An in-car route & parking strategy for event traffic towards the Amsterdam ArenA area to improve throughput

MSc Thesis – Civil Engineering, Transport & Planning

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Delft University of Technology

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Challenge the future

An in-car route and parking strategy for event traffic towards the Amsterdam ArenA area to improve throughput

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Preface

This master thesis is the result of nine months of hard work. On beforehand I could not imagine that I would be this proud on my final work. First of all the topic was very interesting. My thesis was focussing on traffic towards an event; a huge inflow during a limited time frame. I worked on a lot of different parts that deal with the inflow of event traffic. I showed that I am able to work on those several parts but I never lost sight on the final goal; design an in-car strategy to improve traffic throughput during the inflow of an event.

I am dreaming of organising the Olympic Games. I want to make sure that many people can travel to and from a big event within a small time area. Therefore I am interested in the state-of-the-art of current event organisations and where the innovative opportunities are.

During my research I found out that traffic engineering mainly focuses on vehicles and their mathematical characteristics; e.g. flows, speeds, densities and delays. In my master I learned to deal with all different kind of traffic engineering problems. However an essential part of traffic is; humans and their behaviour. During my study I learned how congestion occurs and how it can be prevented. What I did not learn is how human behaviour is linked to traffic and how we, as traffic engineers, can influence human behaviour to improve traffic throughput. I think this is the most important part of traffic; which measures lead to minimum vehicle delay and which do not? I incorporated the human part in my master thesis to increase the chance that people will comply to my in-car advice. In the end I am convinced that I designed an effective and strategic in-car advice system that takes the interest of the individual into account and prevents congestion from occurring.

I would like to thank a few persons who helped me during my graduation thesis. First of all I would like to thank my graduation committee; Bart van Arem, Riender Happee, Paul Wiggenraad and my daily supervisors in particular Raymond Hoogendoorn and Simeon Calvert. Thanks for the helpful meetings. Every meeting with you delivered new valuable input for my process. Secondly I would like to thank TNO for the opportunity to do my graduation work there. Especially André Oldenburger, Taoufik Bakri and Yusen Chen. André for his enthusiasm about the Amsterdam Practical Trial and his ideas. Taoufik and Yusen for their help several times in their spare time. I would like to thank Team Traffic Jam for extra motivation. In the end I would like to thank my friends that listened to me in times I needed it. Thanks to my family who always supported me during my study. They gave me the opportunity to study in the first place and gave me time to explore my personal abilities. I am very grateful for that.

I worked on my master thesis with great pleasure.

I hope you enjoy reading,

Loes Noom

Delft, 3 March 1014

Summary

Managing thousands of people going to the same place at the same time is a challenge for event organisers and local authorities. With the help of road signs and traffic controllers the authorities aim to distribute traffic over the available network. Due to the development of smartphones, travellers are able use in-car information easily to find their route to their final destination. However the large traffic inflow of an event can lead to congestion. Not only on the secondary road network, but on the primary road network as well. This causes environmental damage, economic losses and inaccessibility of certain areas. This research provides insight in the possibilities to guide event traffic effectively through an in-car travel advice strategy to improve traffic throughput. It only focusses on influencing route choice and parking choice.

The Amsterdam ArenA area in the Netherlands is used as a case study. It is a busy area with many attractions such as football stadium Amsterdam ArenA and the concert halls Ziggo Dome and Heineken Music Hall. These event locations have a combined capacity of almost 90.000 seats. The inflow of an event in the ArenA area furthermore leads occasionally to congestion on the primary road network.

A system optimum leads to the lowest total costs for the system (Wardrop, 1952). This means that some people have to make a detour in favour of the travel time of others. The scientific relevance of this research is that it does not only look at the in-car travel time, but includes other parts (egress time, parking costs) of the trip as well to improve the utility of the traveller By increasing this utility the traveller would comply to a travel advice conform a system optimum. The research provides insight into the possibilities to reach the desired traffic throughput towards an event, but also incorporates the preferences of the user. Furthermore this research designs a method to model the current situation and to show the effectiveness of the designed in-car strategy.

The main research question is:
Which route strategy during the inflow of an event leads to a higher throughput at the ArenA area in Amsterdam for most events?

State of the art

The current route strategies used at events predominantly focus on roadside measures. In-car technology is currently not applied to distribute event traffic in an efficient way. Furthermore in-car devices lead to an user equilibrium instead of the desired system optimum (minimum of the total travel time). A system optimum has the potential to lead to a decrease in average trip time by 10-20% if the user equilibrium shifts to a system optimum (Wie, 1995). It is remarkable that in-car advice focusses mainly on in-car travel time. Walking time and parking costs are not taken into account, but are important factors for the route and parking choice of event visitors. This research shows that travellers have a high interest in in-car information when they travel to an unknown destination. Furthermore unfamiliar visitors benefit more from a specific travel advice than only information about for example travel times of different routes.

In-car devices have the advantage that every user is able to receive a personal travel advice. This improves the distribution of vehicles. Furthermore devices are traceable by GPS or Bluetooth allowing advice to be dynamically adapted according to the location of the vehicle.

Analysis of current situation in the ArenA area

An analysis is carried out to gain insight in the current situation at the ArenA area. The government is responsible for the travel information on the primary road network, while the municipality of Amsterdam is responsible for strategies on the secondary road network. The route strategies use route information on Dynamic Route Information Panels (DRIPs) as their mechanism.

The most commonly used static travel information towards the "Amsterdam ArenA" (provided by TomTom or Google Maps) leads every user to the off-ramp on highway A2 towards the Burgemeester Stramanweg. Therefore the static travel information does not use available network capacity in the ArenA area as efficient as possible.

Empirical data analysis shows that the inflow of a concert starts earlier than a football match in the ArenA. The inflow of a concert takes approximately four hours, the inflow of a football match takes only 2.5 hours. In general, Dutch league matches of Ajax or concerts in Ziggo Dome and Heineken Music Hall do not lead to congestion on highway A2 during the inflow period. Matches of the Dutch national team however often lead to congestion. The cause of this congestion is a combination of the total number of visitors, the short inflow time period and the hypothesis that unfamiliar travellers are less able to distribute themselves efficiently over the network compared to familiar visitors. Matches of the Dutch national team have a broader audience and only take place a few times a year, so these attract mainly unfamiliar visitors.

A bottlenecks analysis shows that the inflow is limited by the inflow capacity of parking facilities and the flow capacity of certain intersections. If demand is higher than the capacity of a certain route or parking facility a queue will occur. This can lead to spillback and eventually to congestion on the primary road network. Empirical observations show that the inflow of certain parking facilities is relatively low because a parking warden controls the inflow by checking the parking reservations of visitors by hand. Since the entrances of parking facilities are one of the bottlenecks during the inflow it is of importance to maximize the inflow capacity. The capacity of the ArenA area is able to handle the peak inflow of most events. This means that congestion and waiting queues can be prevented. The cause of congestion in the current situation is therefore often a lack of efficient distribution.

Design of the in-car strategy

To improve traffic throughput it is important to distribute the vehicles over the available parking facilities and routes. The goal of this criteria is to prevent spillback and congestion from happening. Additionally the strategy must be dynamic and focus on personal advice. Dynamics are important since the high inflows during an event can change the traffic situation in the area within short time. Personal travel advice furthermore provides a greater possibility to distribute the vehicles.

The criteria from a traveller's point of view is that visitors would like to get a specific travel advice instead of only some information. Furthermore they would like to receive a travel advice that removes or reduces the unfamiliarity. The assumption is made that if travellers receive an advice regarding their preferences towards parking costs and walking time the chance they will comply increases.

When a user of the in-car system departs to the ArenA area by car he is asked for his preferences regarding parking costs and walking time. The three possibilities are shown in figure A. The system knows all characteristics of the network and the parking facilities. In the first part of the trip the user gets a basic route advice towards the ArenA area. Current navigation technology satisfies. The user gets a parking and route advice when he enters the ArenA area. The ArenA area starts before the junctions, therefore several routes are still possible. The final route and parking advice is based on the origin and preferences of the traveller and the real-time situation. The real-time situation means the available parking places and routes at that moment. The advantage of the strategy is that the user does not select one specific parking facility. A category creates the dynamic element to guide users to available routes and parking facilities and gives the opportunity to prevent waiting queues from occurring.

Figure A: Input to generate a personal travel advice; the preferences of the event visitors with three possible option regarding walking time and parking cost.

The designed strategy contains route constraints to prevent large detours and crossing traffic. Crossing traffic is prevented to optimize throughput in the desired directions.

Ex-ante evaluation of the designed strategy

Before putting this strategy into practice, an ex-ante evaluation is needed to show if the desired results can be achieved and which penetration level is required to achieve a substantial effect on traffic throughput. A model is designed to perform the ex-ante evaluation.

The model consists of three parts. Firstly a parking choice model is used to distribute the demand of event traffic over the routes and parking facilities. Secondly a method is applied to determine the network capacity based on the infrastructure and the capacity of parking facilities. Thirdly a queuing model is used to calculate the effects of waiting queues on the network and determine if this leads to congestion on the primary road network.

The parking choice model contains a gravity method. It distributes the traffic demand over the available parking facilities according to their relative accessibility and utility opportunity. Input is given as the distance from an off-ramp to a parking facility, number of turning movements and the capacity of the parking facility. Furthermore the hypothesis about the familiarity and unfamiliarity of visitors is incorporated in the model. Since it is assumed that unfamiliar visitors are less able to distribute themselves over the available parking facilities, they are divided over less parking facilities than familiar visitors.

The output of the complete model is the total travel distance of event traffic, the shortage of capacity (i.e. if waiting queues occur or not) and the length of congestion on the primary road network after one hour. With these three indicators the model is able to show the effectiveness of the designed in-car strategy.

Results of the ex-ante evaluation

The results of the ex-ante evaluation show that the designed in-car strategy is able to distribute the users over available routes and parking facilities for most events. This improved distribution leads to less waiting queues and therefore can prevent congestion from occurring. The higher the penetration level of the strategy the higher traffic throughput. Additionally the results show that the in-car strategy does not lead to a significant detour for most users.

The strength but also the constraints of the in-car strategy are the preferences of the users and the limited number of routes to prevent crossing traffic. For an average event in the Amsterdam ArenA this would not lead to a problem. However, when demand approaches capacity the in-car strategy will only shift congestion and waiting queues from one point to another. This happens when the strategy is applied to the ArenA area when three events take place at the same time. The model also shows the sensitivity of the infrastructural network. The maximum traffic throughput in the area is shown to be sensitive to the inflow capacity of the parking facilities.

Conclusion

This research concludes that an in-car route strategy, that generates travel advice to distribute vehicles over the available routes and parking facilities based on the real-time traffic situation, improves the traffic throughput in the ArenA area for most events. This is conform a system optimum. The distribution of vehicles over the network can be accomplished through in-car information since all travellers can receive a personal travel advice. To increase compliance, the travel advice is based on the preferences of the users themselves. They are assigned to a parking facility which complies to their preferences regarding parking costs and walking time. The generated travel advice of the in-car strategy is based on their origin and personal preferences and the real-time traffic situation in the ArenA area. Furthermore the generated routes prevent unnecessary detours and crossing traffic and in doing so improve throughput and limit the effects of spillback. This designed in-car strategy provides a travel advice conform system optimum, but increases the utility for the users as well.

Recommendations

Recommendations for practical application:

- It must be decided where waiting queues and congestion is acceptable when these are inevitable;
- Agreements should be made with the parking garage owners about the difference in parking costs (low parking fee for faraway parking facilities, high parking fee for parking facilities close to the ArenA);
- The route strategies of the road authorities should be incorporated in the in-car strategy;
- To encourage throughput in the area it is important to use the inflow capacity of parking facilities as efficient as possible;

Recommendation for further research:

- The influence of incorporating parking costs and walking time in travel advice should be studied. By not only looking at in-car travel time this new approach can lead to a better distribution of vehicles over the network. Not only at events;
- In this research the assumption is made that unfamiliar visitors are less able to distribute themselves over the network compared to familiar visitors and therefore

this is assumed to be a cause of congestion. This assumption should be studied in further future research;

- The assumption is made that travellers will comply to a travel advice regarding their preferences. This assumption should be studied in future research;

List of definitions

A2L	= highway A2 directed to the center of Amsterdam
A2R	= highway A2 directed to the south
A10L	= highway A10 directed to the east
A10R	= highway A10 directed to the west
A9L	= highway A9 directed to the east
A9R	= highway A9 directed to the west
ArenA area	= the area where the Amsterdam ArenA, Ziggo Dome and Heineken Music Hall are located including the surrounding highways. The area includes the junctions between the highways A2, A10 and A9.
Crossing traffic	= vehicles that cross each other's route
Cruising traffic	= vehicles that drive slower than permitted with a higher following distance. This behavior can be caused by drivers that are searching for a parking spot
Event	= large activity that starts at a certain time and where many visitors (> 5.000) go to
Event traffic	= vehicles that go to an event
Off-ramp A2L	= short notation to indicate the off-ramp towards the ArenA area coming from highway A2L
Robustness analysis	= analysis to show if – in this case - a traffic measure is applicable to different scenarios
Scenario	= type of event with specific characteristics (number of event traffic, number of regular traffic, relation familiar and unfamiliar visitors)
Sensitivity analysis	= analysis to show the effect of the value of different parameters
Shortest path	= shortest route between two nodes regarding travel time or travel distance
Strategy	= contains a plan regarding route information, advice, guidance and/or steering
System optimum	= traffic situation where the total system costs are minimized
User equilibrium	= traffic situation that results in an equilibrium where all travelers have the same travel time or cost. No individual traveler can reduce his travel time by changing routes
Vehicle delay	= difference between the actual driven travel time and the free flow travel time on that specific route

Table of Content

1 Introduction

This first chapter introduces the research. First background information is given. Secondly the problem is described. This chapter finishes with the structure of the report.

