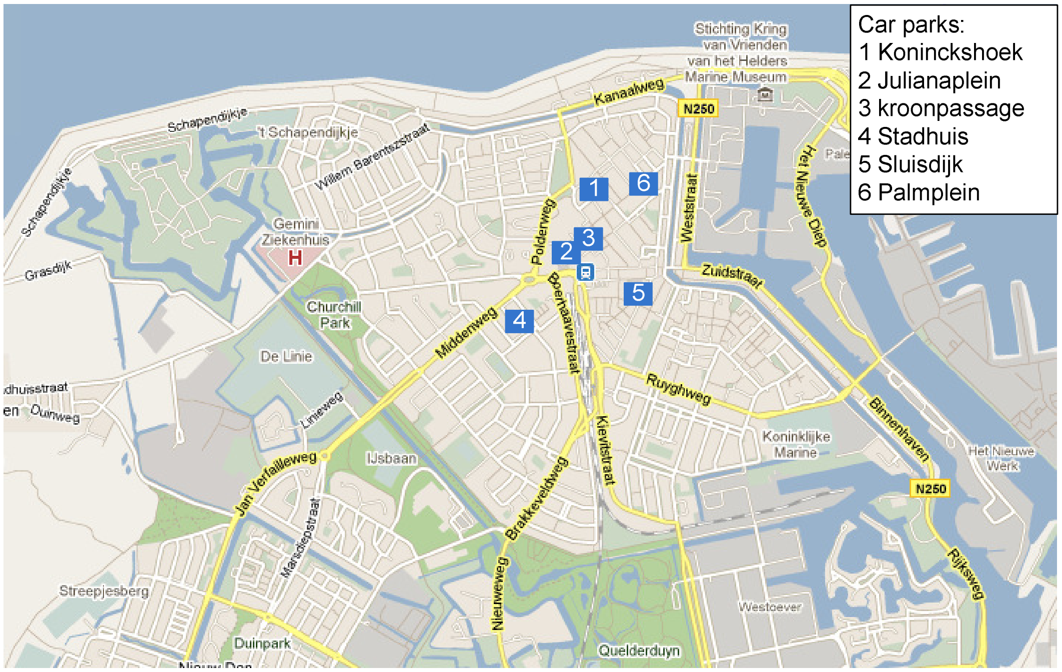


Figure 6-2: Overview car parks Den Helder

The capacities of the car parks are shown in Table 6-1.

Table 6-1: Overview capacities car parks Den Helder

Name car park	capacity
Koninckshoek	250
Julianaplein	215
Kroonpassage	95
Stadhuis	200
Sluisdijk	212
Palmplein	85

The municipality of Den Helder is also looking at the possibilities of implementing a PGS. With the implementation of PGS the municipality of Den Helder aims to gain a more balanced distribution of cars parked at the several parking locations.

The implementation of PGS is still in the exploration phase and no possible setups for such a system have been investigated yet by the municipality of Den Helder. For this master thesis a setup for the possible PGS has been defined in consultation with the municipality. This setup consists of seven PGS signs which are placed around the city centre (explained further in section 4).

6.3 Car park model Den Helder

For Den Helder a calibrated model of 2009 is available. Based on this 2009 model a 2020 was developed as well. In these models the car parks in the city centre are represented by zones. In the 2020 model the zones are replaced by car parks, to make the model suitable for the PGS tool. The car parks Julianaplein and Kroonpassage are combined to one car park in the model, because they share the same entrance link.

A screenshot of the Den Helder model as can be found in Appendix 2. The model of Den Helder includes the city of Den Helder as well as its neighbouring town Julianadorp. The focus for the implementation of the PGS tool is the city centre of Den Helder, where the parking facilities are located.

The Den Helder model of 2020 contains OD-matrices for the morning and evening peak of a weekday. During the weekdays however no parking problems occur in Den Helder. The PGS tool can only be used on a network at which car park capacity problems occur, which is on a Saturday in the case of Den Helder. The PGS tool is merely functioning, when the occupancies of car parks in the model do not reach its capacity.

Therefore a simple Saturday model for Den Helder is created. It is based on the OD-matrices of the available morning and evening peak model. The car park occupancies are roughly 'calibrated' on the expectancies for 2020 of the parking expert at the municipality of Den Hen Helder. This model is used as the basis for the addition of the PGS tool.

6.4 Implementation PGS tool and setup PGS tool for model Den Helder

This section describes the setup for the PGS tool for the Den Helder case in four sub-sections:

- Sub-section 1: describes the creation of the 'PGS sensitive' vehicle type in the OD-matrix;
- Sub-section 2: describes the locations of the ITS controllers and waypoints in the model of Den Helder;
- Sub-section 3: describes the defining of the scenario conditions for the PGS tool;
- Sub-section 4: describes the defining of the advice algorithm of the PGS tool.

6.4.1 Creating a vehicle type proportion

A first step for implementing the PGS tool is creating a special vehicle proportion which will follow the PGS re-routing instructions. The vehicle type proportion is set to 18% in this case, to reflect the amount of car users who use the PGS information on a Saturday. The vehicle type proportion exists of 18% of the car drivers which have the vehicle type 2 in the model. The settings (sensitivity to cost factors) of this vehicle type are exactly the same as the other vehicle type (1) used.

6.4.2 Location of ITS controllers and waypoints in Den Helder model

In consultation with the Den Helder municipality a setup of 7 PGS signs for this case study was defined. For the model it is important to locate the ITS controllers at places at which car drivers have to make a route choice. Figure 6-3 shows an overview of the locations of the ITS controllers in the model. They are placed mainly on the approach roads, right before a junction at which the car drivers make a route choice. To determine at which locations route choices are made, selected link analyses can be useful. With a selected link analysis an insight is gain in the route choices in the model. The locations of the ITS controllers are based on selected link analyses, which showed at which locations route decisions were made by vehicles in the model.

The waypoints are placed on the roads of the city centre, to make it possible to 'guide' car drivers in the model via a waypoint. Waypoints are used to influence the route choice process of car drivers in the model. Therefore the waypoints are placed at locations after a route choice moment (e.g. intersection). The locations of the waypoints are also illustrated in Figure 6-3.

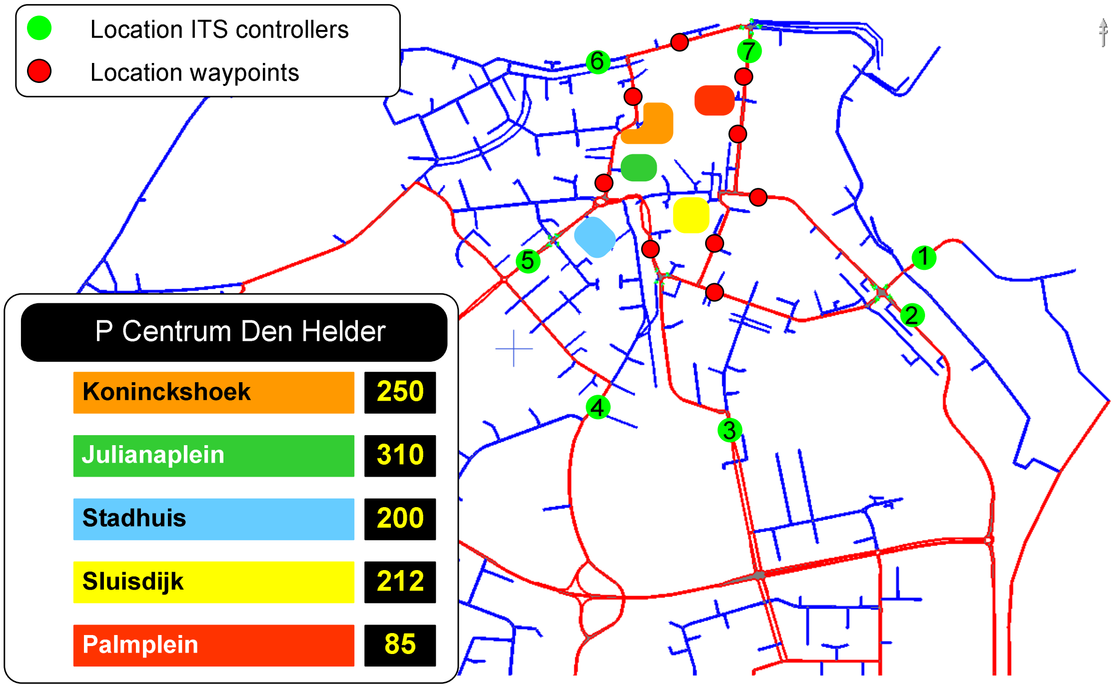


Figure 6-3: location ITS controllers and waypoints

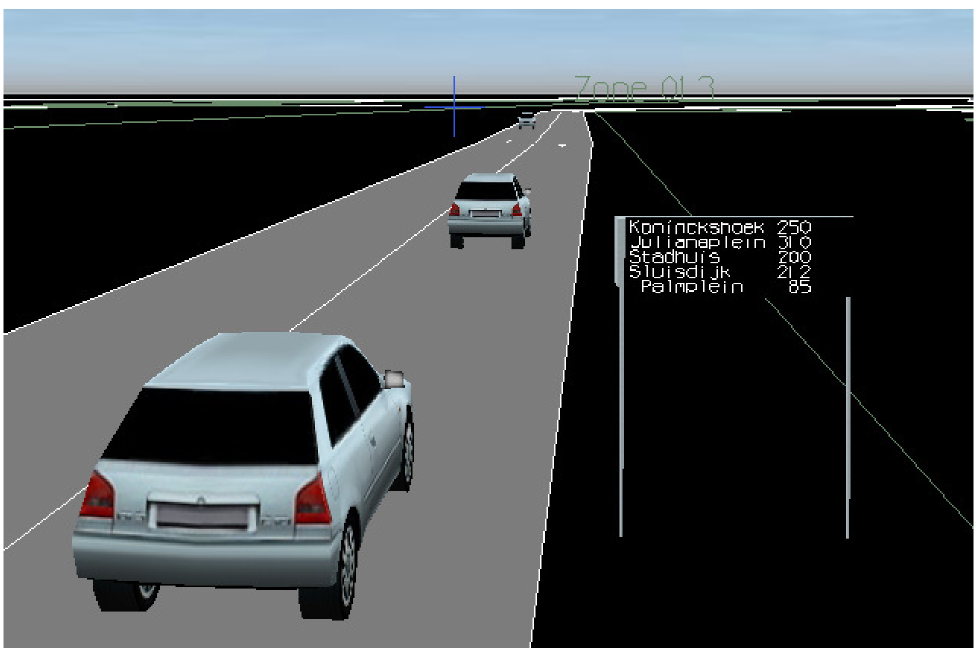


Figure 6-4: example ITS controller in S-Paramics

6.4.3 Defining the scenario conditions

The scenario conditions define the situation at which a car park advice is given by the PGS tool. Different scenario conditions are possible:

- Scenarios which use the current car park occupancies and base the advice in the model on the current car park occupancies;
- Scenarios which use the predicted car park occupancies on PGS signs - occupancies which car drivers can expect once they arrive at the car park – for the advice in the model.

The City of Den Helder is interested in using the last option in case a PGS is implemented in Den Helder. Therefore this option is used in this model. To determine at what stage the PGS sign should show ‘full’ in the model, the graphs of the car park occupancies and the travel time from the PGS sign to the car park are important.

The method described in chapter 4 is used to determine the scenario conditions:

- Determine the average travel time from the PGS sign to the car park (TT_{pgs});
- Determine the time of day at which the car park is full for the first time (T_{full});
- Substract the travel time from the time of day ($T_{full} – TT_{pgs}$);
- Determine the occupancy (capacity – x) at ($T_{full} – TT_{pgs}$);
- Set occupancy as scenario condition.

As example the situation for the Palmplein car park is illustrated.

- In the model an ITS controllers is placed at approximately 5 minutes of travel time away from the car parks (TT_{pgs}).
- T_{full} = 12h50
- $T_{full} – T_{pgs}$ = 12h50 – 0h05 = 12h45
- Occupancy at $T_{full} – T_{pgs}$ = 80

Therefore the advice by the PGS tool will be given in the model at the car park occupancy of 80 (and thus with 5 car park spaces left). This means that a car passing the ITS controller while the current occupancy is 80, can expect the car park to be full once it arrives at the car park.

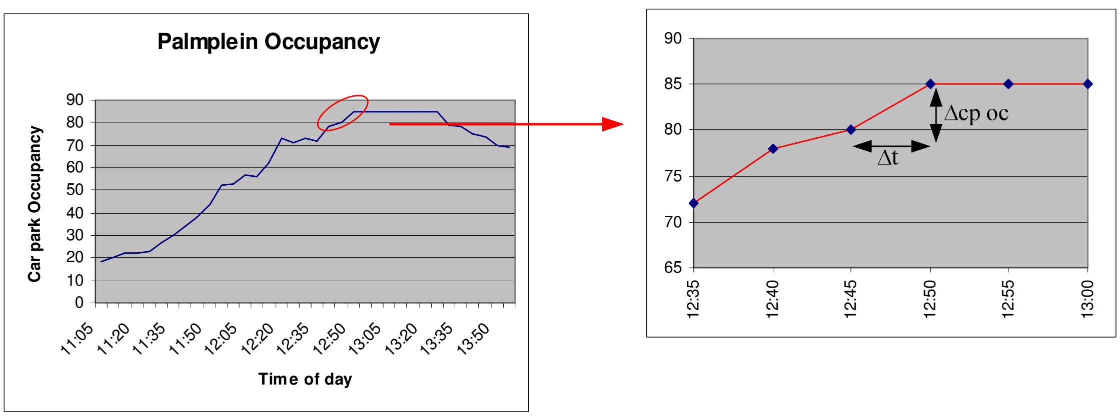


Figure 6-5: Car park occupancy Palmplein

This method is carried out for all car parks and ITS controllers. Appendix 3 shows an overview of the scenario conditions.

6.4.4 Defining the advice algorithm

When the condition is met for activating a scenario re-routing measures are enabled. Per ITS controller an alternative car park can be set as the new destination, instead of the full car park. This new destination is the ‘advice’ which a percentage of the car drivers will follow.

In reality the interpretation by car drivers of the PGS information can lead to a change in destination car park. Therefore the most logical choice of car drivers has to be given as an advice in the model. What the most logical choice for car drivers is for an alternative car park is determined in consultation with the municipality of Den Helder.

What the advice is, can also differ from the location of the ITS controller. Figure 6-6 shows an example of two ITS controllers, representing a PGS sign which shows that car park ‘Julianaplein’ is full (‘vol’), on the east and west side of the city centre.