1.1 Background

This section describes the background for this master thesis. In addition, specific information is provided about the case study Amsterdam ArenA. The section ends with a description of the involved actors.

1.1.1 General

Managing thousands of people going to the same place at the same time is a challenge for event organisers and local authorities. Actors are still developing solutions to reduce congestion and delays, to provide clear and safe traffic situations for road users and to keep the area accessible at all times. This can be done by building or redesigning the infrastructure. However, this is an expensive solution. Dynamic traffic management is more and more applied to use the existing infrastructure as efficiently as possible.

People who travel by car may use a navigation system or smartphone and give a signal to transmission towers, by GPS or with Bluetooth. By giving a signal, people, and so the vehicles, are traceable. The generated data is called floating car data. It is valuable information to use for dynamic traffic management. Information about origin, destination, travel mode, speed, routes, and other preferences can be determined. This gives possibilities to develop dynamic traffic management further more.

People who travel to the location of an event by car are guided by road signs, dynamic route information panels (DRIPs) or their in-car navigation system. The first two forms of information are accessible to everyone. An In-car navigation system indicates the user the fastest route to his destination. Overall this means that large groups of road users are given exactly the same travel information. This is contrary to the principle of distributing vehicles over the existing infrastructure. The current route navigation systems are conform users equilibrium. It leads to the fastest route for the individual user. If each driver optimises his own travel time, this will lead to a user equilibrium. However the total travel time in a network at the user equilibrium is not necessarily the lowest as possible (Wardrop, 1952). Wardrop states that a system optimum is reached when the situation of the total travel time is at its minimum. The average trip time could be reduced by 10-20% if the user equilibrium was shifted to a system optimum (Wie, 1995). In-car navigation systems and the traceability of vehicles are ideal to provide road users personal travel advice, conform a system optimum. Next to route information, personal travel advice can lead road users towards the most attractive parking facility based on origin, parking costs and walking time.

All information together creates the question how in-car travel information can lead to more efficient use of the existing infrastructure towards an event and if this leads to improved traffic throughput.

1.1.2 Case study: Amsterdam ArenA

A familiar location that is commonly visited simultaneously by thousands of people is the area of the Amsterdam ArenA. This area is used as case study for this graduation research. The reason for this is the field operational test (Amsterdam Practical Trial) that takes place in this same area. The Amsterdam Practical Trial has the main goal to minimize vehicle delay through in-car information.

1.1.2.1 *The ArenA area*

The ArenA area is located in Amsterdam South East, the Netherlands. There are three important event locations, namely the Amsterdam ArenA[1], Ziggo Dome[2] and Heineken Music Hall[3] with a total capacity of almost 90.000 visitors. Besides these event locations the area houses different shops, night venues, offices and living properties. This all together makes the area bustling and economically important. Therefore it is of importance that the area is accessible at all time.

Figure 1 shows the main roads around the ArenA area. Drivers on the primary road network are able to take ten exits towards this area. A perfect location to test the value of personal travel advice and distribution of vehicles over the current exits. Three highways can be reached within a 10 minutes' drive from the ArenA, namely A2, A9 and A10. Next to that, the provincial road S112 is close by as well. With the current infrastructure the parking facilities around the ArenA are easy to reach. People can use the road signs and/or a navigation system towards an event. According to the municipality of Amsterdam this leads to one main route; driving to highway A2 and taking exit 1 towards the ArenA (van Motman, 2013).

Figure 1: Main roads of the ArenA area (background Google Maps).
Red = highway, Yellow = provincial road, orange = secondary road network

[1] Amsterdam ArenA has a capacity of 65.000 people (Amsterdam ArenA, 2013)
[2] Ziggo Dome has a capacity of 17.000 people (Ziggo Dome, 2013)
[3] Heineken Music Hall has a capacity of 7.000 people (Heineken Music Hall, 2013)

The municipality of Amsterdam states that the inflow of event traffic at the A2 leads to congestion on the secondary road network and in the end to spillback on highway A2 (van Motman, 2013).

1.1.2.2 *Actors*

A lot of authorities are responsible for and/or benefit from the accessibility of the ArenA area. This next list shows the most important actors:

- Government (Rijkswaterstaat, Provincie Noord-Holland, Municipality of Amsterdam, Municipality of Ouder-Amstel)
- Police
- Event location (ArenA, Ziggo Dome, Heineken Music Hall)
- Event organization (Mojo, Ajax)
- Event visitors
- Owners parking facilities
- Companies located in the area
- Residents
- Public transport operators

The governmental institutions have the responsibility for the accessibility of an area, the police is responsible for safety and the stakeholders of an event wants to make sure that every visitor will be in time for the beginning of the show. A familiar disadvantage of so many actors is that everyone has his own interest. Owners of parking facilities try to lead car drivers to their own parking location, while the government wants to distribute the vehicle over the available network for continue throughput. Residents and companies want to reach their homes and offices at all time. Also when there is an event going on. The challenge is to deal with all these interests and develop the most desired solution.

1.2 Problem description

This section describes the problem description which is the motivation for this graduation research. It is focussing on the traffic situation in the ArenA area.

1.2.1 Traffic situation

The traffic situation around the ArenA area described in this section, is based on the information given for Amsterdam Practical Trial and prepared by the Dutch Ministry of Infrastructure and Environment (Rijkswaterstaat, 2013). The type of event and date is unknown but the given information reflects a basic traffic situation towards events.

Figure 2 shows the traffic situation during the inflow of an event. The inflow concentrates on the highway A2 and then taking exit 1 towards the ArenA. The network cannot handle this peak of inflow. This leads to spillback and possibly congestion on highway A2. Not only visitors of the event have a longer travel time than expected but also other road users are affected. The traffic flows on the network and the use of parking facilities are divided unequally. This causes congestion on the one hand and free roads and parking facilities on the other hand. Congestion during the inflow of an event could lead to the fact that visitors will not be in time for their event Congestion must be prevented since it leads to environmental damage, economic losses because of delays and inaccessibility of certain areas, and dissatisfaction of road users..

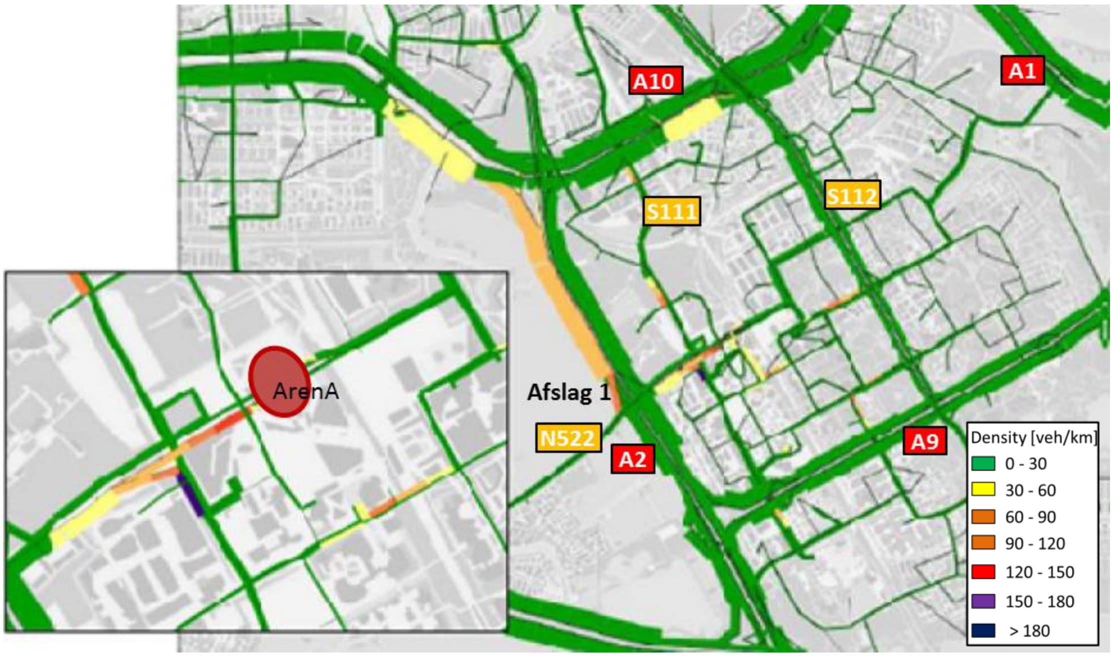


Figure 2: Traffic situation during the inflow of an unknown event in the ArenA area (Rijkswaterstaat, 2013)

1.3 Structure of the report

This section describes the structure of the report. First the goal and the approach of this research is discussed in chapter 2. It describes the research goal, the research questions, the relevance and the scope of this research. Chapter 3 discusses the state-of-the art regarding event traffic. It gains insight in the current route strategies for traffic towards events. Furthermore it shows which measures of travel information provide high compliance and what the current developments are around dynamic travel information. Chapter 4 carries out an analysis of the current situation in the ArenA area to gain insight in the characteristics of different events in 2013 and to show what the bottlenecks of the ArenA area are. Based on the state-of-the-art and the analysis of the current situation an in-car strategy is designed in chapter 5. Before a strategy is applied into practice it is of importance to carry out an ex-ante evaluation to show the possible effects. This evaluation is model-based. The model design and the evaluation are described in chapter 6. The approach and results of the research are discussed in chapter 7: discussion. This research ends with conclusions and recommendations in chapter 8. The recommendations are divided into recommendations for further research and recommendations for practical application.

2 Research outline

This chapter describes the approach of this research. Firstly the scope of the research is presented including the research question. Secondly the approach is described with the use of a research framework.

2.1 Scope of the research

First of all the scope of the research is discussed. This section contains the objective of this research, research questions, relevance of the work, study area and important assumptions.

2.1.1 Objective

The research objective of the graduation project is:

Research objective:
Gain insight into the effective measures to direct event traffic towards a route and parking facility to improve traffic throughput

2.1.2 Questions

The main question of this graduation project is:

Research question:
Which route strategy during the inflow of an event leads to a higher throughput at the ArenA area in Amsterdam for most events?

The sub questions need to be answered to answer the main question.

Infrastructure

a. What is the capacity [vehicles/hour] of the exits, secondary road network, and parking facilities near the ArenA?

Current situation

b. What are currently the frequent bottlenecks during the inflow of event traffic in the ArenA area?
c. What are the current route strategies in the ArenA area during the inflow of an event?
d. What are the characteristics of the current inflow of multiple events in the ArenA area?

Strategy

e. Which criteria are of importance in the design of route guidance strategies for the inflow of event traffic at the ArenA area, from a traffic point of view and a traveller's point of view?
f. Which method is appropriate to show the possible effects of the route strategy on traffic throughput in the Amsterdam ArenA area ex-ante?
g. For which level of compliance has the route strategy a positive effect on throughput?

2.1.3 Relevance

This research provides insight in the effectiveness of route and parking guidance and the possibilities of in-car technology. The current route strategies of the government during events are focussed on road side measures and do not include in-car technology. Due to the development of smartphones the accessibility to in-car navigation systems has increased rapidly. Therefore it is remarkable that the strategies do not include in-car technology. One of the characteristics of event traffic is that many people travel towards the same final destination in a limited timeframe. This makes it very important to use the infrastructure as efficiently as possible. The current in-car systems give the user advice about the fastest or shortest route. This is conform user equilibrium while system optimum leads to the lowest possible total travel time. This research looks at the possibilities of in-car route strategies during events to distribute vehicles over the available infrastructure and parking facilities. The relevance of this research can be divided into scientific and practical relevance.

2.1.3.1 *Scientific relevance*

The scientific relevance is that this research provides insight in the possible effectiveness of a travel advice that includes more factors than only in-car travel time. Currently this is already used in travel advice for public transport. This advice not only contains in-vehicle time, but also access time, egress time and direct costs. With other words, it provides insight in the total trip. This approach of public transport is applied to the travel advice for trips by car towards an event. Factors as parking costs and walking time to the final destination can affect the parking choice of event visitors. In addition, in-car advices are currently not used to guide a large event inflow towards a destination. The advantage of in-car advices is that it provides the possibility of giving every user a personal advice that suits the preferences of the user itself. This research also develops a method that is applicable to demonstrate the effectiveness of an in-car travel advice in a simple but efficient way. This graduation work shows therefore an interesting and different approach in transport studies but still has the same main goal; prevent traffic congestion from occurring and improve throughput.

2.1.3.2 *Practical relevance*

The practical relevance is that the vehicle lost hours during an event at ArenA area are too high. The area suffers from congestion which leads to inaccessibility of areas during the inflow of events. Congestion gives the possibility that visitors are not in time at the event. The government wants to decline the vehicle lost hours and also the spillback onto the highways. The relevance of this research is to give the government and private companies insight in the measures that can work to guide event traffic. To invest in the right measures, insight into the effective measures is important. The practical relevance for TNO is that this company gains insight in the possibilities of in-car technology since the company is developing an application for smartphones which generates travel advice. Furthermore the practical relevance is that the interests of the travellers is seen as most important. In-car travel advice is not compulsory. To increase compliance the travel advice has to focus on the utility of the travellers.

2.1.4 Study area

The study area contains the most important roads in the ArenA Area towards the Amsterdam ArenA and the surrounding parking facilities, see Figure 1. The study area includes the primary road network, starting downstream the surrounding junctions or exits. This gives an overview of the vehicles who are driving to the ArenA area and which route they could take towards an exit. The parking facilities with a capacity higher than 200 parking lots and within 15 minutes walking time to the ArenA are included in the study area. Smaller facilities or with a longer walking time are expected not to be relevant in this research since it does not have significant impact on the travel time of the most road users towards the ArenA. Not all roads on the secondary road network are included in the study area. It can be assumed that most of the vehicles come from the primary road network. Therefore only the roads of the secondary network that connect the highways with the parking facilities and the ArenA are of importance.

2.1.5 Overview of the scope

This section will give an overview of the scope of this research. It gives a definition of the subject.

- The goal of the research is to gain insight in the effect of possible strategies for event traffic in the ArenA area;
- The study focuses on a specific solution for the ArenA area rather than generic solutions;
- Mobility management (mode choice and departure time choice) is out of the scope of the research, since it is out of the scope for the Amsterdam Practical Trial as well;
- Infrastructural changes are out of the scope;
- Change the design of parking facilities to increase the inflow capacity is out of the scope;
- The focus is on optimizing traffic throughput, not on behaviour;

2.2 Approach

To answer the research questions the following approach is used. An overview is given in Figure 3. First the state of the art is carried out; what are currently the used measures and strategies to guide vehicles at several events? How does in-car navigation works towards an event and what is known about the use and compliance of travel information? These questions gain insight into the criteria that are of importance for the design of a route strategy. After that an analysis of the current situation is carried out. This gains insight in the current route strategies towards the ArenA. It also provides an analysis of available data to explore the bottlenecks in the area and the traffic demand during the inflow of an event. Based on the conclusions of the state-of-the-art and the current situation the strategy is designed. The final part of this research consists of an ex-ante evaluation to show the possible effects of the strategy on traffic throughput. Therefore a methodology is designed. The strategy is tested on different scenarios with varied penetration levels to test its robustness. In the end the results show the effectiveness of the strategy and the main research question can be answered.

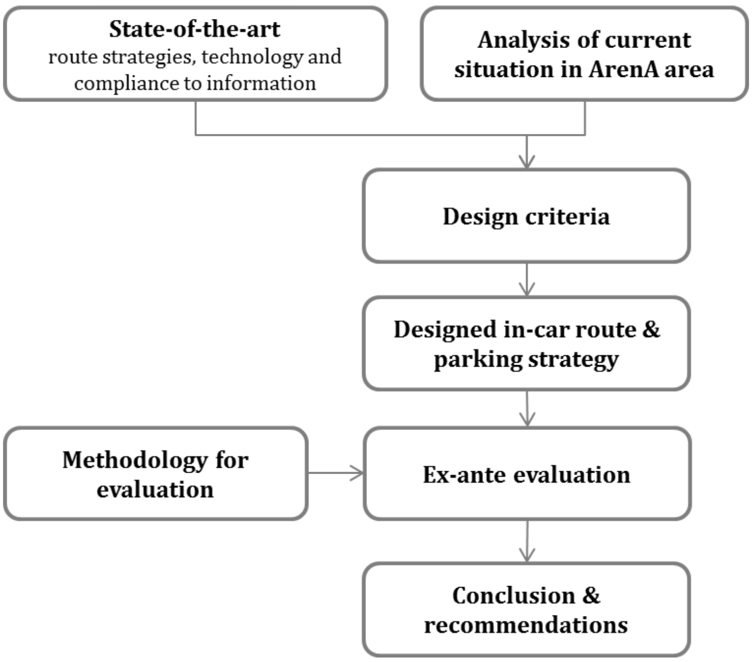


Figure 3: Schematic overview of research approach

3 State of the art

In this chapter the state of the art is discussed. First different route strategies that are applicable for event traffic are discussed. Second the current developments of route information including navigation devices are looked into. Thereafter the compliance rate of those different forms of route information are discussed. In the end of this chapter the different kind of traffic data is discussed since traffic data is essential input for real-time travel information.

3.1 Route strategies during events

This research is about route strategies during events at the ArenA area in Amsterdam. An event is defined in this research as a large activity that starts at a fixed time and where many visitors (>5.000) go to. Before a new strategy is designed for the ArenA area it is important to look at the state of the art of route strategies during events. Innovative strategies but also simple basic strategies with potentially a lot of effect. What are currently measures to manage thousands of people going to the same place at the same time? The strategies that are currently used at the Amsterdam ArenA are discussed in chapter 0.

3.1.1 Basic strategies

When an event is organized one or more of the following measures will be used to lead traffic to their final destination.

- Traffic signs
- Traffic controllers and police (Verkeersdiensten, 2013)
- Road blockades and redirections
- Use of Dynamic Route Information Panels (DRIP)
- Use of Parking Route Information System (PRIS) with full/free signals or numbers of available parking places (Imtech, 2013)
- Route information on the website of the event location or ticket services
- A recommendation to turn navigation devices off and follow the traffic signs (Pinkpop, 2013)
- Use of shuttle buses

Figure 4 shows some pictures of basic route strategies.

Figure 4: Basic route strategies - traffic controller (left), PRIS (middle) and advice to turn navigation device off (right)

The goal of the basic strategies is to minimalize cruising and crossing traffic, and guide traffic towards the available parking facilities in an effective way. Another solutions to manage event traffic is to distribute vehicles over time and convince people to travel by public transport.

However, these solutions are considered as mobility management which is out of the scope of this research.

Navigation devices are not involved yet in the current strategies to manage large groups of event visitors towards their destination. Sometimes it even seems that in-car navigation devices have a negative effect. This leads to the advice that people should turn off their devices and follow the signs. In the current situation the government institutions are responsible for guiding and controlling traffic, while in the meantime private parties develop in-car navigation systems. The government aims to get a system optimum, while private parties (e.g. TomTom, Garmin) like to give its user the best advice which is conform a user equilibrium. The information provided by both parties can therefore be contradicted. The fact that navigation devices are not used in event traffic management and the possible contradictory between roadside advice and in-car advice offers room for improvement.

3.1.2 In-car strategy for event traffic

The government and private parties start to see the lack of using navigation devices to manage event traffic. Therefore one track of the Amsterdam Practical Trial is to develop an in-car system especially for event traffic in the capital of the Netherlands.

TNO designed a smartphone application for a one-day event in the Netherlands; Queensday 2013. The app was called "Kom Naar De Kroning- App" and designed for all citizen who wanted to travel towards Amsterdam on the 30th of April. The travel information for car drivers consisted of route information and parking advice. When a traveller installed the app on his smartphone and turned on his GPS, the total route of the car could be traced. When a car was detected near the ring of Amsterdam a parking advice was generated based on its location. This parking advice was based on a simple algorithm; Amsterdam was divided into pie slices. If a car drove into a certain pie slice – so within benchmarks of GPS coordinates – the driver got a parking advice of an available facility within that same pie slice. The goal of the strategy was to minimize the number of cars going to the city centre of Amsterdam (van der Haak, 2013).

The "Kom Naar De Kroning" application could be downloaded during the end of April 2013 in the appstore. The app however was not evaluated. The technology worked but it is unknown if users complied to the advice that was given by the app, if they experienced it as useful and what the effect was on the traffic network.

3.2 Route navigation

When people travel to a certain destination they look for the most efficient way to get there. This can be before or during their trip. Route information can help people find their destination or get more specific information. There are several forms of route navigation, namely statically, dynamically and socially. The explanation of these types of route navigation can be read in this section.

3.2.1 Static navigation

Static navigation assumes that all data are known in advance and that its independent on time (Toth & Vigo, 2002). The traveller only has route information and no information about the current situation (e.g. congestion, road blockades) on the road. Examples of static navigation are road maps, static navigation system, fixed traffic signs and fixed route information on the internet. A traveller could also determine its route by experience or the experience of others; this often does not include information about the current traffic situation as well. If a route is searched on the internet, the traveller gets an indication of the travel time which is based on free flow travel time.

3.2.2 Dynamic navigation

More and more websites with a ‘route finder’ option include real-time traffic data and historical traffic data to give reliable travel advice. This is dynamic navigation. Dynamic navigation gives route information which includes the current situation on the road network. The travel advice is updated frequently based on prevailing traffic conditions. The input for the dynamic travel advice is real-time traffic data. This data can be provided by in-car devices or road side equipment. Section 3.4 gives more information about this subject.

Different sources of travel information are be based on different input and different algorithms. The user does not know which information is most reliable.

3.2.2.1 *Dynamic roadside information*

The goal of dynamic travel information is to give the traveller the most updated and reliable travel information. This can be accomplished by roadside information (DRIPs) or in-car devices. Current used DRIPs on the Dutch road network – which show travel times - provide instantaneous travel time. In general, instantaneous travel time underestimates real travel time when congestion sets in and the other way around when congestion dissolves (van Lint, 2004). This makes it unreliable. Current in-car devices are more sophisticated.

3.2.2.2 *Dynamic in-car information*

In-car navigations systems give the user the fastest route to his destination. This means that large groups of road users get exactly the same travel information. This is contrary to the principle of distributing vehicle over the existing infrastructure. The current route navigation systems are conform the wishes of the individual user; the fastest route. If each driver optimises his own travel time, this will lead to a user equilibrium. However the total travel time in the network at the user equilibrium is not necessarily the lowest as possible (Wardrop, 1952). Wardrop stated that a system optimum is reached where the situation of the total travel time is at its minimum. In the end the average trip time could be reduced by 10-20% if the user equilibrium was shifted to system optimum (Wie, 1995).

3.2.2.3 *Dutch travel time prediction models*

In 2008 the travel time prediction application build by Model-IT was pronounced as best publically available travel time prediction model (van Lint, 2012). The application is used by VID (Dutch: Verkeersinformatiedienst), Trip Cast and the smartphone applications of TNO. Since the inflow timeframe of an event is limited and the number of vehicles can be large, the traffic situation can change very fast. Therefore it is of importance to use the possibilities of travel predictions.

3.2.3 Social navigation

The conclusion of Wardrop (1952) that system optimum leads to less total travel time than user equilibrium is the important reason to investigate the possibilities of bringing this into practice. Van den Bosch & Van Arem (2011) carried out an experiment to shift traffic flows in a network from user equilibrium to system optimum by the use of social navigation. Participants of the experiment got a route advice based on individual travel time and the marginal total travel time in the network. Experimental results show that the total travel time in the network could be decreased by 10%. (van den Bosch & van Arem, 2011)

3.2.4 Smart routing

Smart Routing (SR) is a route strategy where changing traffic conditions are taken into account to divide traffic over the available routes. The advantage of SR is that a consideration can be made between individual interest (user equilibrium) and public interest (system optimum). Besides that, a route can be determined based on expected travel times instead of real-time and historical travel times. A Smart Routing navigation device determines ten possible routes as a maximum. Factors that are taken into account to determine these routes are destination, origin (or present location) and total travel time of the vehicle and the capacity of the road, which includes remaining road capacity. At this moment smart routing is used at a pilot of TNO in the Dutch city Assen. In practice the development of smart routing is not that far. The several routes are based on free flow travel time (static) so no real-time or historical data is used. The advantage of the current device is that people with exactly the same destination are divided stochastically over the available routes. A requirement is that the routes do not differ more than two minutes from the most optimal route (Minderhoud, 2013).