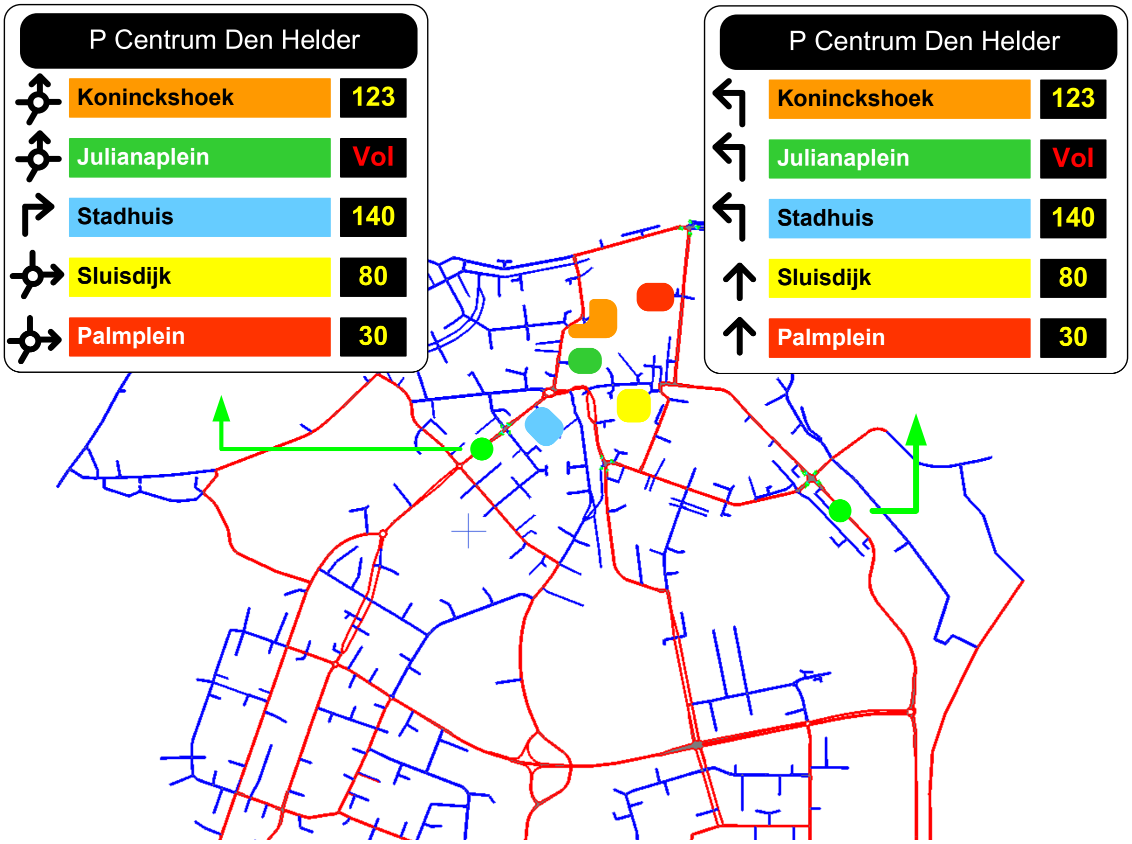


Figure 6-6: example of possible occupancy situation

For the car drivers passing the PGS sign on the west side with ‘Julianaplein’ as destination car park, the ‘Koninckshoek’ car park is the closest car park to their destination. For the drivers passing the PGS sign on the east side with ‘Julianaplein’ as destination, the car park ‘Sluisdijk’ is a better alternative. ‘Sluisdijk’ is also close to their destination and has a shorter travel time, than Koninckshoek for instance. The assumption is that therefore drivers approaching from the east side and who do use the PGS information will reroute to car park ‘Sluisdijk’.

The same reasoning is used for the other ITS controllers. In Appendix 4 there is an overview of all the alternative car park advices, once a car park or multiple car parks are full. In the case of Den Helder the parking fees at the different parking locations are equal and do therefore not play a role in defining the alternative car parks.

6.5 Analysis outcomes

This section deals with the analysis of the outcomes of the model runs with and without the PGS tool. Three aspects of the outcomes are analysed:

- The ‘PGS tool verification checks’;
- The stability of the outcomes; and
- The possibilities for analyzing the differences in the model runs with and without the PGS tool.

These aspects are described in three sub-sections.

6.5.1 PGS tool ‘verification checks’

For the Den Helder case the same verification checks were performed as for the test on the smaller networks. The checks are shown in Appendix 5 and verify that:

- The PGS tool enables and disables the scenarios at the right time;
- The right vehicles (right destination car park and vehicle type) are re-routed;

- The vehicles are re-routed to the right 'alternative' car park.

6.5.2 'Stability' of outcomes
The checks of the tool show that the PGS tool functions as intended. Another important aspect of the tool is to check whether the tool gives stable outcomes. On average ten simulation runs are carried out in S-Paramics to gain reliable outcomes (averages). Per simulation there is a small randomness in the release of vehicles on the network and the perception of travel time per car driver in the model. This can lead to slightly different car park occupancy accumulation profiles. An example of differences in the accumulation profiles is shown in Figure 6-7. The left figures show for instance a stable accumulation profile of the car park occupancies.

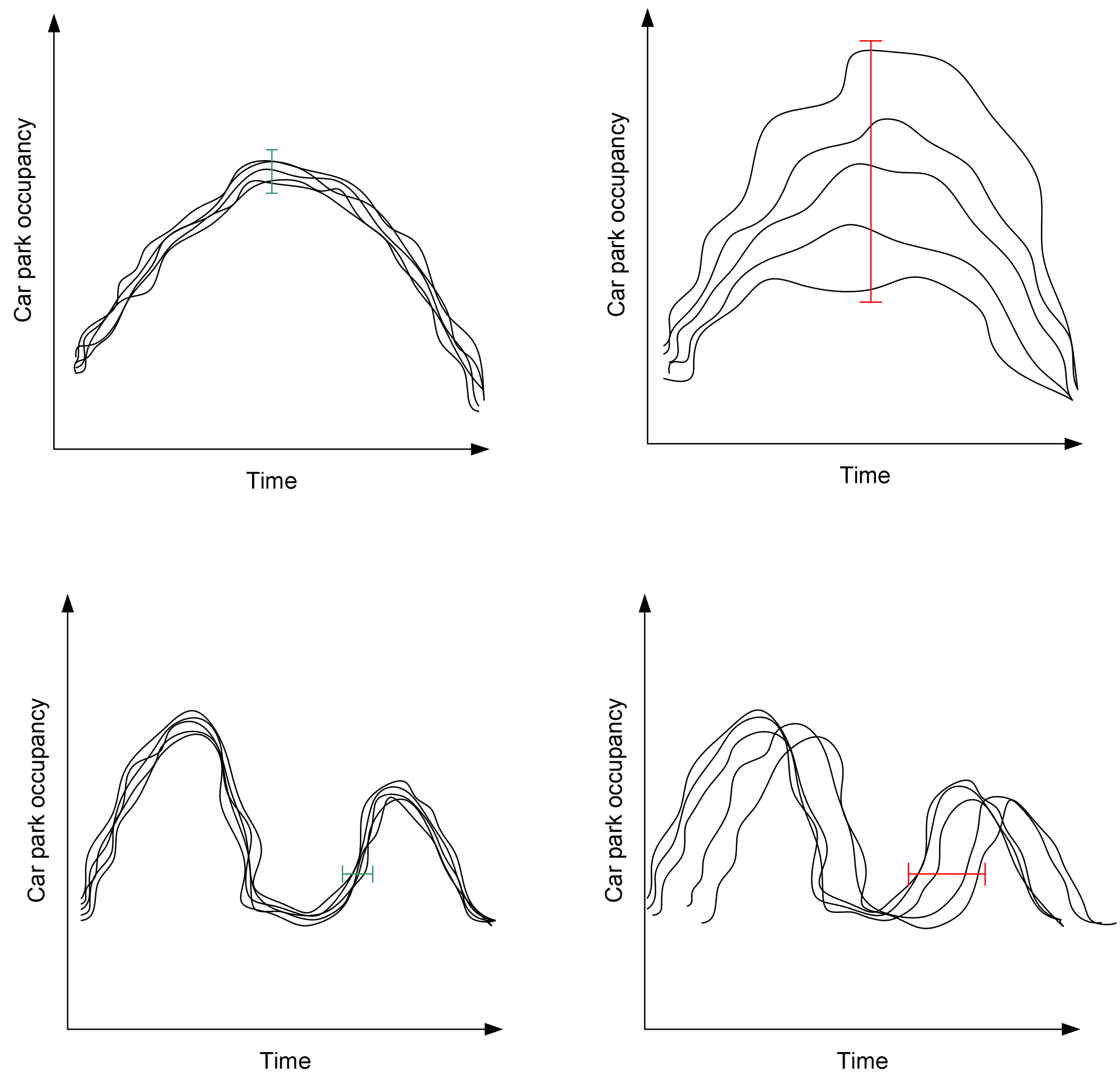


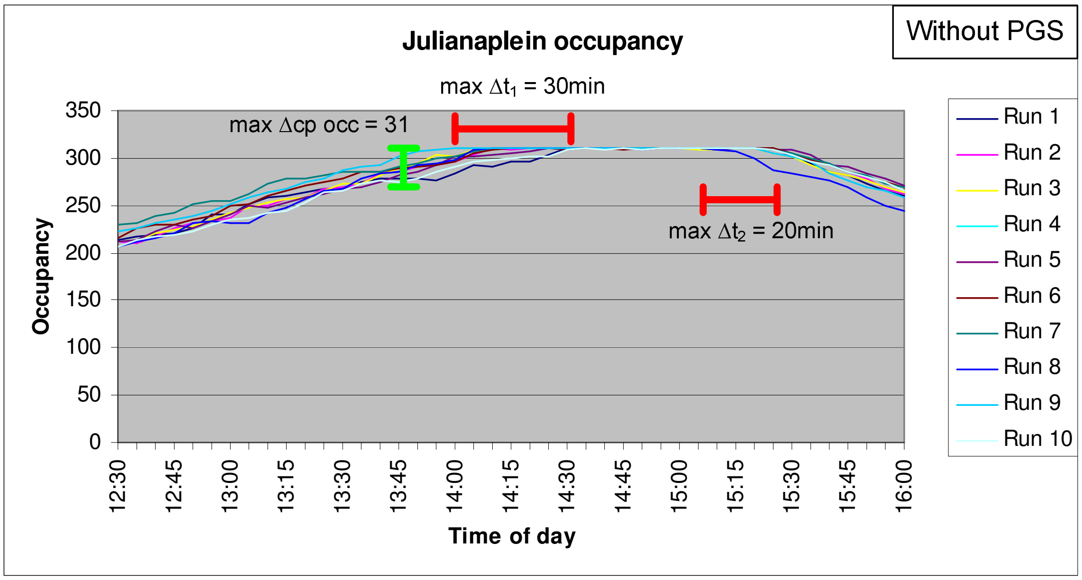
Figure 6-7: Possible outcomes of different model runs

It is important that the different model runs with the PGS tool show comparable outcomes, to use the outcomes to make predictions. The right figures show for instance outcomes which are less reliable, because there is a significant difference per model run.
The upper figure shows a significant difference in the values of the car park occupancy, which makes the outcomes unreliable for making predictions. The bottom figure shows that the shape of the accumulation profile is the same per model run, but changes over time. These outcomes

can however be used to draw conclusions about the duration of the occupancy reaching the capacity for instance.

For the Den Helder case the same set of 10 random seeds was used for the model runs with and without the PGS tool. Ten model runs with and without the PGS tool are analyzed. Figure 6-8 shows an overview of both outcomes. Three aspects are shown in the graphs:

- Max Δcp occ: the maximum difference between the occupancy numbers of different simulation runs at the same time;
- Max Δt_1: the maximum time difference between simulation runs at which the car park occupancy has reached its capacity;
- Max Δt_2: the maximum time difference between simulation runs at which the car park occupancy is dropping from its capacity again.



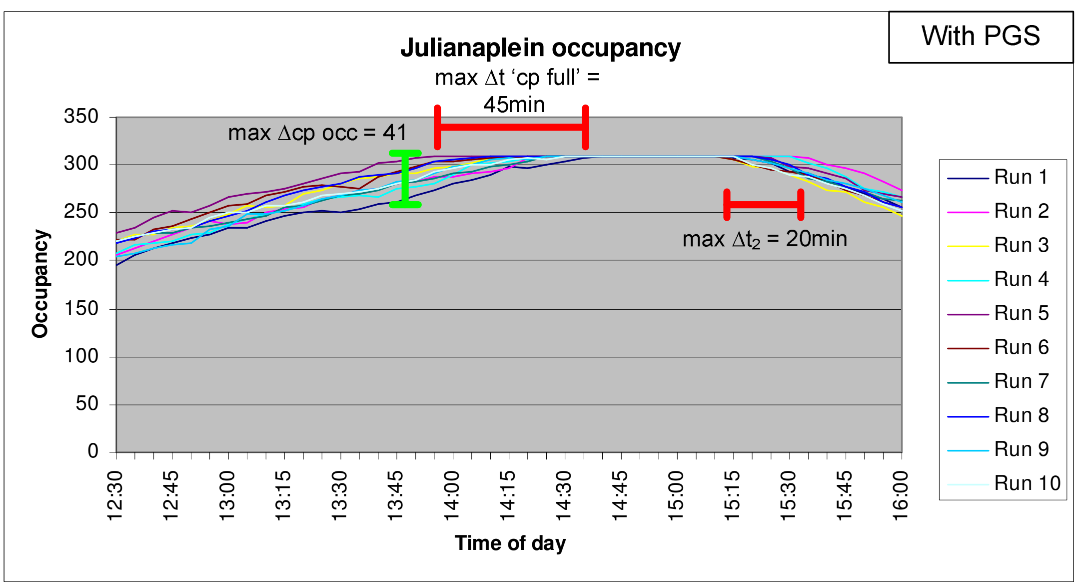


Figure 6-8: car park occupancies Julianaplein

The simulation runs without the PGS tool show a difference in occupancies with a maximum difference of 31. This difference increases to 41 in the simulation runs which include the PGS tool. This higher difference is mainly caused by one simulation run (run 1). In case this one was not part of the simulation runs the 'max Δcp occ.' would be 35 and 'max Δt_1' would be 35mins.

Reasons for a higher difference between the simulation runs with the PGS tool are the activation of other scenarios. The activation of other scenarios (with Julianaplein as alternative car park) leads to more traffic to the Julianaplein car park in this case.

The higher difference in 'max Δcp occ.' also leads to the difference in 'Δt_1', which is the difference in time at which the car park is full. This difference is larger when the PGS tool is in use.

This larger difference in the car park occupancies in the simulation runs with the PGS tool is also illustrated by the graph of the standard deviation (see Figure 6-9). The standard deviation is larger in the simulation runs with the PGS tool, especially at the time when (one of) the other car parks is almost full and re-routing scenarios are activated.

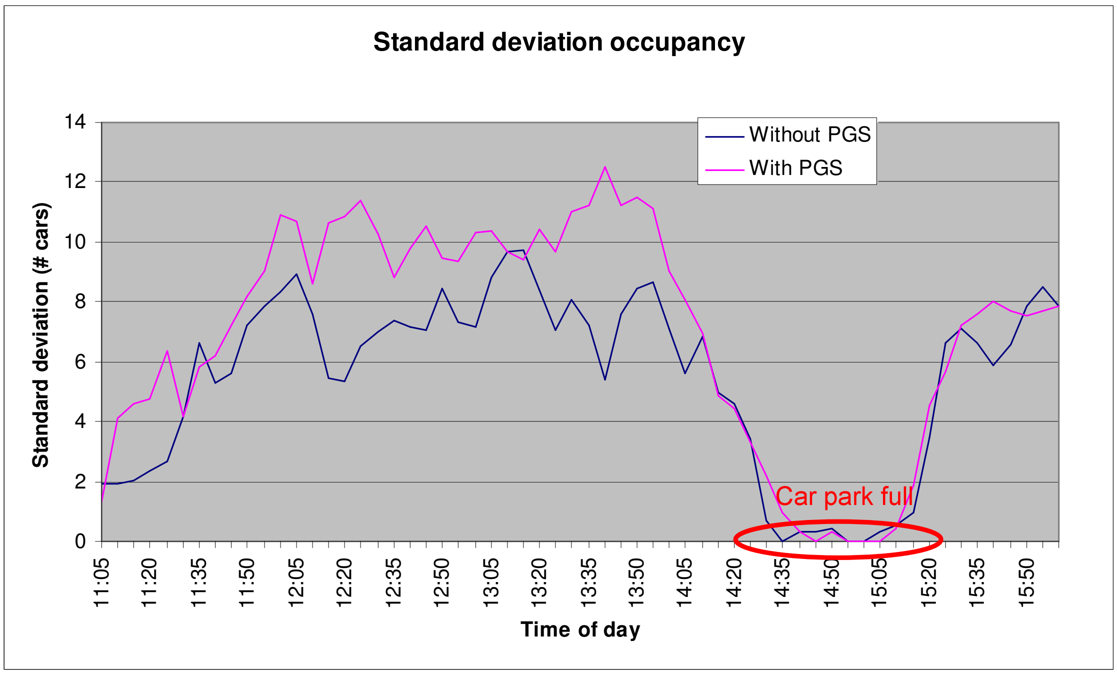


Figure 6-9: standard deviation car park occupancies Julianaplein

The standard deviation of the other car park accumulation profiles shows a comparable result when the PGS tool is in use. This means that in order to gain an average car park accumulation profile, when the PGS tool is in use, more runs are needed compared to the model runs without the PGS tool.

The duration of the car park being full shows variation for the simulation runs with and without the use of the PGS tool (Table 6-2). The standard deviations of the 'full duration' are comparable for the simulation runs with and without the PGS tool. The simulation runs with the PGS tool also show a slightly higher standard deviation.

Table 6-2: duration of Julianaplein car park being full

	Without PGS	With PGS
Average	72,5	58,1
Standard deviation	3,78	5,30

These outcomes show that the accumulation profiles of the different runs for car park have the same shape, but differ slightly over time. This means that the outcomes are more useful to make predictions about changes in the accumulation profile, than the exact number of occupied parking spaces at a certain time of the day.

The consequence is that the car park occupancies can mainly be used to make predictions about global changes in the accumulation profiles of car parks and not the exact occupancy at a particular moment.

Based on these results it is concluded the stability of the model runs are lower with the PGS tool, than without the PGS tool added to a S-Paramics network. To gain a reliable average it is therefore recommended to carry out more than 10 runs with the same set of random seeds.

6.5.3 Analyses of the outcomes

Third objective of this PGS tool case study is to investigate the options for showing the effect of the implemented PGS system on a network. The following indicators are investigated for showing the effects of the PGS tool:

- Car park occupancies;
- Queuing lines at entrance links of car parks;
- Queuing time at entrance links of car parks;
- Travel time;
- Traffic intensities.

<u>Car park occupancies</u>

The first traffic performance indicator which is investigated is the car park occupancy. The overall conclusion is that the effects of the PGS tool on the occupancies mainly result in:

- a shorter duration of time at which the ‘full car parks’ are full (see Julianaplein, Figure 6-10)
- a higher occupancy of the ‘non-full car parks’ (see Sluisdijk, Figure 6-11)

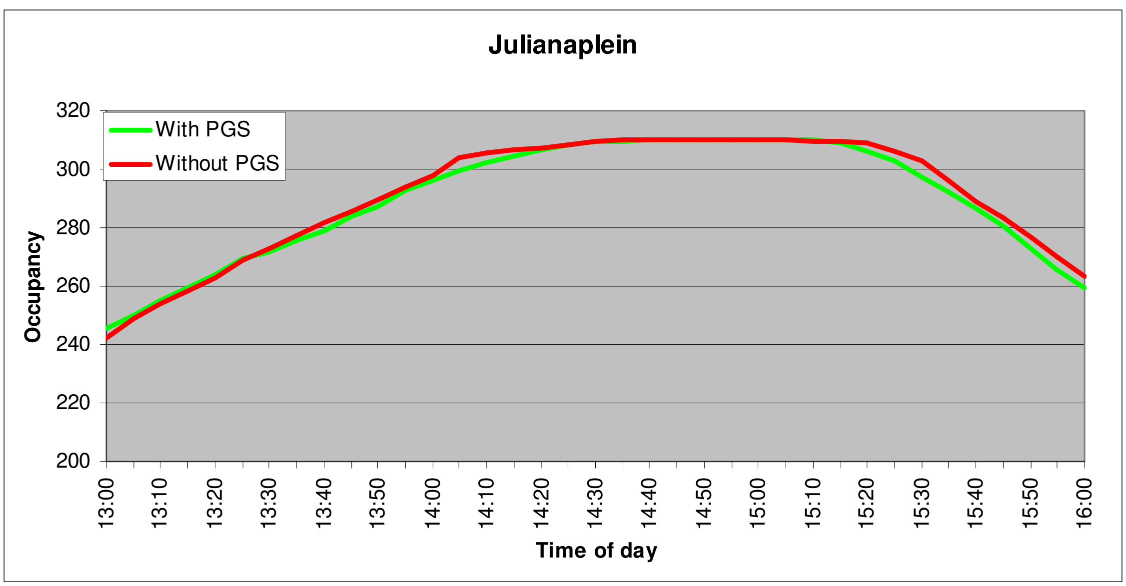


Figure 6-10: Julianaplein occupancy (average of 10 random seeds)

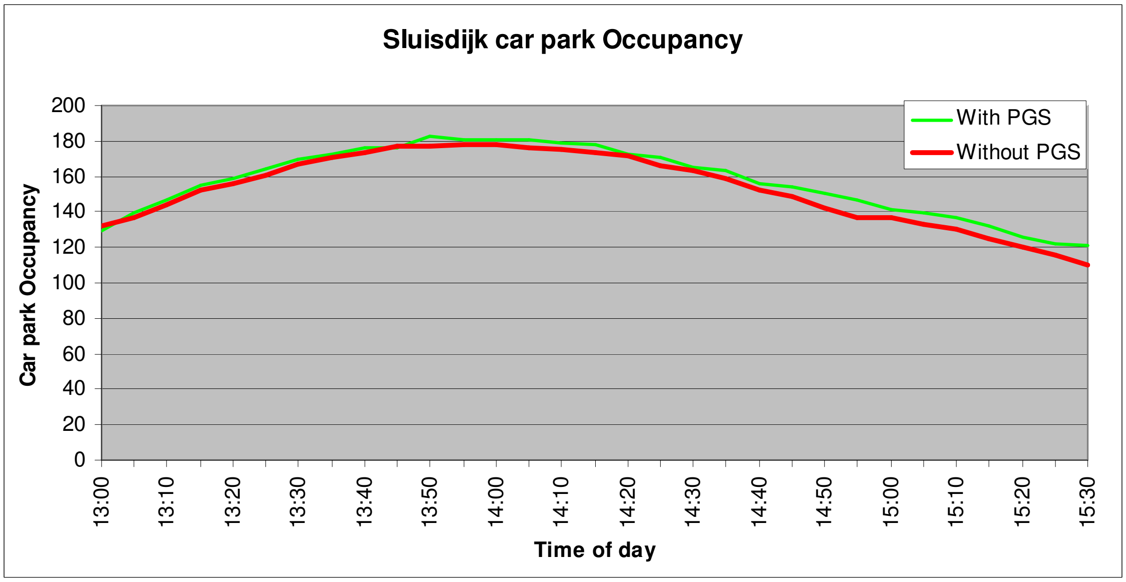


Figure 6-11: Sluisdijk occupancy (average of 10 random seeds)

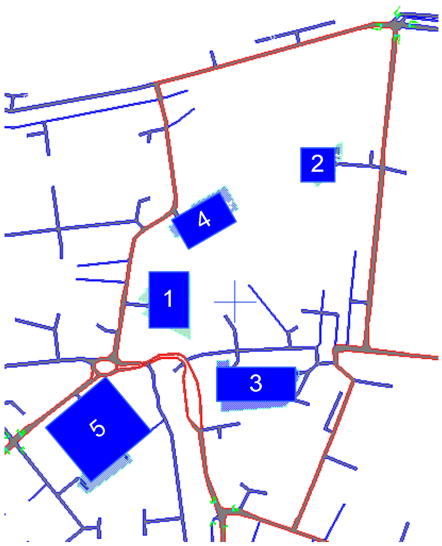
Table 6-3: duration 'full time' car park Julianaplein

	Without PGS	With PGS
Average	72.5	58.1
Standard devia-tion	3.78	5.30

The calculations in Appendix 6 show that the decrease in the full time (19.8%) in this case is a significant difference, using a significance level of 5%.

For the increase in car park occupancy at for instance the Sluisdijk car park, it is not proven that the maximum car park occupancy differs significantly, using a significance level of 5%, at a certain time of the day (Appendix 6). This is mainly caused by the larger standard deviation of the values at a certain time of the day.

A difference between the total occupancy of all car parks is not significant in the situation with and a without the PGS tool. Figure 6-12 shows an overview of the car park occupancies at 14h30 during the simulation runs. It shows that in the simulation runs the Julianaplein car park (1) and the Palmplein car park (2) are both full.



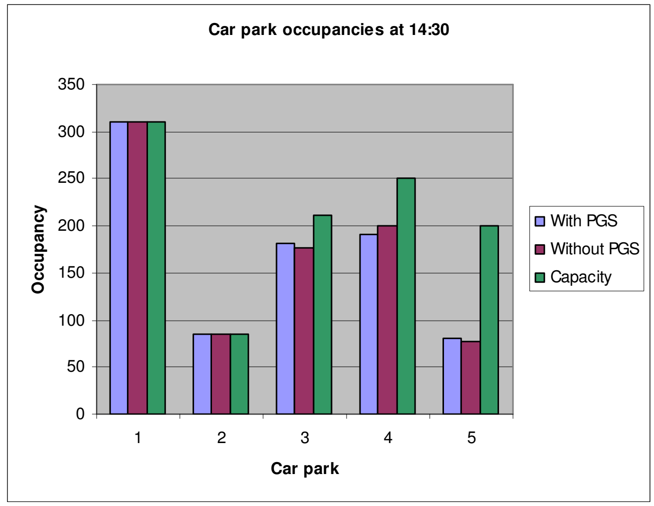


Figure 6-12: Overview car park occupancies

The Sluisdijk car park (3) is an alternative car park for the ‘full’ car parks and therefore shows an increased occupancy. The re-routing of cars to Sluisdijk also leads to a lower occupancy at the Koninckshoek car park (4) in this case. This is because a lower amount of cars will drive to the Julianaplein car park (1). In the situation without PGS more cars will drive to the Julianaplein car park at first. In case the car drivers notice the long queue in front of the Julianaplein car park, they will re-route to the Koninckshoek car park. This is less often the case in the situation with the PGS and therefore leads to a slightly lower occupation at the Koninckshoek car park.

<u>Queuing lines and travel time analysis</u>
As a result of cars being re-routed in the model by the PGS tool, the queuing lines and waiting times are expected to be reduced in front of the car parks. The reduction in queuing lines is measured at best in S-Paramics by the reduction in average queue length and waiting time.

Figure 6-13 and Figure 6-14 show the differences in the average queue length in front of the car park, between the simulation runs with and without the PGS.

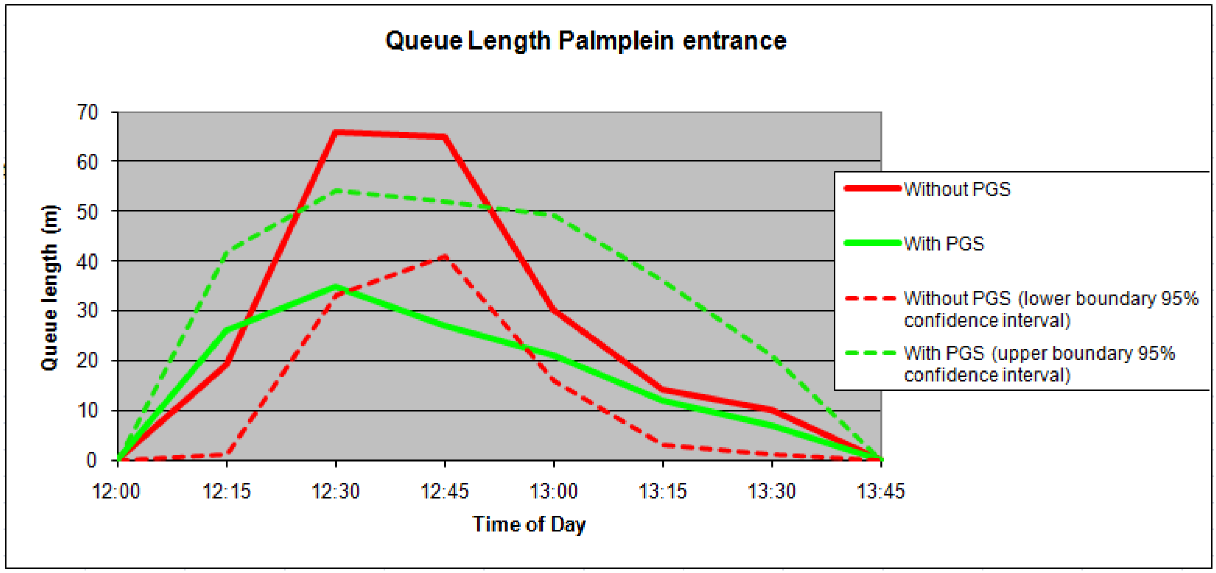


Figure 6-13: Queue length Palmplein

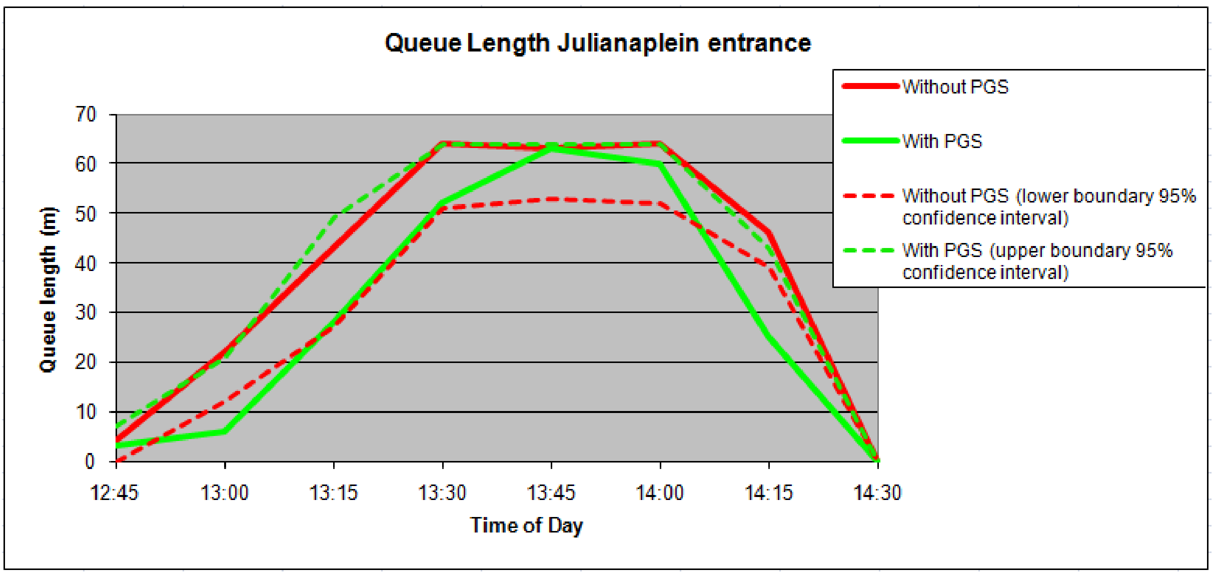


Figure 6-14: Queue length Julianaplein

The figures show a global decrease of the queuing lengths, because the total 'full time' of a car park is also reduced. The duration of the queues in front of the car parks also decrease significantly as a result of the decreased full time.

The queue lengths vary too much per simulation run at a certain time of day, to prove that this difference is statistical significant. Figure 6-13 and Figure 6-14 show the boundaries of the 95% confidence interval. These boundaries illustrate the high variation in queue lengths in the different simulation runs. This variation in the queue lengths at a certain time of day is caused by the accumulation profile of the car parks.

The reduction in queue length is also noticeable in the average wait time. This results in a shorter total travel time to a car park. Figure 6-15 shows an overview of the travel time over a route to the Palmplein car park. It shows that the average 'wait time' is reduced, in the model with the PGS tool applied.