3.2.5 Smartphone applications with route navigation

Smart routing and social navigation are great experiments but are not covered in practice yet. As mentioned before, private parties who design navigation devices give their user the best travel advice which is conform a user equilibrium instead of system optimum. This section describes the currently most used navigation systems and their features.

Google maps is a very common used system for route navigation. The maps of Google are incorporated into a lot of other navigation systems as well. The user gets a route advice based on the real-time shortest path. Information about any possible delay and the cause of it is unknown, since the maps are static. In addition, Google Maps is giving route advice to the final destination, not to an available parking place.

Waze is a navigation system which is based on the input of the user itself (Waze, 2013). If a user runs into a traffic jam he passes this information to Waze. Another user who is entering that same traffic jam confirms the fact that there is congestion. This way the information becomes more and more reliable. The same trick happens with incidents, police traps and road blockades. Information about speed and location is gathered automatically when the app is used. Traffic information from the government is in this way not needed. Waze uses the maps of Google as well.

Sygic GPS Navigation is downloaded more than 33 million times worldwide. It is based on TomTom maps and gives the user three alternative routes. It is a static navigation system but it can be updated with real-time traffic information for a paying user. Points of interests are included, but the focus is on tourist attractions instead of parking facilities (Sygic GPS Navigation, 2013).

3.2.6 Navigation towards parking facilities

This part describes how navigation towards a parking facility takes place through in-car systems and roadside signs.

3.2.6.1 *In-car*

Navigation devices have extra options. TomTom for example, gives the user the opportunity to search for parking nearby. However, this is not basic information but it needs an extra action.

TomTom also includes Points of Interest (POIs), see Figure 5. It are useful places on a map, for example parking garages (TomTom, 2013).

Figure 5: Button to find a Point Of Interest near the planned destination in TomTom

Parking costs, opening hours of the parking facility and walking distance from the parking facility to the final destination are not included in the travel advice. However, these are important factors to choose for a specific parking facility or even consider a park-and-ride facility. Also real-time information, such as parking availability, is not included into in-car information. In June 2013 the Dutch Minister of Infrastructure & Environment announced the wish to release data of parking facilities, namely locations, costs, opening hours and real-time availability (ANP, 2013). The goal is to let companies build application for smartphones that help drivers find a place to park. Arguments are that driving around to find a parking space is annoying and bad for the environment. First the data of the biggest cities of the Netherlands will be released. In 2015 a large part of the Netherlands should have real-time information about parking facilities.

There exists several smartphone applications that help users regarding parking lots. Some applications focus on digital payment for a parking lot (Yellowbrick, 2013). Others focus on finding a parking garage (Parkeerlijn.nl, 2013). The apps can give a route advice to a parking facility. The main goal of the apps is to provide information for the users not to distribute the vehicles over the network towards the parking facilities.

3.2.6.2 *Roadside*

Information about available parking places is shown dynamically on Parking Route Information Systems (PRIS). It is a roadside sign with full/free information or the number of available parking places (Imtech, 2013). A new development are sensors in parking places which direct drivers directly to a free spot in a parking garage.

3.2.7 Generation of route advice (access, in-vehicle and egress)

A route advice can be given from door to door. The general approach of generating route advice is based on the shortest travel time or shortest path. In the case of public transport a traveller gets an advice including access time, in-vehicle time and egress time (9292ov.nl). This makes sense since the train does not stop at people's front door. However, the advice for travelling by car is only focussing on in-car travel time. The majority of trips by car are able to park close to their final destination, but this does not apply for most trips to a city centre or specified to this research: an event.

For example, a person travels by car from Leiden to the Amsterdam ArenA. The in-car travel time is approximately 25 minutes. The parking facilities in the ArenA area have a walking time to the ArenA varying from 3 to 15 minutes. This means that more than 35 percent of the total travel time could consist of walking. It is remarkable that this part of the trip is not included yet in the total travel advice. In addition, there is the factor 'parking costs' as well. This may be considered by the traveller as more important than the in-car travel time.

3.3 Compliance rate of travel information

A traveler can use different sources of travel information to make its route choice. There is static travel information, dynamic travel information and also several in-car devices. The information could be the same but the information and the advice could also differ. The question is which type of travel information a traveler complies to.

3.3.1 Traveler's choice

First of all it is important to look how people make their choice. Figure 6 shows this in a diagram. A choice is based on a subjective expectation of the quality of the alternatives. People have their own experiences but also lots of information where they can base their expectations on. Every choice gives new experiences which influences the subjective expectation and so the next choice that will be made.

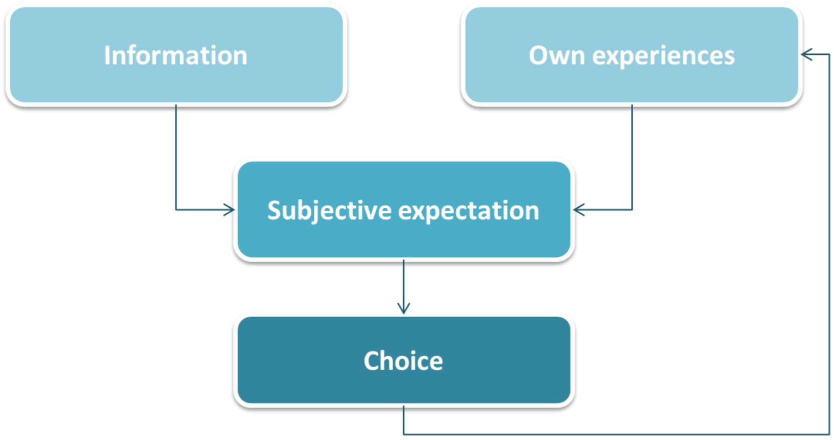


Figure 6: The cycle of choice (Reader Transport & Planning, 2011)

This cycle of choice shows how important own experiences are. The more own experiences the more this will lead to habitual behaviour. On the other hand this means that inexperienced drivers are sensitive to the information they receive. A lot of events have the characteristic that they are held once a year or even less which may lead to a lot of inexperienced travellers. This is the ideal circumstances to influence drivers' route choice, since they base their choice on information.

In 2007 there is studied if the choices of travellers actual can be changed by the information they get. The outcome of the research was that it is hard to change the mode choice of travellers. Changes in departure time choice and route choice are more easily to reach. Furthermore this same research showed that people put more effort making a good choice – and therefore want more information – when the interests are higher (Chorus, 2007).

Another research about traffic information and the traveller's choice confirms the diagram in Figure 6. This research shows also that it is hard to change structural travel behaviour (Bogers, 2009). The research concludes that en-route information helps the driver to get a better long-term travel time expectation. This will change the departure time or route choices of travellers and leads in the end to a reduction in total travel time.

3.3.2 Effective information

A lot of scientific research is performed on which information could be effective to change the choices of a traveller. Many research confirms that it is difficult to change habitual behaviour. A PhD thesis about psychological aspects of travel information presentation, gives insight in effective on-trip travel information (Dicke-Ogenia, 2013). The most important conclusions are listed here:

- In-car advices are followed most efficiently;
- Concrete advice, travel time predictions and quantitative indication of current delays will lead to the most route changes and compliance;
- Nowadays travellers still use roadside information a lot;
- Travellers will use in-car devices more in the future;
- 'Perfect' travel advice differs per individual traveller;
- Travellers who are familiar with the route (or network) want information that takes uncertainties away;
- Travellers who are unfamiliar with the route want information that takes this unfamiliarity away;
- Information to the driver should make the trip easier, not more complex;

'Perfect' travel advice differs per individual traveller because every individual has its own preferences. Familiar Ajax supporters for example like to know if there is a waiting queue on their basic route and if their parking facility has still enough parking places, while unfamiliar visitors like to know more about parking costs and walking time from parking facility to their final destination. The development of personal travel advice gives the opportunity to optimize 'perfect' travel advice per individual.

3.3.3 Travellers with in-car navigation device

It is hard to find information how many people use a navigation device nowadays. In 2007, 20% of the car drivers had a navigation device and it was mainly used when travelling towards unfamiliar destinations (SWOV, 2010). In 2010, 25% of vehicles in Europe had some sort of navigation device (Zuurbier, 2010). Nowadays, the smartphone is also used as a navigation device. More than 61% of the Dutch citizens has a smartphone in 2013 (Volkskrant, 2013). Navigation applications can be installed on every smartphone, so every traveller with a smartphone is able to get real-time route information. How many people use their smartphone when they travel by car is unfortunately unknown. A small research in 2002 showed that 95% of the owners of a navigation device use this device when travelling to an unknown destination (Oei, 2002). 57% uses it when traveling to a (more) familiar destination. However, the users state that the advised route was not always the most optimal one. How many users comply to the advised route has not been studied in this research.

3.4 Traffic data

To generate travel time predictions and reliable travel advice, data is needed. Travel time information can be based on free flow travel times, however this is not reliable in congested circumstances. To generate real-time travel information sufficient input data is needed. This research aims to use the infrastructure as efficient as possible. Therefore enough data of the real-time situation is needed including remaining road capacities. This section describes the data which is currently available and the quality of it.

3.4.1 National Data Warehouse

National Data Warehouse (NDW) for travel information is developed by various authorities in the Netherlands in 2007 (Nationaal Databank Wegverkeergegevens, 2013). This database for traffic information is created to develop traffic management and traffic information. The database has information of the Dutch motorways, secondary roads and urban thoroughfares of the participating authorities. The data is collected by cameras, detections loops, passive infrared and

Bluetooth of in-car devices. It concerns the following data 1. Traffic flow, 2. Realized travel time, 3. Estimated travel time, 4. Traffic speed and 5. Vehicle classes.

Road authorities and external data providers (e.g. Bluetooth) supply NDW with real-time traffic data and status information. Status information is about road works, congestion, accidents, open/closed bridges, peak lanes and regular lanes. At NDW, all data is processed, and distributed to road authorities and traffic information providers (e.g. TomTom, various radio stations) to inform the road users. The data is distributed to research institutes as well e.g. for traffic policy and traffic simulation.

The different authorities have the responsibility for the quality of their own delivered data. NDW checks the quality by random sampling. The University of Leuven conducted a research to give insight in the needed quality and quantity of the data for the use of dynamic traffic management (DTM) measures (Tampère, 2011). The conclusion was that the algorithms that are used for DTM measures are already inaccurate without any measurement errors in traffic data.

The current data that NDW delivers are mainly of the highways, provincial roads and main urban roads. Since parking facilities in the ArenA area are accessible via the local roads, it is of importance to have sufficient data to give reliable travel advice based on the real-time situation at the parking facilities. The data delivered for these local roads is delivered by the Open Data Amsterdam which can be read in the next paragraph.

3.4.2 Open data Amsterdam

The government started a project in 2012 to release data of some cities in the Netherlands. Amsterdam aims to strengthen the position of the metropolis to make data publically available. In this way commercial parties can design their own smartphone applications with this open data. Examples of open data are information about parking costs, park and ride facilities, real-time information on DRIPs, road works and real-time traffic data. The real-time traffic data is currently update every five minutes and only the mains roads owned by the city of Amsterdam are included. The information on the DRIPs is updated every minute (Dienst IVV, 2013).

The real-time traffic data – travel times and speeds on the roads of Amsterdam – are determined by MoCo (Monitoring Corridors). This is done by license plate recognition cameras. In combination with historical data and actual data of 10 or 20 measured travel times, the real-time travel time is estimated. The municipality of Amsterdam does not expect big changes on the short term (Muizelaar, 2013)

3.4.3 Floating car data

More precise information of individual vehicles can be gathered by floating car data. A car can be detected by GPS, WiFi, Bluetooth, cell ID, terrestrial transmitters and more. These signals can be spread by mobile phones or navigation devices. The speed on the roads can be determined by floating car data and in this way detector loops are not needed to detect congestion (de Boer & Krootjes, 2012). This could save money. Disadvantages are that intensities cannot be determined with a lot of certainty and that it is hard to estimate the travel mode (car, train, bicycle), since the infrastructure is very close together. For the ArenA area this means that it is hard to distinguish a walking person from a car that drives into a parking facility by mobile phone data since the speed is comparable and the infrastructure is close to each other.