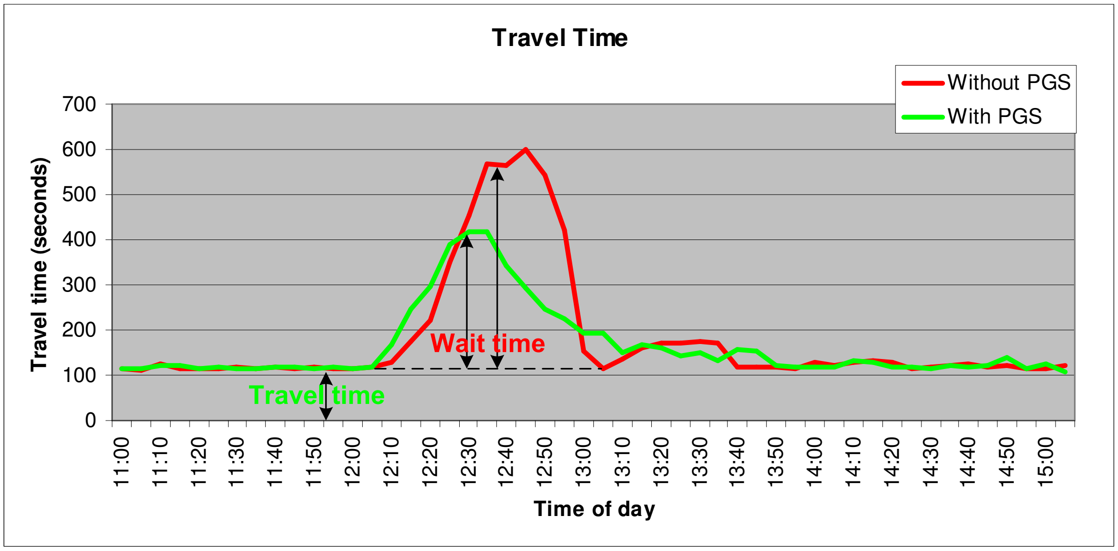


Figure 6-15: Travel time over route to car park

The wait time is related to the queue length. The queue length shows a high variation per simulation run (indicated by the confidence interval boundaries). Therefore the wait time also shows a high variation per simulation run. The average travel times seem to show a significant reduction in Figure 6-15. There is however also a high variation in the wait time at a certain time of day per simulation run. This variation is too high to prove that the reduction is significant for a certain time of day. Therefore a better indicator is the reduction measured in the total travel time within a cordon of the city centre.

The modelled network of Den Helder is large compared to the city centre where the car parks are located. Therefore a cordon around the city centre is used to measure the total travel time on the city centre part of the network. This is illustrated in Figure 6-16.

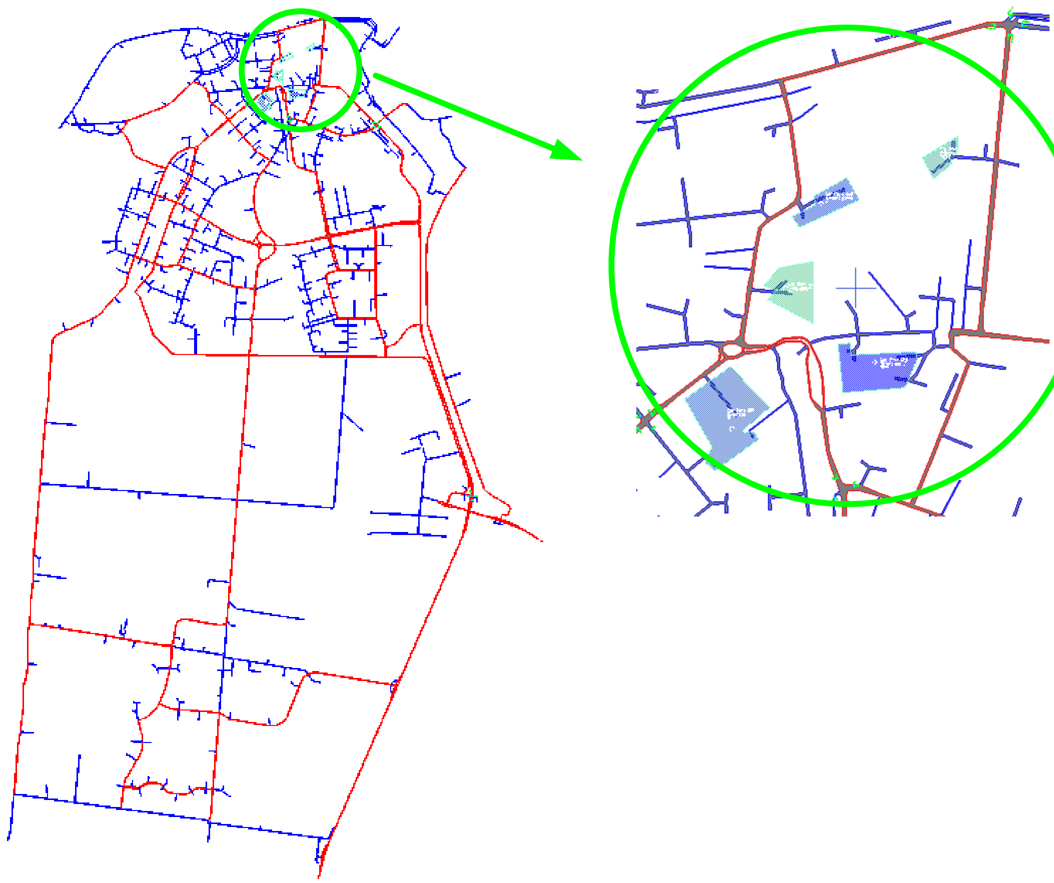


Figure 6-16: Overview 'travel time cordon'

The results of the reduction in the total travel time are shown in Table 6-4, and show that over the simulation time of 4 hours the total travel time within the cordon is decreased by 4.3%.

Table 6-4: total travel time

Simulation run	Total travel time within cordon (hours)	Difference
Without PGS	280.8	12 hours, reduction of 4.3% of total travel time within cordon.
With PGS	268.8	

The calculations in Appendix 6 show that the difference in total travel time within the 4 hours of modelling is a significant difference. Using the traffic performance indicator 'total travel time' within a cordon seems a better (more stable) traffic performance indicator then the wait times.

<u>Traffic intensities</u>
The link intensities in the model runs with and without the PGS tool are also compared. In this particular Den Helder case, the plots with the differences in link intensities do not show significant differences.

6.6 Discussion results

For the application of the PGS tool in the Den Helder model some assumptions and simplifications are used, which can deviate from the reality. This section discuses what can be implied from the analysis of section 5 taking into account the simplifications and assumptions in the model.

For applying the PGS tool a model with car parks is the basis. In this case a calibrated model was available for the morning and evening peak of weekdays, but such a model was not available for the Saturday. A Saturday model was therefore created based on the OD-matrices of the morning and evening peak models. The Saturday model was created for 2020 (which is based on the 2009 model) and can therefore not be calibrated on the car park occupancies. In this case the model was roughly 'calibrated' on the occupancy expectancies of the parking expert at the Municipality of Den Helder.
This brings the first limitation of the model and where it can finally deviate from the reality (in 2020). The main objective of this case study however is to demonstrate how to setup the PGS tool, analyse the stability of the outcomes and look at the possible indicators for assessing the impact of implementing PGS. And not what the exact effect of implementing PGS is on the traffic performance indicators, because the base model is not calibrated.

The assumptions which are part of the PGS tool could also have an effect on the stability of the simulation runs and the outcomes of the indicators. The main assumptions which can deviate from reality are:

- The amount of car drivers changing their car park destination based on the PGS information; and
- The actual choice for the new car park destination by the car drivers, based on the PGS information.

The amount of car drivers which change their car park destination based on the PGS information is set to 18%. This percentage was chosen, because surveys show that similar percentages of car drivers changing their car park destination. Surveys in different cities (European and Asian cities) show comparable outcomes on this matter. Therefore the choice for this percentage of car drivers changing their car park location can be justified.

A possibly less reliable assumption is the second assumption. For the case of Den Helder per ITS controller (representing a PGS sign) an alternative car park was set for car drivers, once a car park was full. In the model the assumption is that all car drivers which change their parking location based on the information of a PGS sign, will chose the same alternative car park. This alternative car park was in all cases the car park close to the original car park destination with the shortest travel time. For the case of Den Helder the possibilities for alternative car parks were therefore rather limited.

In reality it is possible that not all car drivers will chose the same alternative car park based on the displayed information on a PGS sign. This could lead to other results, than the results of the simulation runs. For the Den Helder case the alternatives are rather limited. For instance: cars approaching the city centre from the east side parking at Palmplein, only had one car park close to their original car park destination and destination zone. This was the Sluisdijk car park. Therefore it seems justified that most of the car drivers, who change their car park destination based on PGS information, will make this change.

In case a part of the car drivers however park in another alternative car park in reality than is the case in the model, then:

- Stability of accumulation profiles remains the same:
  The test case showed that the simulation runs without the PGS tool showed more stable accumulation profiles, than the simulation runs without the PGS tool. It is likely that this will remain the same once car drivers make another choice for an alternative car park in reality than is the case in the model. The accumulation shape of the full car parks stays the same, while the accumulation profiles of the non-full car parks might vary more.

- The shortened duration of ‘full time’ for car park A remains the same:
  A percentage of car drivers will re-route to another alternative car park C instead of the modelled alternative car park B. The effect on the duration of the full time of the car park A will however be the same, as in both situations the cars will not drive to car park A.

- The occupation of ‘non-full’ car parks change:
  In the occupation of the ‘non-full’ car parks there was no statistical significant difference found in the model runs with and without the PGS tool. This is mainly due to the high standard deviation as a result of the variation in time of the accumulation profiles. In the case a percentage of car drivers will re-route to another alternative car park C instead of the modelled alternative car park B, it is likely that there still will be no statistical significant difference.

- The reduction in queue length and wait time at the entrance of full car parks remain the same:
  For the queue length and wait time the same reasoning can be used as for the shortened duration of the ‘full time’.

- The decrease in total travel time within the cordon might change slightly:
  The decrease in total travel time, when the PGS tool is applied, is mainly caused by the reduction in wait time. The decreased wait time remains the same. The travel time however might increase slightly, in case some cars drive to an alternative car park which has a longer travel distance.

Overall it can be concluded that in case the alternative car park choice in reality differs from the modelled alternative car park choice:

- Does not change the traffic performance indicators related to the full car parks;
- Does change the traffic performance indicators of the ‘non-full’ car parks;
- Does not significantly change the traffic performance indicator total travel time.

The outcomes of this case study match with the observations of municipalities according to Dijkshoorn (2000). Most municipalities in the Netherlands noticed that there was a better distribution of parked cars over the car parks and that the queuing lines reduced at the entrance of car parks.

6.7 Summary

This chapter discussed the implementation of the PGS tool on a larger network. In the fourth section a demonstration is given about the setup of the PGS tool.

The ‘verification checks’ of the fifth section show that the tool functions as intended on a larger network. The ‘stability checks’ in the fifth section show that the stability of the simulation runs with the PGS applied is slightly lower. This stability is based on the accumulation profiles of the car parks, which do have the same shape but show some difference in time. This is caused by the small randomness in the release of vehicles on the network for instance, which causes small differences in the different model runs.
Therefore a recommendation is, to carry out more simulation runs, in case the PGS tool is applied. The standard deviation in the car park is occupancy is higher when the tool is in use, and therefore more simulation runs give a better estimation of the average.

The higher standard deviation of simulation runs in which the PGS tool is applied also plays a role in analyzing the traffic performance indicators. A difference can be made in the traffic performance indicators. The analyzed traffic performance indicators are:

- Indicators of which the value is summed up over a time period:
  - Duration of ‘full time’ of car parks;
  - Total travel time;
  - Traffic intensities.

- Indicators which are related to the value of a variable at a certain time of the day
  - Car park occupancy;
  - Queuing length;
  - Waiting time.

The analysis showed that mainly the indicators which are summed up over a time period do show a significant difference. The duration of the 'full time' of car parks and the total travel time did show significant differences between the simulation runs with and without the PGS tool.

The indicators which are related to the value of a variable at a certain time of the day, do show global differences in the simulation runs with and without the PGS tool. These indicators have however larger variations at a certain time of the day and do therefore not show significant differences.

7 Discussion and recommendations

In this final chapter the final product is discussed and recommendations are given. Section 7.1 describes the final product. Section 7.2 discusses the weaknesses of the PGS tool and section 7.3 discusses the strengths of the PGS tool. Section 7.4 gives recommendations for improving the technical functionality of the PGS tool. For a better representation of reality section 7.5 gives recommendation for additional research with regards to PGS. Finally section 7.6 gives recommendations about future possibilities for the application of the PGS tool.

7.1 The final product

The objective of this master thesis is formulated as:

> *"to develop an S-Paramics tool for modelling the effects of the implementation of parking guidance systems on the traffic performance"*

The final product of this master thesis is a PGS tool, programmed in external software, which is an addition to the current S-Paramics software. The PGS tool simulates the implementation of PGS on a network.

The PGS tool functions technically and the functionality is based on information from field studies with regards to PGS. The information of the field studies and the possibilities and limitations of S-Paramics have led to the following basic assumptions for the PGS tool:

- Car drivers use the information displayed on PGS signs to change their parking location, once their 'original' car park destination shows 'full' on the PGS sign;
- The PGS tool translates the change in parking location to an 'advice';
- This PGS 'advice' is an alternative car park close to their original car park;
- The 'advice' also contains a route advice, which is the shortest route over the main roads;
- The 'advice' depends on the location in the model where it is given;
- 15% to 18% of the car drivers in the model follow the PGS 'advice'.

These assumptions are translated to three steps for the functioning of the PGS tool:

- The input (car park occupancies) is retrieved from S-Paramics;
- Scenarios are activated/deactivated based on these car park occupancies;
- The activated scenarios contain measures, which start re-routing traffic to alternative car parks, in case their 'original' car parks are full.

The application of the PGS tool is location specific and therefore needs input for every specific model to which it is added. The input consists of:

- Addition of PGS infrastructure:
  - ITS controllers (representing PGS signs): the locations at which car driver behaviour is influenced.
  - Waypoints: the locations via which car drivers can be re-routed to alternative car parks in the model.
- PGS tool input
  - The scenario conditions (car park occupancies) define which advices are given by the PGS tool in the model.
  - Alternative car parks are defined as part of the PGS tool advice.
  - Routes to alternative car parks are defined as part of the PGS tool advice.

- Response settings define which car drivers and what percentage of car drivers follow to the PGS tool advice.

The PGS tool is a simplification of reality and the known effects of PGS. Some of the known effects of PGS are represented well in the PGS tool. Other effects deviate slightly in the PGS tool from reality. Table 7-1 shows an overview of the factors in reality and the representative factors in the PGS tool and S-Paramics.

Table 7-1: Overview representative factors PGS tool and S-Paramics

Factors in Reality	**Representative factors in S-Paramics and PGS tool**
Car drivers use PGS sign information to change their parking location, once their original locations shows ‘full’.	Scenarios are activated, once car parks are full in S-Paramics. The scenarios contain the alternative car park destinations for car drivers in the model, which represents the change in a car driver’s parking location.
Just a fraction (15 – 18%) of all car drivers change their parking location, because the PGS sign shows that their ‘original’ parking location is full.	A response profile can be defined in the PGS tool. This response profile includes the ‘original’ car park location and a response rate (the fraction of car drivers changing parking location).
The majority of the car drivers, which change their parking location based on the PGS information, are less familiar with the neighbourhood. These car drivers therefore follow the route instructions on the PGS signs.	Waypoints in the S-Paramics model can be used to re-route car drivers via the ‘parking route’ to their alternative car park destination.

Table 7-2 shows an overview of replacement factors in the PGS tool and S-Paramics, which slightly deviate from reality. These deviations have consequences, which are mentioned also in Table 7-2 and further discussed in section 7.2. In section 7.4 recommendations are made to overcome these consequences.

Table 7-2: Overview replacement factors in PGS tool and S-Paramics

Factors in Reality	**Replacement factors in S-Paramics and PGS tool and the side effects**
56% - 80% of the car drivers notice the PGS signs along the roads.	Whether or not car drivers notice PGS signs is not part of the PGS tool. As a consequence a change in the amount of car drivers noticing the PGS signs, does not change the amount of car drivers changing their car park location based on the PGS sign information in S-Paramics
Trip frequency and familiarity with the neighbourhood determines the likelihood of car drivers changing their parking location based on the PGS information.	The amount of car drivers following the PGS advice is set as a different vehicle type in the OD-matrix of S-Paramics. This brings the limitation that it is not possible to set different type of sensitivities (PGS follow-up percentages) of different ‘type’ of car drivers advices of the PGS tool.
Not all car drivers who change their parking location, because the PGS sign shows that their ‘original’ parking location is full, will drive to the same alternative car park.	The PGS tool re-routes all car drivers to the same alternative car park, in case their ‘original’ car park is full. A consequence is that the occupancy for some alternative car parks deviates from reality.

The case study showed that the PGS tool technically functions and that the effect of implementing PGS is noticeable on multiple traffic performance indicators, mainly the ‘full duration’ of a car park and the total travel time.

7.2 Weaknesses of the PGS tool

The weaknesses of the PGS tool are related to the modelling of parking behaviour in S-Paramics, the stability of the outcomes of simulation runs and the replacement factors in the PGS tool as illustrated in Table 7-2.

<u>The effect of PGS on ‘searching traffic’ is hard to model and measure in S-Paramics</u>
An important reason for municipalities to implement PGS is to reduce ‘searching traffic’. ‘Searching traffic’ exists of car drivers who are looking for a parking space, might not be familiar with the road network and are sometimes driving around ‘clueless’. The implementation of PGS helps to steer these car drivers towards an available parking space. ‘Search traffic’ is however very hard to model and to measure within the S-Paramics environment. Car drivers in S-Paramics are ‘intelligent’, know the road network and always drive towards their destination.

Without applying the PGS tool car drivers in S-Paramics decide to drive to an alternative car park, in case their original car park destination is full and there is a long queue on its entrance link. The car drivers will take the shortest route to this alternative car park and do not need any guidance (by PGS signs for instance). The application of the PGS tool ensures that a fraction of the car drivers will not drive to full car parks and will re-route to car parks with spaces available.

Therefore the total travel time or the distance travelled by car drivers might be underestimated in the simulation runs without the PGS tool. The effect of implementing PGS on the total travel time in the model is therefore also smaller then in reality.

<u>PGS tool causes higher standard deviations in traffic performance indicators</u>
Per simulation run there is a small randomness in the release of vehicles on the network and the perception of travel time per car driver in the model. The randomness in release of vehicles

leads to slightly different accumulation profiles of car parks. The Den Helder test case showed that these differences are slightly amplified by the application of the PGS tool. This has two consequences:

- The occupancy numbers of car parks have a higher standard deviation at a certain time of day, in case the PGS tool is applied. It is recommended to carry out more simulation runs, in case the PGS tool is applied. This will lead to a better estimation of the average occupation numbers.
- The larger standard deviation in the occupancy numbers also influences other traffic performance indicators. Several traffic performance indicators are related to the car park occupancies and show larger standard deviations as well. For the Den Helder case these indicators were less useful to determine if significant differences between the situation with and without PGS occurred at a certain time of day. This was the case for the indicators queuing length and waiting time. This can however be case specific, because in case studies with larger parking problems (e.g. longer queuing lines and waiting times) the variation can be relatively smaller in the model.

<u>Simplifications in model, necessary for PGS tool, lead to less detail in car park search model</u>
Chapter 2 described the available car park models in S-Paramics. Some of these models include different trip motives with different sensitivities to the parking costs factors. Different trip motives are set by using different vehicle types. The fraction of every vehicle type is defined in the ‘vehicle type proportions’ in the OD-matrix.
Chapter 5 described that a different vehicle type in the OD-matrix, which is sensitive to the PGS advices in the model, has to be created. This is done to solve a limitation of the PGS tool.

This has two consequences:

- It is not possible to use different sensitivities for different trip purposes towards the information displayed on a PGS signs. E.g. 30% of all car drivers with the trip motive shopping follow the PGS advices in the model, while only 5% of the commuters follow the PGS advices in the model.
- The vehicle type fraction of car drivers which follows the PGS advices in the model, has to be subtracted from another vehicle type in case different trip motives are used.

For instance the following trip motives and vehicle type proportion in the OD-matrix are used in an S-Paramics model with car parks:

- Vehicle type 1: Commuter trips (60%);
- Vehicle type 2: Shopping trips (30%);
- Vehicle type 3: Leisure trips (10%).

Now the PGS tool is applied and in consultancy with the client it is determined that the response rate to the PGS advices in the model is set to 20%. Vehicle type 4 is created in the OD-matrix as vehicle type sensitive to the PGS advices. The proportion of vehicle type 4 is 20%. All ‘vehicle type 4 cars’ will follow the PGS advice, in case it is linked to their destination car park. One of the other vehicle type proportions has to be decreased. The same cost sensitivity settings for vehicle type 4 must be used as the vehicle type from which the fraction is subtracted. E.g. the new setup would be:

- Vehicle type 1: Commuter trips (60%);
- Vehicle type 2: Shopping trips (10%);
- Vehicle type 3: Leisure trips (10%);
- Vehicle type 4: Shopping trips following PGS advice(20%).

7.3 Strengths of the PGS tool

The strengths of the PGS tool are related to the setup of the PGS tool and possibility to evaluate the effect on multiple traffic performance indicators.

<u>Effect on multiple traffic performance indicators can be determined with PGS tool</u>
The PGS tool is applied to the microsimulation software of S-Paramics. Therefore the main strength of the PGS tool is that the tool can determine the expected effects of implementing PGS on multiple traffic performance indicators. The effect on the total travel time, traffic intensi-

ties and queue lines can be determined, besides the effect on the car park occupancies, with the application of the PGS tool.

The setup of the PGS tool uses a clear structure and is transparent for municipalities
In case the PGS tool is used to determine the expected effect of implementing PGS, the setup can be determined in consultation with the municipality. It is a relatively simple tool which overwrites the final car park destination of car drivers in simulation runs. This means that the municipalities do not need to have extensive knowledge about route choice behaviour in the micro-simulation models, to understand the functionality of the tool.

Due to the simple setup of the tool the municipalities can contribute to the input of the tool. The input can be determined by the municipality and consists of the advised alternative car parks and the routes towards the car parks. The simple and transparent setup of the PGS tool also leads to explainable results, once it is applied to a model. This prevents the tool from becoming a black box.

The PGS tool is a flexible tool
The possibility to manually set the input of the PGS tool makes it a flexible tool, which can be used for multiple purposes. For the case study in this master thesis, the PGS tool was used to determine the effects of implementing PGS in Den Helder.
Other purposes for which the tool can be used are:

- Changes in the routing setup of a PGS: In case congestion appears on the network, multiple parking routes can be set as input for the PGS tool. Traffic can be routed clockwise or counterclockwise on a ring road structure for example. The outcomes can show which routing strategy leads to the least congestion and help municipalities in the choice for the setup of the PGS.
- The PGS tool uses a ‘response rate’ to set the amount of car drivers which change their parking location, once they notice on a PGS sign, that their ‘original’ parking location is full. By using different ‘response rate’ scenarios, it can be shown at which ‘response rate’ implementing PGS is really beneficial for a municipality.

Fast computational speed of the PGS tool
The simulation runs of the Den Helder model showed that the addition of the PGS tool to the model increased the calculation time with a few minutes. While the total calculation time of one simulation run for the Den Helder was about 35 minutes per simulation run. This means that the addition of the PGS tool to a model, does not cause a large extension of the total calculation time.

7.4 Recommendations for further development PGS tool

The PGS tool is a newly developed product and there are still possibilities for improvement and further development of the technical functionality.

Calibration of PGS tool
This master thesis focuses on the development of a PGS tool, which can be used to predict the effects of implementing PGS. The modelled effect of PGS is based on surveys, which investigated the use of the information on PGS signs. This means that the modelled effects of the PGS tool, can be used to make predictions about the implementation of PGS.

The PGS tool can however be further calibrated for an existing PGS situation in case municipalities have available of the parking situation before and after the implementation of PGS. Therefore it is recommended to look at the possibilities for calibrating the PGS tool. The setup of the tool remains the same. The additional variables for calibration are then the amount of vehicles responding to the PGS ‘advice’ and the alternative car parks which are set as ‘advice’. This also opens the possibility to investigate what the expected effects are, in case the setup of a PGS in a the city is changed.

<u>Multiple alternative car parks</u>
Currently one of the limitations of the PGS tool, is that it is only possible to set one car park as an alternative car park. As a consequence all the re-routed car drivers (instructed by the same ITS controller) in the model drive to the same alternative car park. This can deviate from reality, where car drivers might re-route to different alternative car parks once they notice that their ‘original’ car park destination is full. Therefore it is recommended to look at the possibilities for improving the ‘re-routing to alternative car parks’ functionality of the tool. A better representation of reality is gain, in case it is possible to re-route cars to multiple alternative car parks.

7.5 Recommendations for further research PGS

The available field studies with regards to PGS are used for the development of the PGS tool. These studies focus on what percentage of car drivers changes behaviour based on information displayed on PGS signs. Secondly the characteristics of these drivers were investigated. The exact change in behaviour, was not often part of these field studies. E.g. in case four car park occupancies were shown on the PGS sign, of which one car park was full, it was not clear which of the other car parks was chosen as new destination by car drivers.

There is little research available about the human factors side of PGS and other dynamic traffic management (DTM) measures. The human factor side is however important to determine the effect of PGS. Therefore it is recommended to further investigate the human factor aspects of PGS. When more insight is gain in the response of car drivers towards the presented information on a PGS sign, the PGS tool can be improved.

7.6 Recommendations for future application

New developments for parking guidance systems also offer new opportunities for the future application of the PGS tool. Two possible future applications for the PGS tool are discussed in this section.

<u>Integrating PGS with other DTM measures</u>
Currently the PGS tool only advices an alternative car park, based on car park occupancies. The latest PGS signs also have a dynamic route display. A route is advised to a car park on this route display, based on the situation on the road network. Grontmij is currently developing an ITS scenario manager, which simulates different DTM measures. These DTM measures are triggered by for instance link intensities or travel times. The PGS tool is incorporated in the ITS scenario manager. Therefore an additional future possibility is to base the PGS route advice on the link intensities or travel times on the road network in the model.

<u>PGS incorporated in in-car system</u>
In section 2.3 a new development with regards to PGS is mentioned: the addition of PGS to in-car navigation systems. New options are possible for the PGS tool, in case the majority of the cars have these in-car navigation systems in the future.

There is a difference between PGS incorporated in in-car systems and PGS signs along roads. In-car systems change the final parking destination, based on the car park occupancies, for the car driver. While the PGS signs along the roads provide information with regards to the car occupancies. Car drivers use this information to determine what their new parking location will be.

This means that for the in-car systems an alternative car park is set as destination, just as now happens with the PGS tool. In case the majority of cars have in-car systems and use this PGS function, the PGS tool can be used to determine the effects of different advice strategies. The in-car systems have more options for ‘steering’ the car drivers, compared to PGS signs.
For instance different scenarios can be ran and compared:

- What happens if car park C instead of car park B is set as new destination for the car drivers?;
- What happens if we re-route cars via point C instead of B towards car park B. etc.

The functionality remains the same for this possible future use of the PGS tool.

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Appendix 1 PGS tool verification tests

This appendix describes the way the parking guidance tool is tested, to prove that the tool functions as intended. This is done in 8 steps.

1. The first section gives a short description of the functionality of the PGS tool;
2. The second section describes the functioning of the scenario conditions;
3. The third section describes the functioning of the response profile;
4. The fourth section describes the possibilities for re-routing car drivers to 2 car parks;
5. The fifth section describes what happens in case a traffic flow passes two ITS controllers;
6. The sixth section describes the need for defining unique scenario conditions;
7. The seventh section gives a short summary and conclusion of this Appendix.

1. Short description of the functionality of the PGS tool
The developed beta tool for parking guidance systems is part of the ITS scenario manager tool. The ITS scenario manager tool is an addition to the software of S-Paramics. Part of the final ITS scenario manager will include:

- Parking guidance systems;
- Variable message signs;
- Ramp metering;
- CCOL traffic lights control system.

The ITS scenario manager is additional software and not integrated in the S-Paramics software. Figure 2 gives a schematic overview.

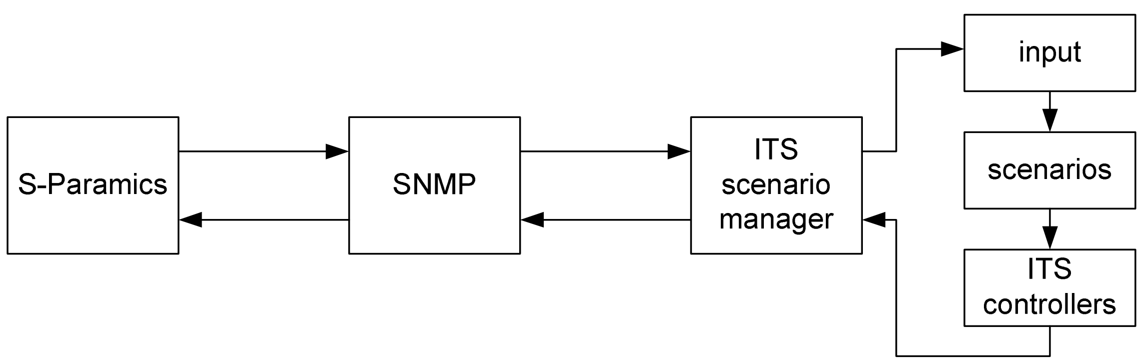


Figure 17: ITS scenariomanager

In S-Paramics the ITS–controllers are placed. These ITS-controllers are used as parking guidance systems. The Simple Network Management Protocol (SNMP) is used for communication between S-Paramics and the ITS scenario manager.

The interface of the ITS scenario manager is currently an XML-file, in which three aspects are defined.

- Input;
- Scenarios;

- ITS-controllers.

On the next page is an example of the XML-code which is defined for a single PGS device which is linked to two car parks.

The XML-code exists of three parts:

- <itscontrollers> </itscontroller>: in between those two headers the re-routing measures are defined. The re-routing measures consist of the behaviour change, the response profile and the visual appearance on the PGS sign;
- <input> </input> : in between those headers the input is defined. The input consists of the car park occupancies and capacities.
- <scenarios> </scenarios> : in between those headers the different possible scenarios are defined. Every scenario contains measures which will be activated once a scenario is enabled. For every scenario enable and disable conditions are set, which can be either the absolute occupancy or occupancy rate.