3.5 Overall conclusion of state of the art

The most important conclusions of the state of the art are given in the following enumeration:

- All strategies towards events are focussed on roadside measures, not on in-car measures;
- The current in-car advices are conform user equilibrium, not system optimum;
- Route strategies towards events are designed by road authorities, while private parties develop in-car information. Road authorities try to distribute vehicles over the available network. Private parties provide travel advice regarding the shortest path. This makes the information often contradictory;
- More than 61% of the Dutch citizen has a smartphone in 2013 and so also access to thus in-car travel information;
- In-car devices can give a route advice to a parking facility, but this needs extra actions by the user. Information about parking costs, opening hours, available parking places and walking time towards the final destination are not included;
- Current in-car travel advices are focussing on the fastest route for the individual driver. However, this is based on in-car travel time, while the total trip is including access time, egress time and parking costs.
- There is a lack in knowledge about the compliance of route advice (in-car and roadside);
- Travellers have a high interest in in-car information when they travel to an unknown destination;
- Traffic data is very accurate on highways of the Netherlands. The responsibility of the quality of the data of the secondary road network lies with the municipality.

The conclusions show room for improvement for route strategies regarding event traffic. Travellers prefer to use in-car information when they travel to an unknown destination. Events are organised not that often so an event location is an unknown destination for many people. Until now, the in-car information is not designed to follow the route strategies of the road authorities. Therefore in-car navigation can be developed to guide event traffic. This creates the possibility to distribute event traffic as efficiently as possible. In-car devices are able to provide personal travel advice that meets the wishes of the (unfamiliar) travellers.

4 Analysis of current situation in the ArenA area

After describing the state-of-the-art of route strategies, navigation, algorithms and traffic data we can start to analyse the current situation in the ArenA area. This chapter describes the current network, applied route strategies by the government, the characteristics per route and analyses of the events in the past based on empirical data. This last section provides a clear overview of the current distribution over the off-ramps towards an event. At the end of this chapter conclusions are presented and the first research questions can be answered.

4.1 Network description

This section describes the network and the infrastructural characteristics such as roads within the scope, the maximum speed, the number of lanes, traffic lights and the location of parking facilities. The scope (research area) of the ArenA area is focused on the urban roads that will lead a vehicle from an off-ramp directly to a parking facility. The highways around the area are also within the scope. A sketch of the ArenA area and the roads within the scope of the project is shown in Figure 7. The information which is described in here is needed to determine the capacity of the network at the end of this chapter.

Figure 7: Sketch of the infrastructural network of the ArenA area

4.1.1 Infrastructure
An important factor that determines the capacity of routes in the ArenA area is the geometric design of the infrastructure. Appendix D gives an overview of the number of lanes which determine the capacity of the road. The distances per road section are also given in the same appendix. The maximum speed on the secondary road network is 50 km/h. The highways around the ArenA area – A2, A9 and A10 – have a maximum speed of 100 km/h and at the S112 people are allowed to drive 70 km/h.

4.1.2 Buses
The ArenA area has several bus lines. Some lines have their own infrastructure. The own infrastructure applies for the Burgemeester Stramanweg, Hoogoorddreef (till Foppingdreef) and the part of the S111 between those two streets (Google Streetview, 2008). The schedule of the different bus lanes depends on the time of the day. Because an event can take place on every part of the day, there is assumed that the number of buses is 32 per hour per direction. This is based on traffic counts of bus lanes of municipality of Amsterdam and the schedule of the bus operator GVB (GVB, 2013). The number of buses are taken into account because buses have priority on intersections. Assumed can be that not-conflicting streams can still continue when a bus enters an intersection.

4.1.3 Pedestrians and cyclists
Every intersection gives the possibility for pedestrians and cyclist to cross. The infrastructure is designed in such a way that the number of pedestrian- and bicycle streams on the intersections are minimized. Main reason is that footpath and bicycle path are located on one side of the main street. Furthermore the area uses bridges only accessible for pedestrians and the exits of the parking facilities are tactical located. At every intersection the pedestrian- and bicycle streams can have their green time at the same time as a few vehicle streams. The only vehicle stream that has a shorter green time caused by a pedestrian stream is the vehicle stream that goes parallel to the footpath and turns to the right, in the direction of the foot path. Because the green time of other streams are determined mainly by the other vehicle streams, the assumption is made that the pedestrian and cyclist have no significant influence and are therefore not taken into account to determine the capacity of the routes.

4.1.4 Signalized intersections
The controlled intersection may be the bottleneck of a particular route. That is why it is important to take the capacity of the intersections into account. The maximum throughput of an intersection depends on green, yellow and red times per stream, the cycle time and the flow ratios in the critical path through the control scheme (Traffic Management and Control - Reader CIE4822, 2011-2012). The capacity could be determined to measure in practice but it could also be determined by theoretical formulas based on geometric conditions. Examples of geometric conditions are number of lanes, lane width and turning movements. Thereby the basic saturation flow is 1800 vehicles per hour.

4.1.5 Parking facilities
The ArenA area contains a lot of parking facilities. A large part of them are owned by the municipality. Other facilities belong to companies which are located in this same area. Since the most events are outside office hours the companies put their parking spaces available during an event. In Figure 8 most important parking facilities are shown. Appendix A shows the characteristics – location, parking cost, capacity – of all the parking facilities in the ArenA area. The total capacity of the most important facilities is 11.943 vehicles (Parkeergebouwen

Amsterdam, 2013). Parking prices are €10,- during a football match and €12,- during another event (e.g. concerts). This holds for the parking facilities of municipality Amsterdam, excluding P1 and P-dome. The parking fares are €20,- over there. Q-park facilities, P21- P24, are €13,50 per event. Table 1 shows an overview of the capacities of the main parking facilities in the ArenA area.

Table 1: Capacity of parking facilities in the ArenA area (total capacity 11.943 places)

Parking Facility	Capacity (#)	Parking Facility	Capacity (#)	Parking Facility	Capacity (#)
P1	2.400	**P6**	399	**P22**	228
P2	2.010	**P10**	814	**P24**	487
P3	366	**P12**	296	**P-Amstelborgh**	700
P4	1.248	**P18**	291	**Dome-garage**	550
P5	1.354	**P21**	450	**Endemol**	350

Figure 8 shows an overview of the location of parking facilities.

Figure 8: Overview of main parking facilities in the ArenA area

4.1.5.1 *Measured inflows*

Besides the number of parking places per facility the inflow capacity is of importance as well. It determines partly the maximum throughput during the peak hours in the ArenA area. Two measurements for this research are carry out in practice to determine the inflow capacity. The number of vehicles are counted for several minutes. The gathered data leads to an estimation of the inflow capacity per hour. Appendix B: Empirical data analysis explains the outcomes and the approach. The first measurement was at P-dome with a total capacity of 550 vehicles. Currently they work with reserved parking places. In practice this means that every vehicle gets checked to see if they really reserved a place and did pay in advance. The second measurement took place at P2; a big asphalt area with a total capacity of 2.010 vehicles. The outcomes are shown in Table 2. An average inflow of 13 vehicles/minute means 780 vehicles/hour and with two entrances it means 390 veh/hour/entrance. An inflow of 3 vehicles/minute results in 180 vehicles/hour. Since P-dome has 550 parking places, it would take almost 3 hours to fill the total parking facility.

Table 2: Measured inflows at parking facilities

Parking facility:	Capacity [# veh]:	Inflow [veh/minute]:	Entrances:
P-dome	550	3	1 (others not used)
P2	2.010	13	2

4.1.5.2 *Estimated inflows*

Other inflows are not measured. The specific saturated inflow is depending on different aspects, namely number of entrees or lanes, the lay-out of the parking facility, presence of an inflow limitation (traffic controller, barrier, ticket control etc.), speed of the vehicle and the following distance.

The NEN 2443 (Dutch design norms) about parking facilities includes an indication of the inflow capacity of an parking facility (NEN 2443, 2013). This inflow is based on limitations by a barrier.

Table 3: Inflow capacity of parking facilities (NEN 2443, 2013)

Entrance with barrier:	Passenger vehicles per hour per entrance
• Ticket issuance	270 - 300
• Card scan	300 - 350
• Credit card	240 - 270

During the inflow of an event some parking facilities do not use the physical barrier. In this situation the bottleneck of the parking garage probably will shift from the entrance to the parking manoeuvres of the drivers. As the inside of the parking garage can be seen as a black box, the assumption is made that the maximum inflow per entrance is 350 passenger vehicles per hour. This assumption is based on the maximum inflow which is indicated by NEN 2443.

It can be argued by a simple equation as well:

$$n = 3600 \ / \ \frac{L_v + L_f}{v}$$

n = number of passenger vehicles per hour per entrance
L_v = length of vehicle [m]
L_f = following distance [m]
v = average speed of the vehicle [m/s]

With L_v = 4.5 m, L_f = 6 m and v = 1.11 m/s (is 4 km/h) it means an inflow of 380 passenger vehicles per hour per entrance. This is comparable to the assumed value of 350 passenger vehicles per hour.

4.2 Applied route strategies

The government is responsible for a safe and continuous inflow and outflow of event traffic in the ArenA area. That is why they designed and apply route strategies. This section describes these route strategies. The description is based on the strategies which are used by Amsterdam at the end of 2012.

The municipality of Amsterdam has different strategies per type of event. They describe the goal in the strategy and the expected bottlenecks and risks. Common expected bottlenecks are queues at the Burgemeester Stramanweg with possible spillback at the A2 and queues towards De Entrée (P3,P4,P5). The goal of the road operators is to distribute event traffic as much as possible over the existing off-ramps and guide them immediately to a parking space. This would minimalize the cruising traffic[4].

4.2.1 Highways

On the highways in the ArenA area there are DRIPs with route information towards the ArenA (or Ziggo Dome and Heineken Music Hall). Rijkswaterstaat owns and controls those DRIPs. The DRIPs are located before the junctions so that drivers are able to change their route. Drivers on the highways are directed to exits towards the S111. Figure 9 shows a clear overview of those recommended routes. If too many vehicles choose to take the exit to S111 and congestion exists, the advice on the DRIPs changes to take the exit towards S112.

Figure 9: Route directions on DRIPs of Rijkswaterstaat

4.2.2 Guiding towards parking facilities

When a driver has chosen an off-ramp he will look for a place to park the car. The government has different measures to guide drivers to the different parking facilities. Normal measures are the PRIS in Amsterdam Zuid-Oost; fixed traffic signs with a dynamic element about the status of the parking facilities (full/free). If the government wants to prevent that people park in a certain facility they put the status on the sign on 'full'.

[4] Cruising traffic: people driving slow to search for a parking place

The structure of the strategy is focused on three chronological steps depending on the inflow. First of all, drivers are informed to go to the closest parking facility. The second step is that drivers are informed to parking facilities to prevent congestion and the last step is to inform drivers to fill up the parking facilities. Informing drivers is done via text on DRIPs. Examples are " P-ArenApoort, follow ↗" or "P-Ziggo Dome, follow ↑". In the ArenA area there can be found six DRIPs. They are located on the Burgemeester Stramanweg, S111 and S112. The strategies contain different schemes which help the executors to decide which text should be put on a DRIP and when. Input could be time, availability of a certain parking facility or intensities on the secondary road network.

To encourage the throughput towards the parking facilities the green times of the traffic lights are adapted. The streams going towards the parking facilities get an increased green time.

4.2.3 Outflow

Basically, everyone wants to leave the area at the same time. The goal of the government is to send vehicles immediately to the closest highway, independent on the destination of the vehicle. To prevent crossing traffic, there are clear routes from parking facilities to the highways. To execute this in practice, traffic controllers will guide the drivers and some traffic lights will be turned off. Figure 10 gives an overview of the controlled routes the drivers will take towards the highways. Since this is seen as an effective strategy and the outflow does not lead to congestion on the highway, the improvement of the outflow is out of the scope of this research. Therefore this thesis only focuses on the inflow.

Figure 10: Directed routes during the outflow of an event

4.2.4 Road blockades

A controlling measure to guide drivers to certain routes or parking facilities are road blockades. This measure however, is not discussed in the route strategy of the government. The experience of multiple observations in the ArenA area learns that the government and police still vary with the roads that they block during the inflow and outflow of an event.

4.3 Route distribution of static navigation

As mentioned in the state of the art, in-car advice is followed most efficiently and especially drivers to an unknown destination use this system. Drivers that do not have a navigation system might search for a suited route in advance at home on the internet. Since pre-trip route information and the most on-trip information is still static traffic information, there is looked into the generated static route advice towards the Amsterdam ArenA area.

Visitors of an event in the ArenA who use static route information might use internet or a navigation device to help them reach their final destination. Most visitors will dial "Amsterdam ArenA" as their destination into their navigation system or on Google Maps. This is assumable since most people do not know the address and secondly because "Amsterdam ArenA" is a point of interest.

4.3.1.1 *Static navigation towards Amsterdam ArenA*

Table 4 shows the advised off-ramp by static route navigation towards "Amsterdam ArenA" for the three most common navigation systems; Google[5], TripCast[6] and TomTom[7]. The route is determined using their websites and is based on the fastest route.