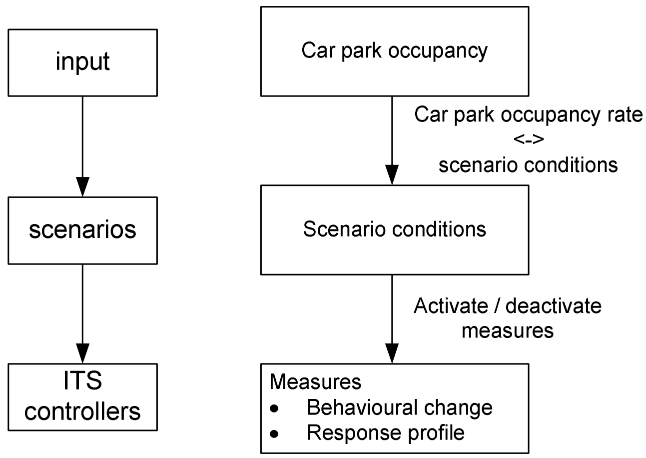
```
<itsscenariomanager xmlns="urn:itsmgr-schema">

<itscontrollers>
   <itscontroller type="pgs" name="PGS">
      <defaulttext> P1 vrij             P2 vrij</defaulttext>
         <measure name="P2toP1">
           <text> P1 vrij             P2 vol</text>
              <behaviour type="carparkadvice" name="P1" target="P2">
                <response type="destinationcarpark" name="P2" tar-
                get="P2"/>
                <response type="responsefactor" name="10" factor="20"/>
              </behaviour>
         </measure>
    </itscontroller>
</itscontrollers>

<input>
    <carparks>
      <carpark name="P1" timestep="59"/>
      <carpark name="P2" timestep="59"/>
      </carparks>
 </input>

<scenarios>
    <scenario name="test">
      <measures>
        <measure controller="PGS" measurename="P2toP1"/>
      </measures>
      <enable>
         <and>
           <exp type="occupancyrate" target="P2" operator="GE">95</exp>
           <exp type="occupancy" target="P1" operator="LT">190</exp>
        </and>
      </enable>
      <disable>
        <or>
          <exp type="occupancyrate" target="P2" operator="LT">95</exp>
          <exp type="occupancy" target="P1" operator="GE">190</exp>
        </or>
      </disable>
    </scenario>
</scenarios>
```

When the ITS scenario manager is started it pauses S-Paramics after a pre-defined time step. Then the following happens in case of the PGS tool:



- The input is retrieved from S-Paramics in this case the car park occupancy;
- The occupancy is compared with the enable and disable conditions of the scenarios
- Scenarios are enabled or disabled;
- Every scenario contains measures which are enabled and set for the ITS controllers;
- The measures of the ITS controllers contain the behavioural change, the response profile of car drivers which respond to the advice displayed and the visual appearance of the PGS advice;
- The behavioural change, response profile and visual appearance are communicated back to (the ITS controllers of) S-Paramics.

2. The scenario conditions

To test whether the scenario conditions functions correctly two tests are carried out. The scenario condition is the occupancy(rate) of a car park at which the PGS device should either start or stop advising in the model.
To test whether these scenarios function as desired, two scenario tests are carried out. The first scenario test run tests the enabling and disabling of a scenario based on the occupancy of one car park. The second scenario test run tests the enabling and disabling of a scenario based on the occupancy of two car parks.

<u>Scenario test 1: Scenario condition based on the occupancy of one car park</u>
A first test of the advice threshold is whether the enabling and disabling of an advice scenario based on an occupancy works. In Figure 18 the setup of the test network is displayed. This test network contains two car parks, where P2 has a much larger walking distance to the destination than P1. Therefore all drivers will drive to P1, since the total trip costs are lower when driving to P1.

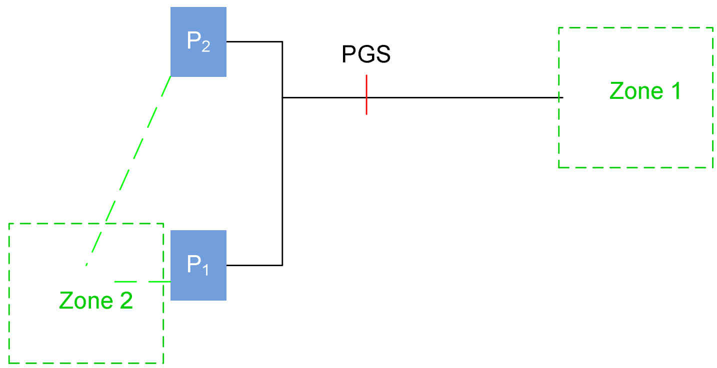


Figure 18: Test network

P1 has a capacity of 40 spaces and P2 has a capacity of 200 spaces. The scenario is defined as follows:

Start/enable advice scenario 'to P2' in case:
P1 occupancy rate $\geq$ 50% (20 parking spaces)
Stop/disable advice scenario 'to P2' in case:
P1 occupancy rate < 50% (20 parking spaces)

For this test case all car drivers (100%) is re-routed once the advice scenario is enabled, to test whether the scenarios function as desired.

Figure 19 shows the occupancy of car park P1 during the simulation run.

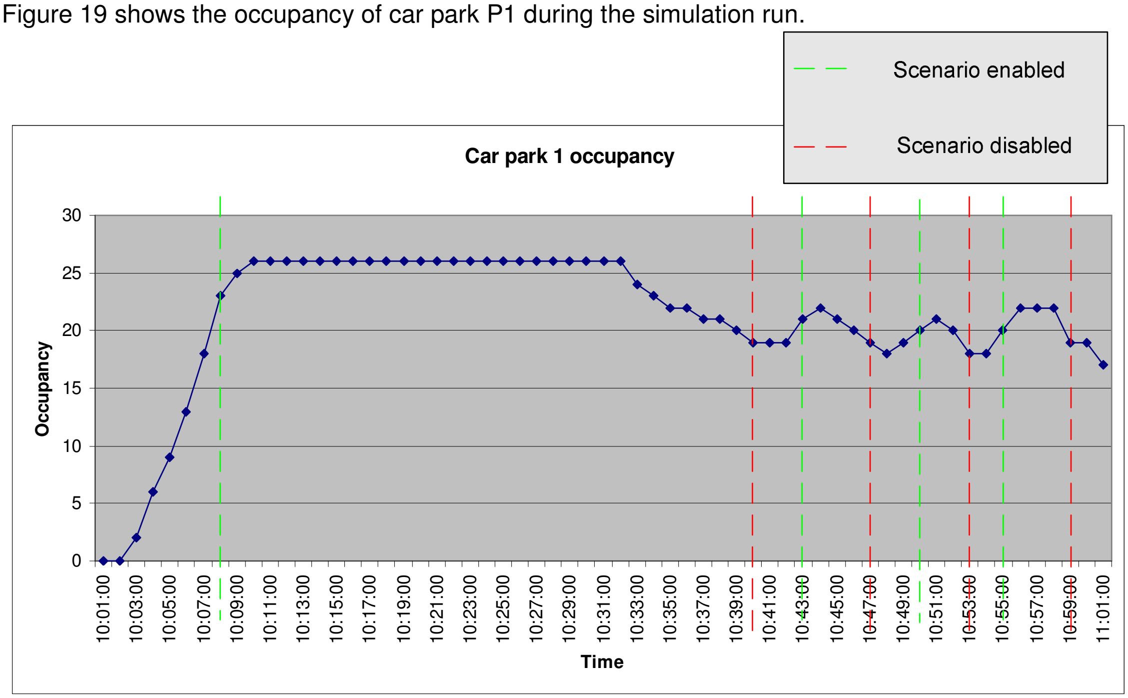


Figure 19: Occupancy car park P1

Below is the simulation run log, which logs at which time in the simulation run the scenarios are enabled and disabled.

Simulation run log:
[ITSManager] 10:08:00: scenario to P2 enabled
[ITSManager] 10:40:00: scenario to P2 disabled
[ITSManager] 10:43:00: scenario to P2 enabled
[ITSManager] 10:47:00: scenario to P2 disabled
[ITSManager] 10:50:00: scenario to P2 enabled
[ITSManager] 10:53:00: scenario to P2 disabled
[ITSManager] 10:55:00: scenario to P2 enabled
[ITSManager] 10:59:00: scenario to P2 disabled

The log file shows that the scenarios are enabled and disabled at the right times, when the numbers of the occupancy graph are used. After the time, at which a scenario is enabled, the occupancy still increases. This is due to the fact that at the time the scenario was enabled a number of cars on the network have already passed the PGS, but have not arrived at the car park at that time.

<u>Scenario test 2: scenario conditions based on the occupancies of two car parks</u>
The second test is to check whether the enabling and disabling of scenarios based on multiple occupancies of car parks works. The same test network is used as for the first test.
The scenario is now defined as follows:

Start/enable advice scenario 'to P2' in case:
P1 occupancy rate ≥ 50% (20 parking spaces)
P2 occupancy < 60 parking spaces
Stop/disable advice scenario 'to P2' in case:
P1 occupancy rate < 50% (20 parking spaces)
P2 occupancy rate ≥ 60 parking spaces

In case this scenario is enabled all cars will be re-routed.

Figure 20 shows the car park occupancies during the simulation run. Since the total trip costs by using P1 are still by far the lowest all car drivers will park in P1. Once the occupancy of P1 is greater than 20 spaces, the scenario is enabled and all car drivers are re-routed to car park P2. Once the occupancy of car park P2 reaches the 60 spaces the scenario is disabled. At this point all drivers will driver to P1 again, because the total trip costs are the lowest using the P1.

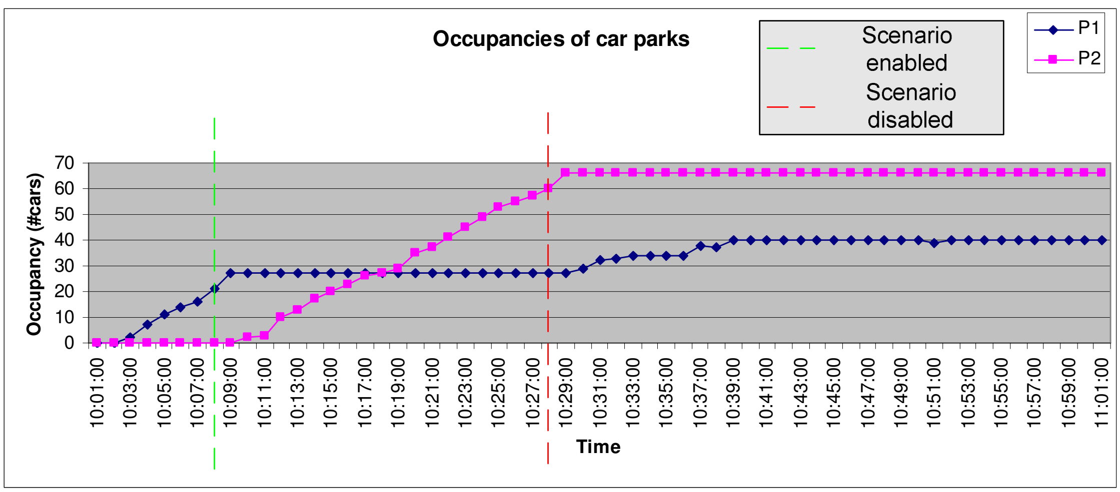


Figure 20: car park occupancies

Logfile ITSManager [ITSManager] 10:08:00: scenario to P2 enabled [ITSManager] 10:28:00: scenario to P2 disabled

The graph of the occupancies and the logfile show that this scenario also functions as desired.

3. Response profile of car drivers
The response profile for the PGS can consist of three response filters/factors:
- the destination car park;
- the vehicle type;
- response rate (percentage).

To test whether these response elements function as desired three tests for each response factor separately were carried out.

Destination car park filter
To demonstrate that the car park destination filter works the test network of Figure 21 was used and the following settings were chosen:
- Only cars with car park P1 as destination will be re-routed;
- 100% of these cars will be re-routed
- The re-routing starts directly at the start of the simulation run;
- 100 cars were released, of which 50 cars with zone 2 as destination and 50 cars with zone 3 as destination.

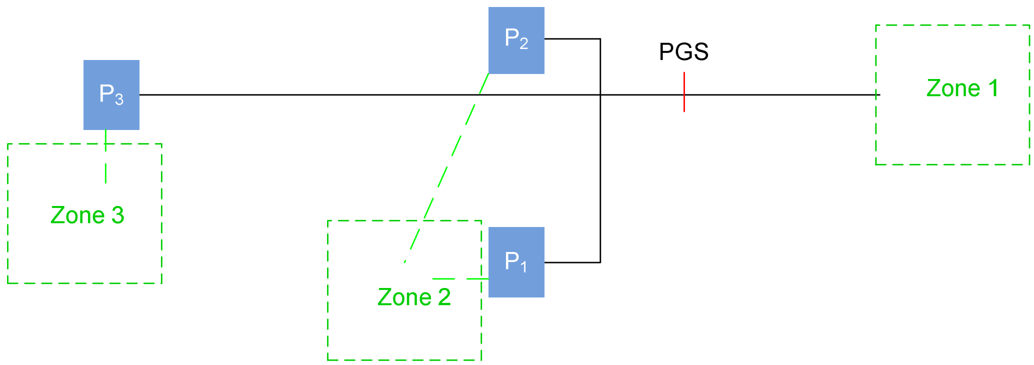


Figure 21: test network

This means that the 50 cars with destination zone 3 and car park P3 should not be re-routed to car park P2. All the cars with zone 2 and originally with car park destination P1 will be re-routed to P2. The selected link analysis of the entrance links P2 and P3 indeed showed that the 50 cars with zone 2 as destination parked in P2, while the 50 cars with zone 3 as destination parked in zone 3.

Vehicle type filter
The second response filter, which was tested is the ‘vehicle type’ filter. For this test the test network of Figure 22 is used. To test whether the vehicle type as response filter functions two vehicle types were used in this simulation run. A total of 200 cars was released on the network and the vehicle proportions are set to:
- Vehicle type 1: 50%
- Vehicle type 2: 50%

The settings of the response filter were set to:
- Only cars with car park destination P2(southern car park) were rerouted to car park P1 (northern car park);
- Only vehicle type 1 is re-routed;
- 100% of these cars is re-routed.

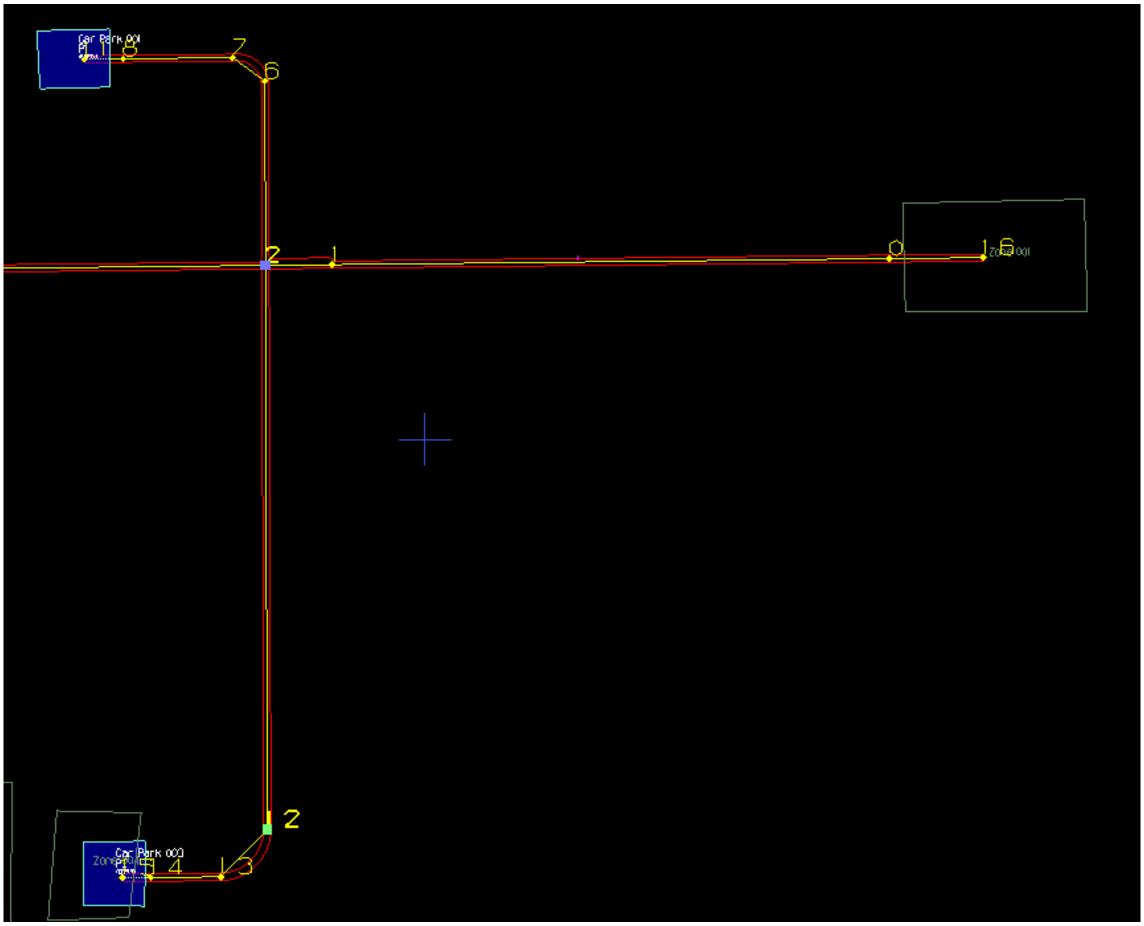


Figure 22: test network

Table 0-1 shows the results of the selected link analysis. Firstly it shows that the vehicle proportions were slightly different than 50% - 50% (in this case 46.5% - 53.5%). Secondly it shows that only and all cars with vehicle type 1 are re-routed to car park 1(vehicle type 1 only uses the links to P1), which means that this filter function works as desired.

Table 0-1: selected link analysis

Link number	Vehicle type 1	Vehicle type 2
0:01	93	107
1:02	93	107
2:06	93	0
2:12	0	107
6:07	93	0
7:08	93	0
12:13	0	107
13:14	0	107

<u>Percentage of re-routed cars</u>
The third response filter which is tested is the response percentage. To test whether the 'right' amount of cars is re-routed 100 cars were released on the network of Figure 18, of which 20% was re-routed to P2.
The outcomes are shown in Figure 23. The outcomes show that at the end of the simulation 80 cars are parked in P1 and 20 cars are parked in P2. A manual check during a simulation run

was carried out to check the way of selecting cars for re-routing. In this case it was notified that 'every fifth' car was selected to be re-routed, thus:

- Cars 1 to 4 headed for car park P1;
- The fifth car re-routed to P2;
- Cars 6 to 9 headed for car park P1;
- The tenth car re-routed to P2;
- Etc.

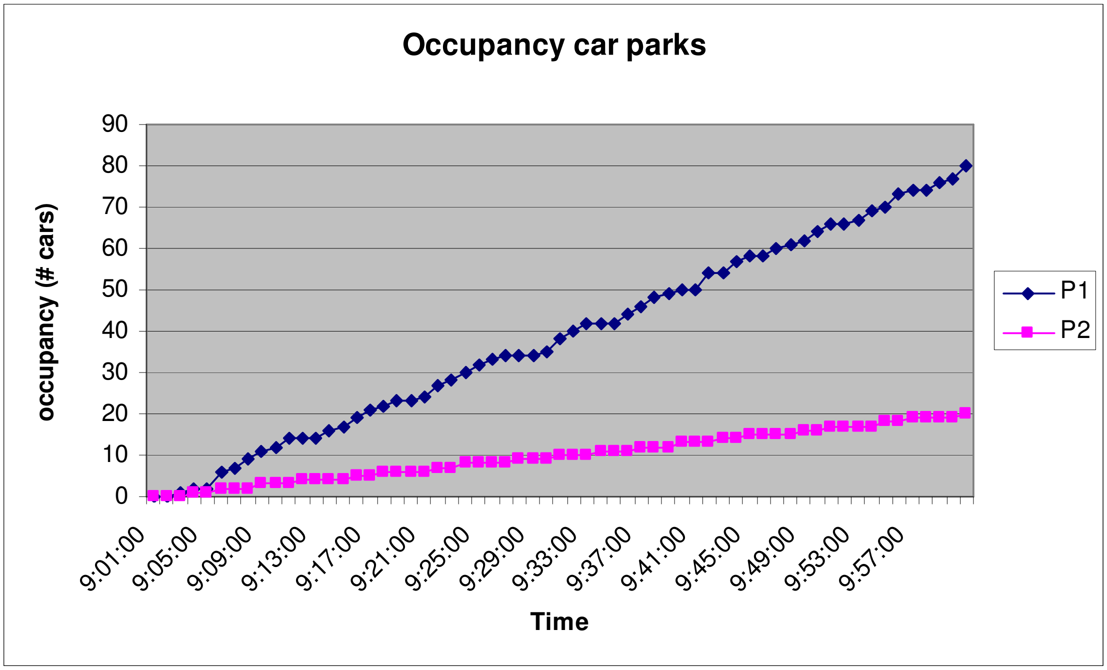


Figure 23: occupancy car parks P1 & P2

This means that the selection of cars for re-routing does not happen randomly.

<u>Priority order of response filters</u>
The PGS tool has three filter options which function. The tool does however have a priority order for giving in these response filters.
For instance if the following code is entered in the XML-code:

```
<behaviour type="carparkadvice" name="P4" target="P4">
            <response type="destinationcarpark" name="P3" tar-
get="P3"/>
            <response type="responsefactor" name="10" factor="10"/>
</behaviour>
```

10% of all car drivers with car park 3 as destination will be re-routed. If however the following is set:

```
<behaviour type="carparkadvice" name="P4" target="P4">
            <response type="responsefactor" name="10" factor="10"/>
            <response type="destinationcarpark" name="P3" target="P3"/>
</behaviour>
```

First 10% of all car drivers chosen for re-routing, secondly of this 10% only the car drivers with destination car park 3 is re-routed. This can give a lower number of re-routed cars then in the first situation. Therefore the percentage of re-routed car drivers should always be the last filter option. Since the response percentage is chosen based on the car drivers who fit the profile for being re-routed.

4. Re-routing to two car parks

In case three car parks are linked to two car parks, cars can be re-routed to two car parks. This does however have a limitation. Below is the code for re-routing cars to two car parks, in case one car park is fully occupied.

```
<measure name="P3vola">
    <text>P1 vrij             P2 vrij             P3 vol</text>
        <behaviour type="carparkadvice" name="P1" target="P1">
            <response type="destinationcarpark" name="P3" tar-
get="P3"/>
            <response type="responsefactor" name="10" factor="10"/>
        </behaviour>
</measure>

<measure name="P3volb">
     <text>P1 vrij             P2 vrij             P3 vol</text>
         <behaviour type="carparkadvice" name="P2" target="P2">
            <response type="destinationcarpark" name="P3" tar-
get="P3"/>
            <response type="responsefactor" name="10" factor="10"/>
         </behaviour>
</measure>
```

In this example the idea is to 10% of the cars is re-routed to P1 and 10% of the cars is re-routed to P2. 100 cars with P3 as car park destination were released on the network and the following happened:

- 10% of the 100 cars (10 cars) were re-routed to P1;
- 10% of the remaining 90 cars (9 cars) were re-routed to P2;

Looking at the code this could be expected: Of 10% of the cars (10 cars) the destination is set to P1, which means only 90 cars fit the profile for measure “P3volb” as they have P3 as destination.

5. Car flows passing 2 PGS devices

The PGS devices in S-Paramics are functioning on itself and therefore start re-routing cars every time a scenario is activated. This means that using too many PGS devices can lead to a higher number of cars being re-routed as was originally intended. In a test network two PGS devices (PGS1 and PGS2) were placed at sequential links.
100 cars were released which fit the profile for being re-routed, however only 20% should be re-routed. This 20% of the car drivers, which originally has P1 as destination car park, should be re-routed to P2. When both devices are set to a response rate of 20% the following will happen:

- At PGS1: 20% of the 100 cars (20 cars) is re-routed to P2;
- At PGS2: 20% of the remaining 80 cars with P1 as destination (16 cars) is re-routed to P2;
- Thus: a total of 36 cars (and thus 36%) of the cars is re-routed to P2.

To prevent this from happening it is important to make a clear plan for the location of the PGS devices in the model. This does not necessarily have to match the reality, since in reality more PGS’s at several locations can be desired to provide the road users with information. In S-Paramics drivers are instructed to park in another car park by the PGS tool and will chose the shortest route and do not have to be guided as drivers in real life.

6. The use of unique scenarios in the XML-code
Every scenario defined in the XML-code must be unique to prevent a 'pinball-effect' of switching between the scenarios every minute. In case the conditions for enabling and disabling scenarios have an overlap, this will happen every minute when the status of the scenarios is updated.

7. Summary and conclusion
The tests performed with the PGS tool have shown that the tool is capable of:

- Re-routing traffic to another car park, as long as the car park is linked to the destination zone;
- Car traffic which will be re-routed can be selected based on:
  - Destination car park;
  - Vehicle type;
  - Response percentage.
- Cars with a full car park as destination can be re-routed to multiple other car parks.

When defining the settings for the PGS devices in the XML-code is important to take into account that:

- The selection criteria for re-routing cars have a priority order: The first formulated criterion will be applied first, then the second etc. Therefore the percentage of car drivers responding to the advice should always be listed as last;
- The conditions for enabling and disabling scenarios must be unique, which results in no possible overlap between scenarios;
- Every PGS device functions independently in S-Paramics, thus a PGS device starts re-routing traffic (in case a scenario is activated) every time traffic passes a PGS device.

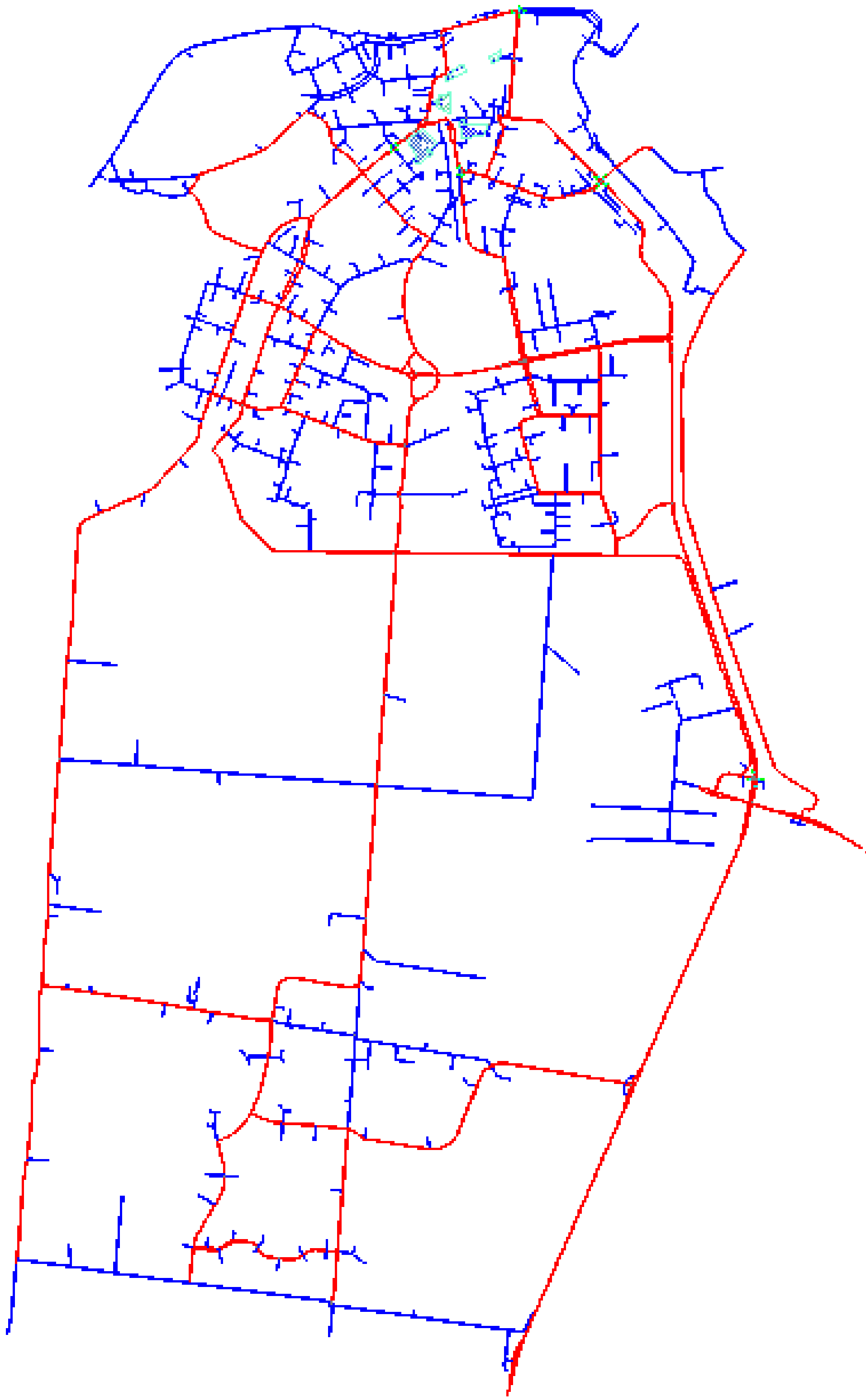
In case the effect of implementing PGS for a larger network is investigated, it is important to keep in mind that every single PGS device in the model functions independently. In case a re-routing percentage is set to 20% and a traffic flow passes two devices a total of 36% will be re-routed. In reality a PGS is implemented in such a way that drivers pass a PGS multiple times: e.g. first on the outer ring road, then again in the inner city etc. This is however not necessary when using the PGS tool in S-Paramics. In reality the PGS is also used to guide the drivers towards a car park. In S-Paramics drivers are instructed to park in another car park by the PGS tool and will chose the shortest route and do not have to be guided as drivers in real life.
To reflect the implementation of PGS in a city, it is important that traffic in the model only passes a PGS device once.

Therefore the locations for the PGS devices in the model must be chosen in such a way that:

- The cars entering the city on the radial roads pass a PGS device;
- The traffic flows do not pass multiple PGS devices.

When these two conditions are met all the traffic entering the city passes a PGS device just once. In case a PGS-scenario is activated a percentage of this traffic is re-routed. The consequence is that cars having an origin and destination within the city centre will not pass a PGS device.
The assumption is made that cars having an origin and destination within the city, is traffic which is familiar with the area. Dijkshoorn (2000) and Mcdonald and Chatterjee (2000) concluded that frequent visitors and thus traffic which is familiar with a destination is barely influenced by PGS's. Therefore this inner city traffic will not be affected by the PGS devices in the model.
According to Dijkshoorn (2000) and Mcdonald and Chatterjee (2000) irregular visitors from nearby municipalities are more likely to use the advice of the PGS. Therefore this traffic is influenced by the PGS devices in the model, in case the PGS devices are located at radial roads.
By using this setup the effect of PGS is reflected at best, using the available knowledge of the effect of PGS.

Appendix 2: Screenshot Den Helder network



Appendix 3: Defining Scenario conditions

Per ITS controller a scenario condition for every car park is determined. For some ITS controllers the scenario conditions are the same because they are at approximately the same travel time of the car parks.