Table 4: Advised off-ramp towards "Amsterdam ArenA" with static navigation

Origin:	Google	Trip Cast	TomTom
A10 (west)	A2, exit 1	A10, exit S112	A2, exit 1
A10 (east)	A2, exit 1	A10, exit S112	A2, exit 1
A2 (south)	A2, exit 1	A2, exit 1	A2, exit 1
A9 (east)	A2, exit 1	A9, exit S112	A2, exit 1

The outcome shows that Google and TomTom will always give the advice to drive to the ArenA via A2, exit 1. The state-of-the-art in this report describes that in-car advices are followed most efficiently. There is also described that 95% of the owners of a navigation device – navigation system or smartphone – uses this device when they travel to an unknown destination. If all unfamiliar visitors towards an event would use a route advice based on static navigation, this will result in the fact that everyone will take A2, exit 1. The problem description in chapter 1 shows that this is one of the main problems; too many people taking the A2 during the inflow of an event. This means that there is room for improvement in static navigation systems to improve the distribution over the off-ramps.

4.3.1.2 *Static navigation towards parking facilities*

Since the goal is to prevent spillback on the primary road network, event traffic has to be distributed over the existing routes and off-ramps. Static route navigation towards the Amsterdam ArenA shows that drivers get (mainly) the same route towards the ArenA. What kind of route advice will people get if they are not navigating to "Amsterdam ArenA" but to a parking facility? The answer is given in Table 5. The results are gathered from Google Maps. Compared to Table 4 it shows more distribution over the available off-ramps. If we estimate the distribution over the off-ramps depending on the parking capacity and assuming that every origin produces

[5] Available on every Android Smartphone
[6] Two times the winner of Dutch competition in travel time prediction systems
[7] One of the most used navigation systems in the Netherlands

the same intensity, we see that 42% of the users gets a route advice over off-ramp A2. 26% will get an advice over A9-S111, 20% goes to A10-S111, 8% to A10-S112 and 3% goes to A9-S112.

Table 5: Static route navigation towards parking facilities based on Google Maps

	P2 et al.	P3 - P6	P10 + P12	P18	P21 - P24	P1
A10 (west)	A10-S111	A2	A2	A2	A10-S112	A2
A10 (east)	A10-S111	A10-S111	A10-S112	A10-S112	A10-S112	A2
A2 (south)	A2	A9-S111	A9-S111	A2	A2	A2
A9 (east)	A9-S111	A9-S111	A9-S111	A9-S112	A9-S112	A2
P-capacity:	2910	3367	1114	291	1165	2400

The empirical data analysis in section 4.5 shows that most people come from A10-west or A2-south. This means that the focus will be even more on off-ramp A2 than the estimated 42%. This analysis shows that static navigation - based on the shortest path to the parking facilities and available parking facilities – does not lead to an equal distribution over the available off-ramps. However this option is better than static navigation to 'Amsterdam ArenA' since that does not distribute vehicles at all.

4.4 Capacity and bottleneck analysis of the network

In previous sections the network is described and so are the route strategies of the government. This sections gains insight in the capacity and bottlenecks of the ArenA area. The capacity is estimated for the infrastructure and the bottlenecks are determined per route.

4.4.1 Approach estimation capacity and bottlenecks of ArenA area

This paragraph shows the detailed information of the capacity estimation with an optimal distribution of vehicles in the ArenA area. The estimation is based on the infrastructure, assumed green times, the (basic) routes from an off-ramp to a parking facility and characteristics of a parking facility (inflow and number of parking lots).

4.4.1.1 *Saturation flow of lanes*

The saturation flow per lane can be estimated. It is based on the formulas in the reader of the course Traffic Management and Control at the TU Delft to determine the saturation flow. The basic saturation in a secondary road network is 1800 pcu/h. Because we look at event traffic the assumption is made that there are no heavy vehicles during the inflow so pcu/h stands in this case for vehicles/hour. The next formula estimates the saturation flow:

$$s = n_{lanes}\, f_{RT}\, f_{LT}\, s_0$$

s = saturation flow (veh/h)
n = number of lanes
f_{RT} = factor right turning movements (0.85)
f_{LT} = factor left turning movement (0.95 for one lane, 0.92 for two lanes)
s_0 = basic saturation flow (1800 veh/h)

The capacity of the highway is assumed at 2000 vehicles/lane/hour.

4.4.1.2 *Green times per direction*
The next sections helped to determine the saturation flow. However, there are signalized intersections which cause a limitation to this flow. The next table gives an overview of the assumed green times per direction. The assumptions are based on the number of conflicting streams (more conflicting streams, less green time and the other way around), and the given information that certain streams have an increased green time during the inflow of an event to encourage the throughput.

Green times per hour per direction:

Left turning stream:	40 %
Continuous stream:	60 %
Right turning stream:	60 %

4.4.1.3 *Capacity per route*
The previous formulas and the knowledge of the infrastructure, parking facilities and basic routes leads to the estimation of the capacity. For every road section, intersection and parking facility the capacity is estimated. The lowest capacity determined the capacity of the route.

Per route the capacity and bottlenecks are estimated. For example, if an off-ramp has one lane, the capacity is 1*2000 = 2000 vehicles/hour. If the secondary road network has one lane, the capacity is 1800 veh/hour. If one lane is turning right at an signalized intersection, the capacity is 1800 * 0.6 * 0.85 = 918 vehicles/hour. And so on. The inflow capacity of the parking facilities is estimated in 4.1.5.2. The total parking places per facility and the number of entrances per facility are given in the appendix.

4.4.2 Bottleneck estimation 1: basic routes
The first analysis is based on a few basic routes from every off-ramp towards parking facilities. Since there are ten exits and fourteen parking facilities within the scope of this research, the possible routes are simplified to estimate the capacity of the routes.

4.4.2.1 *Basic routes*
The basic routes are based on shortest paths from an off-ramp, number of lanes, the route strategy described in the previous section and the aim to avoid crossing traffic.

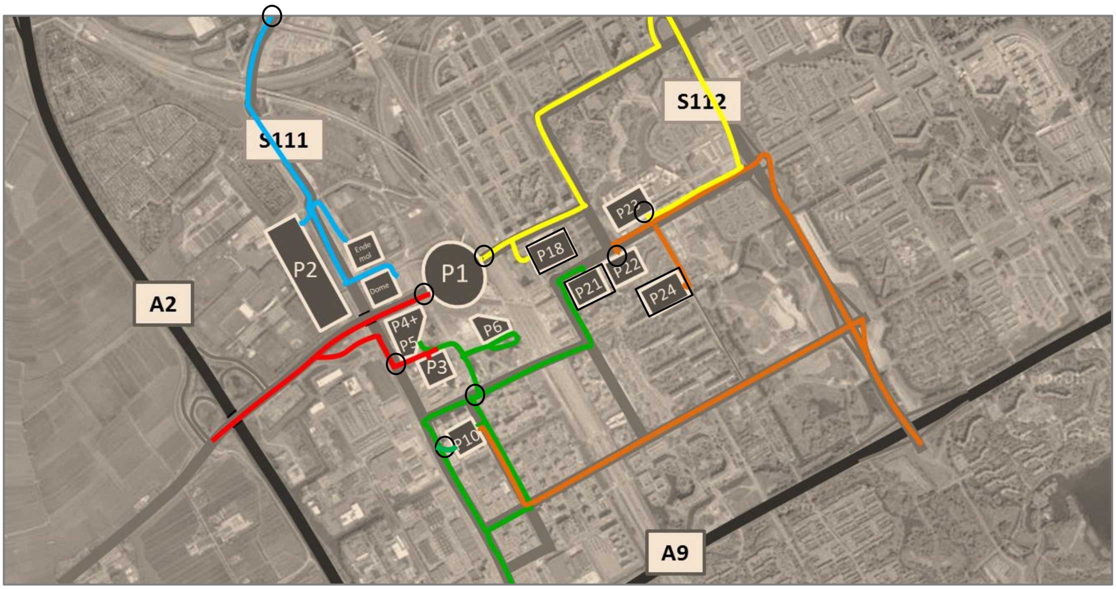


Figure 11: Basic routes from off-ramp to parking facilities

After the distribution the number of routes are declined from 70 possibilities to 13 OD-pairs. The distribution is as follows:

- From the A2 → P1, P3 and P5
- From the A9 to S111 → P4, P6, P10, P21
- From the A9 to S112 → P12, P22, P24
- From the A10 to S111 → P2, P-dome, P-Endemol
- From the A10 to S112 → P1, P18, P23

Figure 11 shows these basic routes. The bottlenecks of the routes could be several points in the network, namely the capacity of parking facilities (number of parking lots), the inflow capacity of the parking facilities (veh/hour), the capacity of the off-ramps (veh/hour) or the normative road characteristics from off-ramp to the parking lot including intersections (veh/hour). Per route the capacity of those four indicators are estimated. The lowest capacity determines the capacity of the specific route. The bottleneck estimation is described in the next section.

4.4.2.2 *Results capacity and bottleneck analysis*

The first bottleneck analysis is carried out with the use of the basic routes of Figure 11 and the approach described in 4.4.1.. The results of the analysis of the limitations in the network are shown in Table 6.

Table 6: Results of bottleneck analysis with basic routes

Route from/to:	Bottleneck:	Capacity [veh/hour]:	Total capacity per off-ramp:
Off-ramp A2			**1360**
to P1	inflow capacity P1	700	
to P3	intersection S111- De Entree	660	
to P5			
Off-ramps A9-S111			**1731**
to P10	inflow capacity P10	700	
to P4	intersection Hoogoorddreef - Haaksbergweg	581	
to P6			
to P21	parking capacity P21	450	
Off-ramp A9-S112			**1010**
to P12	parking capacity P12	300	
to P22	inflow capacity P22	230	
to P24	parking capacity P24	480	
Off-ramp A10-S111			**1325**
to P2	intersection Verlengde van Marwijk Kooystraat-S111 (first intersection after off-ramp)	1325	
to P-Endemol			
to P-dome			
Off-ramp A10-S112			**1340**
to P1	inflow capacity P1	700	
to P18	parking capacity P18	290	
to P23	inflow capacity P23	350	
	Total network inflow capacity [veh/hour]:		6766

The results shows that the 15 routes lead to five times a limitation of the inflow capacity of the parking facility, four times a limitation of the parking capacity and seven times an intersection causes the bottleneck.

If the bottleneck (intersection) of the routes from off-ramp A10-S111 (blue routes) will get a higher green time, then the bottleneck will shift to the limited inflow capacity of the three parking facilities. This would result in a capacity of 1400 vehicles per hour which is close to estimated capacity of 1325 vehicles per hour. At the routes to P4 and P6 coming from off-ramp A9-S111 (green routes) the vehicles have to deal with too much turning movements and intersections with traffic light which lead to a minimization of the capacity per route.

If event visitors will optimally use these routes in practice, the total inflow capacity will be around 6.700 vehicles per hour.

4.4.3 Bottleneck estimation 2: many routes from off-ramp A2

Earlier, this chapter shows that many static route navigation systems leads a traveler from every origin towards the ArenA with a route over off-ramp A2. Therefore it is interesting to look at the bottlenecks of the ArenA area if travelers are able to distribute themselves efficiently over many parking facility in the area. Figure 12 shows the many routes which are included in this bottleneck estimation. There are 9 parking facilities included in this analysis with a total of 14 entrances. With an estimated inflow capacity of 350*14 = 4900 vehicles per hour this means that the inflow capacity of parking facilities will generally not be the bottleneck in this situation.