For ITS controller 1 & 2

Car park	Capacity	Scenario enable condition	Scenario disable condition
Julianaplein	310	≥ 300	< 300
Koninckshoek	250	≥ 239	< 239
Palmplein	85	≥ 82	< 82
Sluisdijk	212	≥ 206	< 206
Stadhuis	200	≥ 190	< 190

For ITS controller 3 & 4

Car park	Capacity	Scenario enable condition	Scenario disable condition
Julianaplein	310	≥ 302	< 302
Koninckshoek	250	≥ 240	< 240
Palmplein	85	≥ 80	< 80
Sluisdijk	212	≥ 206	< 206
Stadhuis	200	≥ 192	< 192

For ITS controller 5

Car park	Capacity	Scenario enable condition	Scenario disable condition
Julianaplein	310	≥ 304	< 304
Koninckshoek	250	≥ 240	< 240
Palmplein	85	≥ 80	< 80
Sluisdijk	212	≥ 202	< 202
Stadhuis	200	≥ 198	< 198

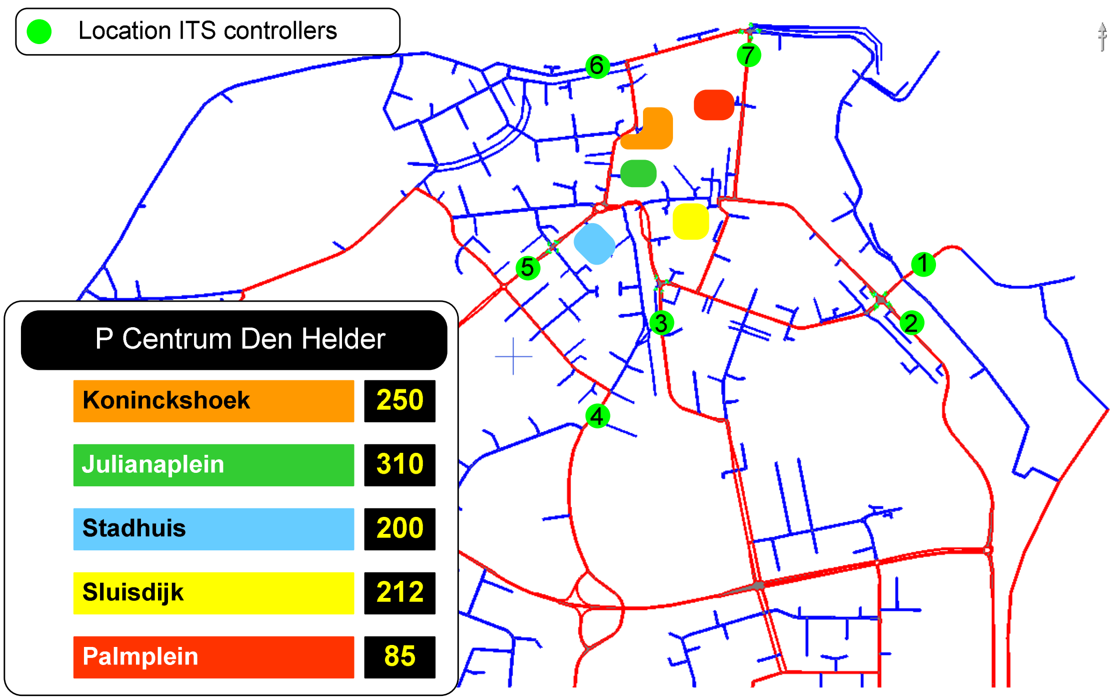
For ITS controller 6

Car park	Capacity	Scenario enable condition	Scenario disable condition
Julianaplein	310	≥ 307	< 307
Koninckshoek	250	≥ 248	< 248
Palmplein	85	≥ 82	< 82
Sluisdijk	212	≥ 202	< 202
Stadhuis	200	≥ 190	< 190

For ITS controller 7

Car park	Capacity	Scenario enable condition	Scenario disable condition
Julianaplein	310	≥ 300	< 300
Koninckshoek	250	≥ 238	< 238
Palmplein	85	≥ 82	< 82
Sluisdijk	212	≥ 206	< 206
Stadhuis	200	≥ 190	< 190

Appendix 4: Alternative car parks Den Helder



ITS controller	Full car park	Alternative car park
1	Julianaplein	Sluisdijk
2	Julianaplein	Sluisdijk
3	Julianaplein	Sluisdijk
4	Julianaplein	Konickshoek
5	Julianaplein	Konickshoek
6	Julianaplein	Konickshoek
7	Julianaplein	Sluisdijk

ITS controller	Full car park	Alternative car park
1	Palmplein	Sluisdijk
2	Palmplein	Sluisdijk
3	Palmplein	Sluisdijk
4	Palmplein	Sluisdijk
5	Palmplein	Konickshoek
6	Palmplein	Konickshoek
7	Palmplein	Sluisdijk

ITS controller	Full car park	Alternative car park
1	Stadhuis	Sluisdijk
2	Stadhuis	Sluisdijk
3	Stadhuis	Sluisdijk
4	Stadhuis	Julianaplein
5	Stadhuis	Julianaplein
6	Stadhuis	Julianaplein
7	Stadhuis	Sluisdijk

ITS controller	Full car park	Alternative car park
1	Koninckshoek	Palmplein
2	Koninckshoek	Palmplein
3	Koninckshoek	Julianaplein
4	Koninckshoek	Julianaplein
5	Koninckshoek	Julianaplein
6	Koninckshoek	Julianaplein
7	Koninckshoek	Palmplein

ITS controller	Full car park	Alternative car park
1	Sluisdijk	Palmplein
2	Sluisdijk	Palmplein
3	Sluisdijk	Julianaplein
4	Sluisdijk	Julianaplein
5	Sluisdijk	Julianaplein
6	Sluisdijk	Julianaplein
7	Sluisdijk	Palmplein

In some cases two car parks are both each other's alternatives. This means that there has to be a different scenario in case the two scenarios are both full. There are three options for two car parks being full, and each other's alternatives. Therefore three different scenarios are defined in case two car parks are full.

ITS controller	**Full car parks**	**Alternative car park**
1	Julianaplein Sluisdijk	Palmplein
2	Julianaplein Sluisdijk	Palmplein
3	Julianaplein Sluisdijk	Koninckshoek
4	Julianaplein Sluisdijk	Konickshoek
5	Julianaplein Sluisdijk	Konickshoek
6	Julianaplein Sluisdijk	Konickshoek
7	Julianaplein Sluisdijk	Palmplein

ITS controller	**Full car parks**	**Alternative car park**
1	Palmplein Sluisdijk	Julianaplein
2	Palmplein Sluisdijk	Julianaplein
3	Palmplein Sluisdijk	Julianaplein
4	Palmplein Sluisdijk	Julianaplein
5	Palmplein Sluisdijk	Julianaplein
6	Palmplein Sluisdijk	Julianaplein
7	Palmplein Sluisdijk	Julianaplein

ITS controller	**Full car parks**	**Alternative car park**
1	Julianaplein Koninckshoek	Sluisdijk
2	Julianaplein Koninckshoek	Sluisdijk
3	Julianaplein Koninckshoek	Sluisdijk
4	Julianaplein Koninckshoek	Sluisdijk
5	Julianaplein Koninckshoek	Sluisdijk
6	Julianaplein Koninckshoek	Sluisdijk
7	Julianaplein Koninckshoek	Sluisdijk

There is also the option that three car parks are full and the alternatives of these car parks are one of the other two full car parks. Therefore two scenarios are formulated in which this is the case.

ITS controller	Full car parks	Alternative car park
1	Julianaplein Koninckshoek Palmplein	Sluisdijk
2	Julianaplein Koninckshoek Palmplein	Sluisdijk
3	Julianaplein Koninckshoek Palmplein	Sluisdijk
4	Julianaplein Koninckshoek Palmplein	Sluisdijk
5	Julianaplein Koninckshoek Palmplein	Sluisdijk
6	Julianaplein Koninckshoek Palmplein	Sluisdijk
7	Julianaplein Koninckshoek Palmplein	Sluisdijk

ITS controller	Full car parks	Alternative car park
1	Julianaplein Koninckshoek Sluisdijk	Palmplein
2	Julianaplein Koninckshoek Sluisdijk	Palmplein
3	Julianaplein Koninckshoek Sluisdijk	Stadhuis
4	Julianaplein Koninckshoek Sluisdijk	Stadhuis
5	Julianaplein Koninckshoek Sluisdijk	Stadhuis
6	Julianaplein Koninckshoek Sluisdijk	Palmplein
7	Julianaplein Koninckshoek Sluisdijk	Palmplein

In case four car parks are full, the advice is to park at the remaining non-full car park.

Appendix 5: Verification checks PGS tool Den Helder

This appendix describes two checks performed for the PGS tool and its application to the Den Helder model.

Check: Times of scenario enabling/disabling
The first check is whether or not the scenarios are activated at the right time, according to the scenario conditions.

Below are the tables showing the occupancies and the times of enabling and disabling scenarios.
In contrast with the test runs, the Den Helder model runs seem to be only paused on the 27th second of every even minute. In the test runs the model runs were paused every minute and scenarios were enabled and/or disabled if necessary. In this test case however the model was paused every 2 minutes.

Example simulation run 8, settings scenario Palmplein vol:
- Activate Palmplein vol if occupancy $\geq$ 80
- Deactivate Palmplein vol if occupancy < 80

Table 1: Scenario 'Palmplein vol' check

Time of day	Occupancy	ITS Scenario Manager logfile
12:05:59	80	
12:06:59	81	12:06:27: scenario Palmplein vol enabled
13:02:59	80	
13:03:59	79	13:04:27: scenario Palmplein vol disabled
13:04:59	77	
13:55:59	77	
13:56:59	80	
13:57:59	80	
13:58:59	81	13:58:27: scenario Palmplein vol enabled
14:16:59	82	
14:17:59	78	14:18:27: scenario Palmplein vol disabled
14:18:59	76	
15:00:59	78	
15:01:59	80	15:02:27: scenario Palmplein vol enabled
15:02:59	82	

Settings Julianaplein vol:

- Activate Julianaplein vol if occupancy $\geq$ 300
- Deactivate Julianaplein vol if occupancy < 300

Table 2: Scenario 'Julianaplein vol' check

Time of day	Occupancy	ITS Scenario Manager logfile
13:01:59	298	
13:02:59	297	
13:03:59	298	
13:04:59	301	13:04:27: scenario Julianaplein vol enabled
13:05:59	301	
13:06:59	302	
13:07:59	299	
13:08:59	301	
13:09:59	305	
14:26:59	301	
14:27:59	298	14:28:27: scenario Julianaplein vol disabled
14:28:59	297	

This was caused by a small bug in the programming code and was fixed, to ensure that the PGS tool also compares the car park occupancy values with the scenario conditions every minute for larger models.

<u>Check: Amount of vehicles re-routed to alternative car parks</u>
The second check consists of checking whether the right amount of vehicles is re-routed once a scenario is activated. Figure 1 shows an example of the check. It is a selected link analysis carried out for the link at which the PGS is located. It shows the routes which are taken to two destination zones to which the Palmplein and Sluisdijk car park are linked. Until the scenario is activated the traffic choses to park at the Palmplein location, because the walking time from this car park to the destination zone is shorter. Once the scenario 'Palmplein vol' is enabled 100% of the cars of vehicle type 2 (18% of total traffic) is re-routed to the alternative car park Sluisdijk. The remaining traffic still proceeds to Palmplein. This is according to the settings of the PGS tool.

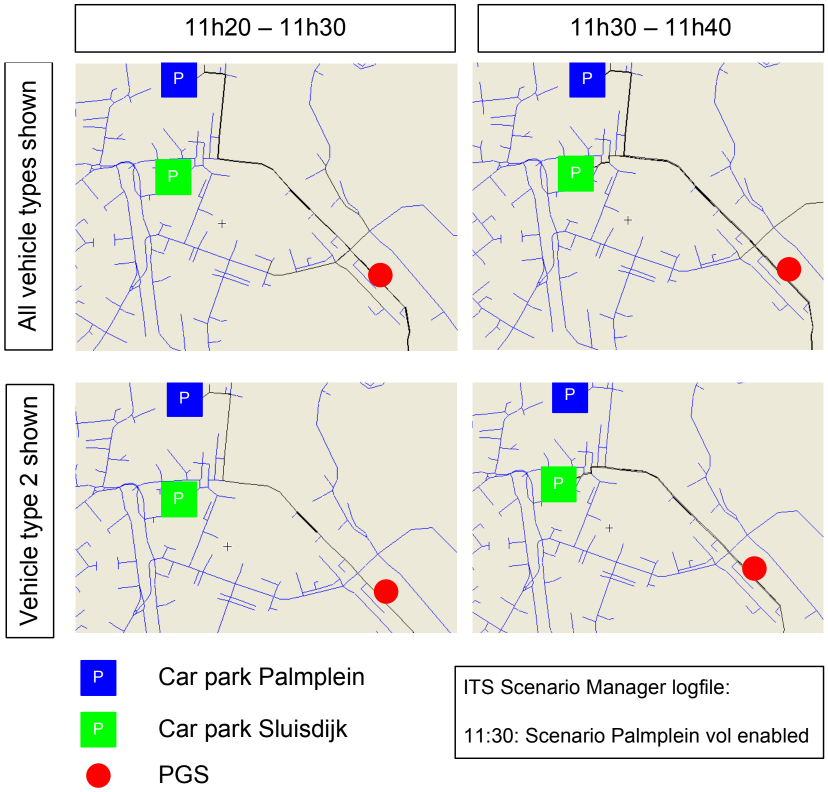


Figure 1: Re-routed traffic

The same checks were performed for the other ITS controllers and showed the same results: Once a scenario is activated 100% of vehicle type 2 (total of 18% of traffic) is re-routed to an alternative car park. This alternative car park was in all cases the alternative car park as defined in the measures.

Appendix 6: Statistical calculations Den Helder outcomes

Duration of 'full time' car park

The table below shows an overview of the average full time of the Juliana car park in the model runs with and without PGS. The table also shows the standard deviation of this average.

'full time'	Without PGS	With PGS
Average	72.5	58.1
Standard deviation	3.78	5.30

To calculate whether there is a significant difference in the 'full times' of the car parks, a significance level of 5% is used. The assumption is that the full time is Gaussian distributed. The full times of the car parks differ significantly, in case the difference in time is larger than 2 times the standard deviation of the difference.

$$|TimeCPfull_{noPGS} - TimeCPfull_{withPGS}| > 2 * S \,?$$

$$S = \sqrt{S_{noPGS}^2 + S_{PGS}^2} = \sqrt{3.78^2 + 5.30^2} = 6.51$$

$$2 * S = 2 * 6{,}51 = 13{,}02$$

$$\Rightarrow |72.5 - 58.1| = 14.4 > 13.02$$

The calculation shows that with a confidence level of 95% it can be concluded that the difference in full times of the car parks in both simulation runs differs significantly.

Car park occupancy differences

In the case of the Sluisdijk there is a higher occupancy in the simulation runs which include PGS. Sluisdijk is one of the alternative car parks to which the PGS tool advices car drivers in the model to drive as alternative car park.

Occupancy (at 13h00)	Without PGS	With PGS
Average	159	164.2
Standard deviation	7.32	13.06

Again a significance level of 5% is used and the assumption is that the variables are Gaussian distributed:

$$| AverageOcc_{noPGS} - AverageOcc_{withPGS} | > 2 * S \,?$$

$$S = \sqrt{S_{noPGS}^2 + S_{PGS}^2} = \sqrt{7.32^2 + 13.06^2} = 14.97$$

$$2 * S = 2 * 14{,}97 = 29{,}94$$

$$\Rightarrow |159 - 164.2| = 4.2 < 29.94$$

The calculation shows that there is no significant difference in occupancy at a 13h00 between the simulation runs with and without PGS.

<u>Total travel time</u>

Total travel time within cordon (hours)	**Without PGS**	**With PGS**
Average	280.8	268,8
Standard deviation	2,72	3,12

Again a significance evel of 5% is used and the assumption is that the variables are Gaussian distributed:

$$| AverageTotalTravelTime_{noPGS} - AverageTotalTravelTime_{withPGS} | > 2 * S \,?$$

$$S = \sqrt{S_{noPGS}^2 + S_{PGS}^2} = \sqrt{2.72^2 + 3.21^2} = 4.14$$

$$2 * S = 2 * 4{,}14 = 8.28$$

$$\Rightarrow |280.8 - 268.8| = 12 > 8.28$$