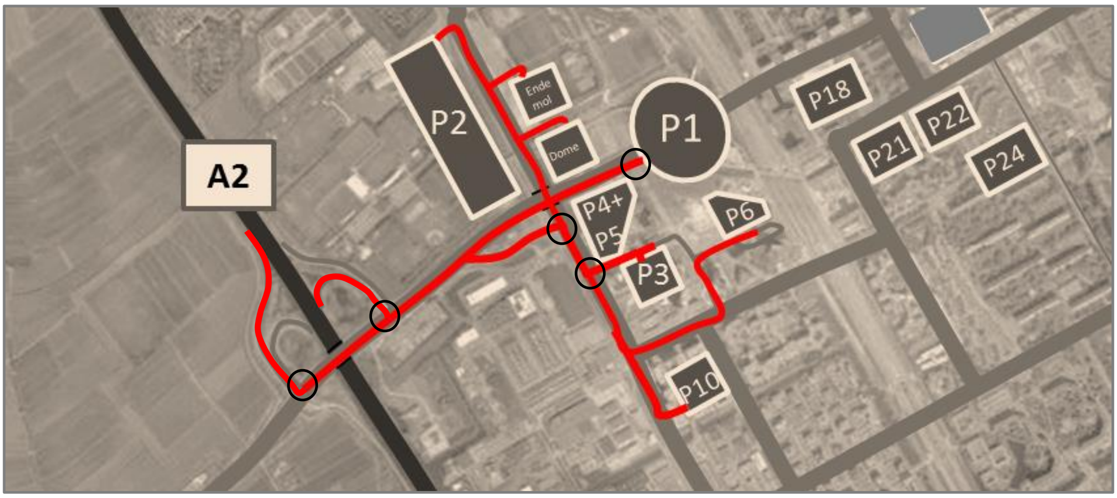


Figure 12: Many parking and route possibilities from off-ramp A2 (black circles are bottlenecks)

The results of the analysis are shown in Table 7. The black circles in Figure 12 show the bottlenecks. The main bottleneck that limits the inflow in the ArenA area are the intersections at the end of the off-ramp A2. It results in a maximum inflow of 3.300 vehicles per hour. The route to P1 is limited by the inflow capacity of this parking facility. The second route leads to P2, P-dome and P-endemol. This route capacity is limited by the intersection from the Burgemeester Stramanweg to S111 (left turning movement). If P-dome and P-endemol would not be available during an event the bottleneck will shift to the inflow capacity of P2. The third route leads event visitors to P3-P6 and P10, P12. The bottleneck towards P3-P5 is the intersection from S111 to De Entrée. Although there are two lanes that will lead vehicles from the S111 to De Entrée, the buffer capacity in front of the traffic light is limited which result in a capacity of 650 vehicles per hour. The fact that the limitation of the number of vehicles is 'remaining traffic' means that the main bottleneck is the inflow capacity of the off-ramp intersections.

Table 7: Results of bottleneck analysis with many routes from off-ramp A2

Route from/to:	Bottleneck:	Capacity [veh/h]
off-ramp A2R	intersection	1656
off-ramp A2L	intersection	1325
to P1	inflow capacity P1	700
to P2, P-Endemol, P-dome	intersection Burg. Stramanweg - S111	1325
to P3-P5	intersection S111 - de Entrée	650
to P6, P10, P12	remaining traffic	275

4.4.4 Conclusions

The capacity and bottleneck analysis of the network shows the limitations of the network. The bottlenecks in the network depend on the route and parking choice of drivers. If too many visitors choose the same parking facility, the inflow capacity will be the bottleneck and this will lead to spillback. If people distribute themselves effectively over the available parking facilities in combination with the available inflow capacity, the bottlenecks of the network are the intersections. The first bottleneck estimation shows that the network inflow capacity could be in theory more than 6.700 vehicles per hour. The second bottleneck estimation shows that maximum inflow of off-ramp A2 is 1650 vehicles per hour coming from the north and 1325 vehicles per hour coming from the south. The next section – analysis of multiple events – shows which capacity is needed.

4.5 Analysis of multiple events in the year 2013

The fixed traffic signs will lead a driver to the A2 and the Burgemeester Stramanweg towards the Amsterdam ArenA. DRIPs and navigation towards parking facilities try to distribute event traffic over the existing off-ramps. What is the distribution in practice? How many vehicles are going to the ArenA area during the inflow of an event? And is there any spillback on the A2? The answer to these questions help to gain insight in the characteristics of the current inflow of multiple events in the ArenA area (sub question d). An empirical data analysis is done for multiple events in 2013. This section gives insight how these data analysis is carried out and what the conclusions are.

4.5.1 Goal

The goal of this data analysis of multiple events is to give insight in:

- The duration of the inflow peak of different events;
- The distribution of vehicles over the off-ramps during the inflow of an event;
- If congestion appeared during the inflow of an event on the highway A2;
- The comparison or differences between different type of events.

The different topics will be discussed in this section of the report.

4.5.2 Data collection and assessment

TNO has access to the data measured by the detectors on the primary road network; speeds and intensities. Unfortunately, TNO has no data of the secondary road network. Therefore, connections with municipality Amsterdam are used to gather some information. Unfortunately, this was old or incomplete information. Because of possible conflicts of interests regarding Amsterdam Practical Trial no more data is released from the municipality.

The following traffic data is available to work with:

- Intensities on the primary road network;
- Speeds on the primary road network, mainly on the A2;
- Intensities of seven off-ramps (out of ten);

The available data of the primary road network is from 1 January 2012 until 30 June 2013. Data before 2012 is out of the scope of this research since the government have adapted their strategies in the meantime.

4.5.2.1 *Methodology to define event traffic*

Event traffic is only a part of the total traffic that uses the infrastructure during the inflow of an event. To define which part of the total traffic is event traffic, a method is developed. The following methodology is carried out to define the event traffic.

Formula:

$$Event\ Traffic = Intensity_{event} - (\frac{1}{6}a + \frac{1}{3}b + \frac{1}{3}c + \frac{1}{6}d)$$

- a = intensity 2 weeks before
- b = intensity 1 week before
- c = intensity 1 week after
- d = intensity 2 weeks after

Through the formula the average ‘normal day’ is defined in that time period by four days; two before and two after the event. In this way the effects of weather conditions, sales in megastores and so on are limited. One condition of a ‘normal day’ is that there are no events in the ArenA area on that day. In practice it turned out that it was sometimes hard to find those days that satisfied this condition. Only the days which satisfy this condition are taken into account and the formula is adapted to those circumstances.

Figure 13 shows the approach to define event traffic and define peak hours. The formula given above is only applied during the peak hours. Peak hours are based on visual observations. When the intensity of the event day is clearly increasing compared to an average normal day, the peak starts. The other way around, when intensity of the event day is back at the average level of a normal day, the peak is over.

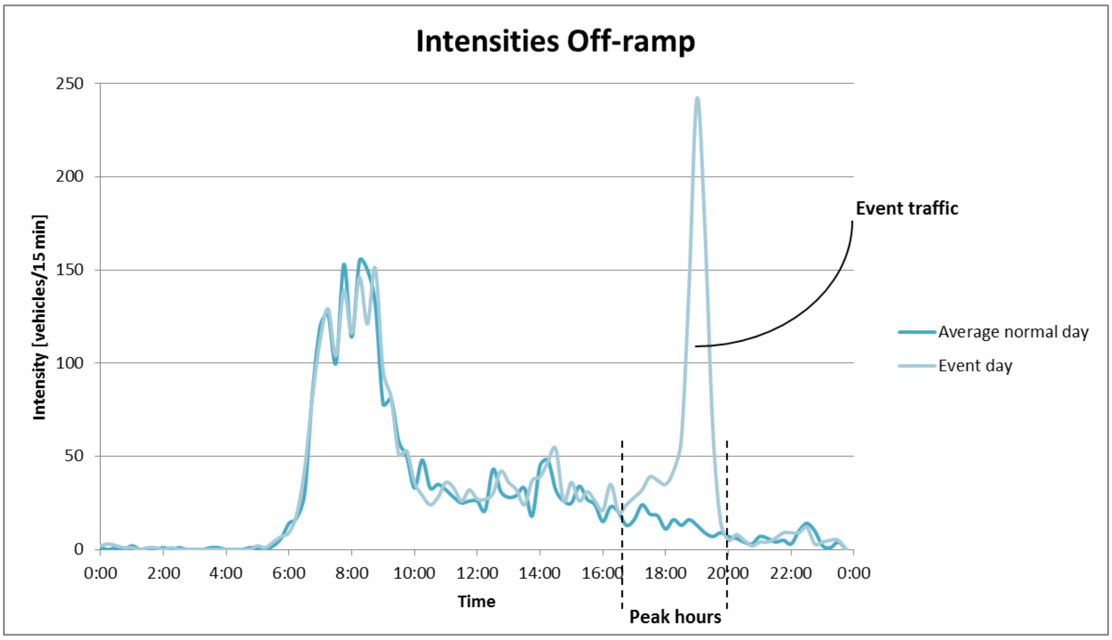


Figure 13: Approach to define event traffic and peak hours

4.5.2.2 *Methodology to determine intensities on an off-ramp without detectors*

There are ten off-ramps within the scope of this research. Unfortunately, not all off-ramps have sufficient data during the year. Some off-ramps do not have detectors and some detectors on off-ramps are defect during (a part of) the year. To determine the distributions of vehicles over the off-ramps, the intensities on the off-ramps need to be estimated. This is done in the following way:

$$Intensity_{Off-ramp} = Intensity_{Highway\ before\ off-ramp} - Intensity_{Highway\ after\ off-ramp}$$

The method and its calibration is detailed in the appendix. Off-ramp A10L towards the S112 did not give sufficient data at all. Since this off-ramp is indicated as not the most relevant off-ramp and comparable with off-ramp A9L towards the S112, the intensities of the last mentioned off-ramp are copied to off-ramp A10L and used in the analysis. The DRIPs show route information during the inflow of an event towards off-ramps to the S111. Off-ramps towards S112 are only advised when there is congestion on S111. Therefore the assumption is made that the number of event traffic using off-ramp A10-S112 is comparable to off-ramp A9-S112.

4.5.2.3 *Approach to determine congestion on the highway*

With the use of Matlab and the available speed data on the highways, speed-contour plots are created. In this way there can be determined if there was congestion on the highways A2 and A10 during the inflow, what time it started, what time it ended and the maximum length of the congestion. If congestion starts at the location of the off-ramp it can be assumed that event inflow is the cause of that congestion. The appendix analysis shows the speed-contour plots created in Matlab of three events.

4.5.2.4 *Selected events*

There are several type of events in the ArenA area. The Amsterdam ArenA, Ziggo Dome and Heineken Music Hall are the most important attractors in the area. Besides the different locations the type of events differ. Therefore the events are categorized as follows: football matches of

Ajax, football matches of the Dutch National Team, concerts in the ArenA, concerts in Ziggo Dome and a triple – three events at the same time - . As described in the state-of-the-art people choose their route based on information and experience. Ajax supporters are assumed to be more familiar with a match in the ArenA than people who visit the ArenA for a match of the national team or a concert. Therefore a distinction is made between these type of events. Furthermore there will be looked at the effect of a concert at Ziggo Dome. The question can be answered if a concert with 17.000 visitors will be enough to create congestion on the highway A2. Table 8 presents the events which are taken into account in the analysis. An event in the ArenA attracts approximately 45.000 visitors, an event in Ziggo Dome attracts 17.000 visitors. The triple (event in ArenA, HMH and Ziggo Dome at the same time) attracts around 90.000 visitors.

Table 8: Selected events in 2013 for the empirical data analysis

Event:	Day:	Date:	Start:
Concerts ArenA			
Toppers on Friday	fr	24-5-2013	20:00
Toppers on Saturday	sa	25-5-2013	20:00
Toppers on Sunday	su	26-5-2013	20:00
Football Ajax			
Ajax-Feyenoord	su	20-1-2013	14:30
Ajax-NEC	su	31-3-2013	16:30
Ajax-Willem II	su	5-5-2013	12:30
Ajax-ADO Den Haag	su	24-2-2013	14:30
Ajax-Heracles	su	7-4-2013	16:30
Football National Team			
Netherlands-Estonia	fr	22-3-2013	20:30
Netherlands-Romania	tu	26-3-2013	20:30
Netherland-Italy	we	6-2-2013	20:30
Concerts Ziggo Dome			
Mumford and Sons	sa	30-3-2013	20:00
Beyoncé	su	21-4-2013	20:00
One Direction	fr	3-5-2013	19:30
Triple			
Ajax-Pink-Eddie Izzard	fr	19-4-2013	20:00

Besides the type of event an important condition was the fact that there was no other big event in the ArenA area that might influence the effect.

4.5.3 General results

For every selected event an empirical data analysis is carried out as described above. This means the determination of event traffic, peak hours, and presence of congestion on the highway caused by the inflow of event traffic. Table 9 shows the output of this empirical data analysis.

The results show that the inflow of concerts takes in general 4 hours. Because of the spread arrival of event visitors it does not lead to congestion on the highway. The peak inflow of football matches on the other hand is much shorter; between 2,5 – 3 hours. This may be due to the fixed starting time of a football match, while concerts often have a warm-up act and not a clear starting time of the main show. This assumption can also explain the fact that the inflow of the concerts at Ziggo Dome ends 30 minutes after the starting time. Another possible explanation for the difference in peak inflow time is that visitors of a concert will probably make a more 'daytrip' out of it than a supporter of Ajax who visits his football club every two weeks.

Table 9: Results empirical data analysis of the inflow of several events in the ArenA area

Event:	Day:	Start:	Congestion on A2:	Peak hours:	Inflow [h]	# event traffic
Concerts ArenA						
Toppers on Friday	fr	20:00 h	no	16:00 - 20:15	4,25	> 7.300
Toppers on Saturday	sa	20:00 h	no	16:00 - 20:15	4,25	7.700
Toppers on Sunday	su	20:00 h	no	16:00 - 20:15	4,25	9.800
Football Ajax						
Ajax-Feyenoord	su	14:30 h	yes[8]	12:00 - 14:30	2,5	> 6.600
Ajax-NEC	su	16:30 h	no	14:00 - 16:30	2,5	5.200
Ajax-Willem II	su	12:30 h	no	09:00 - 12:30	3,5	7.700
Ajax-ADO	su	14:30 h	no	11:30 - 14:30	3,0	> 4.600
Ajax-Heracles	su	16:30 h	no	13:30 - 16:30	3,0	> 5.300
Football National Team						
Neth-Estonia	fr	20:30 h	yes	18:00 - 20:30	2,5	> 7.000
Neth-Romania	tu	20:30 h	yes	17:00 - 20:30	3,5	7.000
Neth-Italy	we	20:30 h	yes	18:00 - 20:30	2,5	> 5.300
Concerts Ziggo Dome						
Mumford and Sons	sa	20:00 h	no	16:00 - 20:30	4,5	2.200
Beyoncé	su	20:00 h	no	16:00 - 20:30	4,5	3.400
One Direction	fr	20:00 h	no	16:00 - 20:30	4,5	> 1.700
Triple						
Ajax-Pink-E. Izzard	fr	20:00 h	yes	16:00 - 20:00	4,0	12.000

Remarkable is the difference between a football match of Ajax and a football match of the Dutch national team in the presence of congestion on highway A2. The peak hours and the total event traffic are comparable. However, the inflow of a match of the national team leads in general to congestion and the inflow of an Ajax match does not. A possible explanation is the experience of Ajax supporters; they know how to distribute themselves over the network and the parking facilities. Ajax plays at least 34 matches in the ArenA each year, while the national team has approximately six matches in the Arena each year. The supporters of the Dutch team are probably more unfamiliar with the ArenA area. This last assumption will return in later stage of this research, in 4.5.6 Familiar and unfamiliar visitors. Furthermore congestion occurs with much less demand than the available capacity in the network. This concludes that the network is not used optimally.

[8] There was heavy snowfall during the inflow of the match Ajax-Feyenoord

4.5.3.1 *Selected events for scenarios*

Based on the general results three scenarios are chosen that represent the possible inflow during different events towards the ArenA area. These scenarios are analyzed into detail and are also used as input and validation for the final model. Conditions for the selected events are:

- Sufficient data available to determine event traffic and total traffic during the inflow of an event on all ten off-ramps towards the ArenA area;
- Difference in type of events;
- Difference in congestion on the A2;

The first condition makes sure that only eight out of fifteen events of the selected events of 2013 are able to function as a scenario. This is the case for all events that have a fixed total number of event traffic in Table 9.

Since all three matches of the Dutch national team led to congestion on the A2 and only the match Netherlands-Romania has sufficient data, this event is selected as a scenario. Secondly a match of Ajax did not lead to congestion on the A2 in the first 6 months of 2013 so Ajax-NEC is also selected as a scenario. Ajax-Willem II satisfies the condition as well, but since this match was a special event to earn the championship this event is not selected. The last selected event is the event that led to the biggest congestion during the inflow; the triple on 19 April. In summary, the selected events for scenarios are:

1. Football match Ajax – NEC on Sunday 31 March 2013;
2. Football match Dutch national team – Romania on Tuesday 26 March 2013;
3. Triple ArenA, Ziggo Dome and HMH on Friday 19 April 2013.

4.5.4 Congestion on highway A2

Table 9 shows that some events led to congestion on highway A2. The speed-contour plots, where this is based on, can be found in Appendix C. This section shows the corresponding intensities on highway A2 during the inflow of the three selected events; Ajax-NEC, Netherlands-Romania and triple ArenA, Ziggo Dome & HMH.

The flow-time plots given in the following paragraphs are following the approach mentioned in “Methodology to define event traffic”. Not only the intensities of the event day is given, the ‘regular days’ are given as well. The comparison between the event day and the ‘regular days’ shows clearly the peak of event traffic.

The capacity analysis of the network in the ArenA area in part 4.4 showed that the off-ramps A2L and A2R together have a limited capacity, but that the main cause of congestion is probably the limited flow capacity of the secondary road network. The goal of this section is find out if this is the case.

4.5.4.1 *Intensities off-ramp A2 during inflow Ajax-NEC*

Figure 14 shows intensities on off-ramps A2L and A2R including the inflow of event Ajax-NEC.

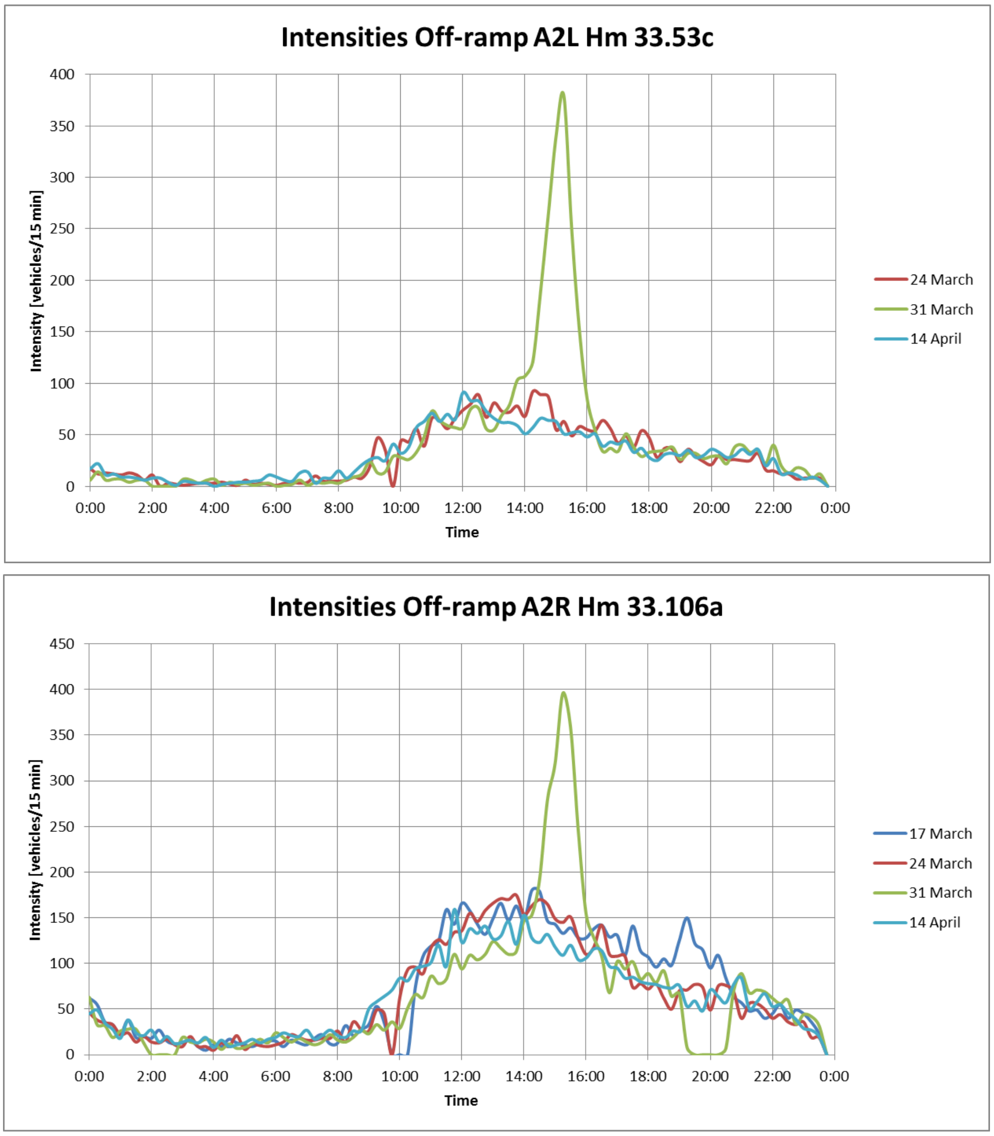


Figure 14: Intensities off-ramps A2L and A2R including event Ajax-NEC on 31 March 2013

The match Ajax-NEC started at 16.30 hour on a Sunday. It can be seen that the huge inflow peak was between 15.00 and 15.30 hour. The inflow did not lead to congestion on the highway A2, so there can be stated that the peak inflow can be handled by the intersections after the off-ramps. This is approximately 380 vehicles/15 minutes taking A2L (coming from the south) and 400 vehicles/15 minutes taking A2R (coming from the north) both at 15.15 hour. Besides that, there can be assumed that every supporter coming by car was in time in the ArenA since the event peak ended 30 minutes before the match.

4.5.4.2 *Intensities off-ramp A2 during inflow Netherlands-Romania*

The match of the Dutch national team against Romania started at 20.30 hour on a Tuesday. The morning peak and the event peak are visible. The event peak ended around 20.00 hour so there can be assumed that the supporters were in time for this match as well. The dotted blue area indicate the timeframe when there was congestion caused by the inflow.

It can be concluded that the intersections after the off-ramps can handle the intensities of the inflow and are not the cause of congestion. The first reason is that the peak before congestion sets in on both off-ramps lower than the peak of Ajax-NEC.

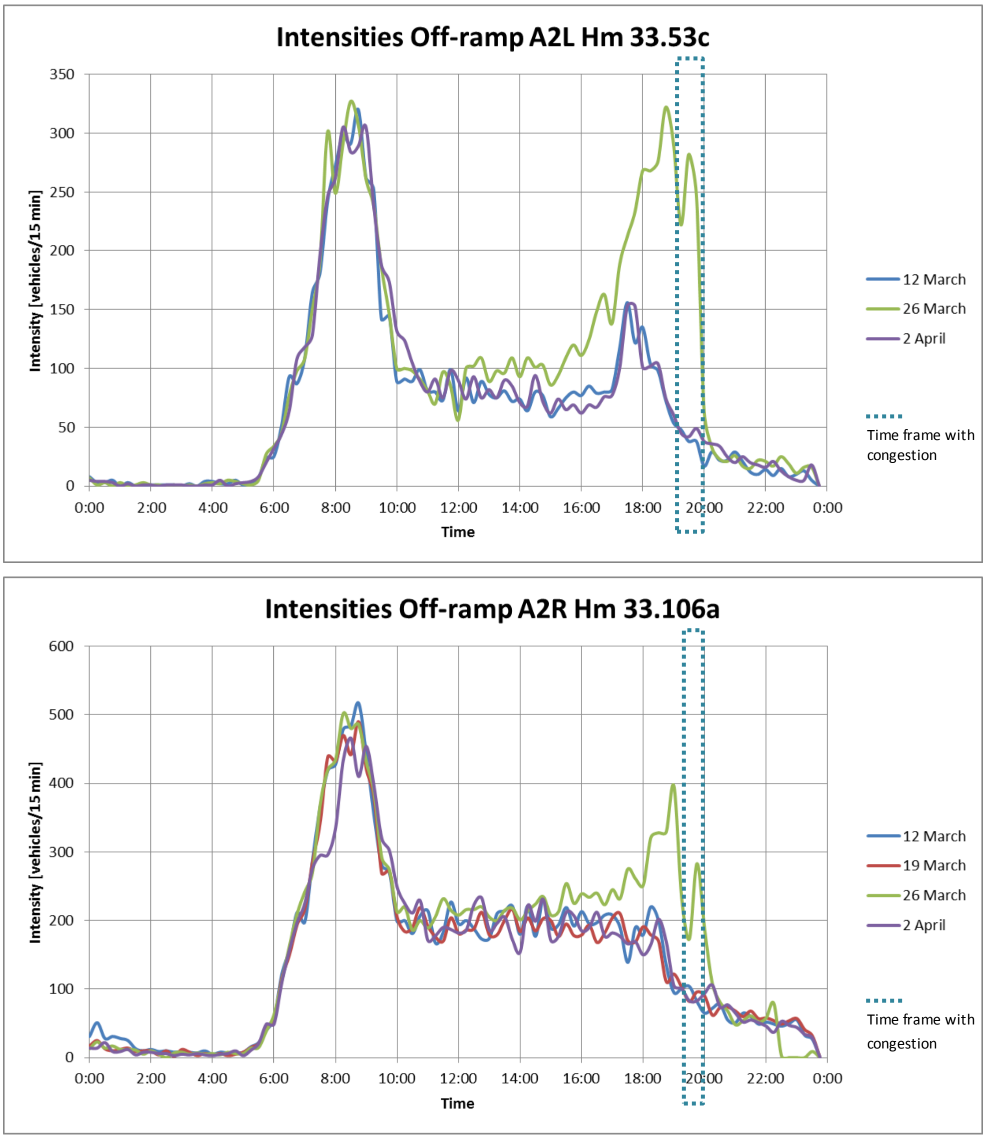


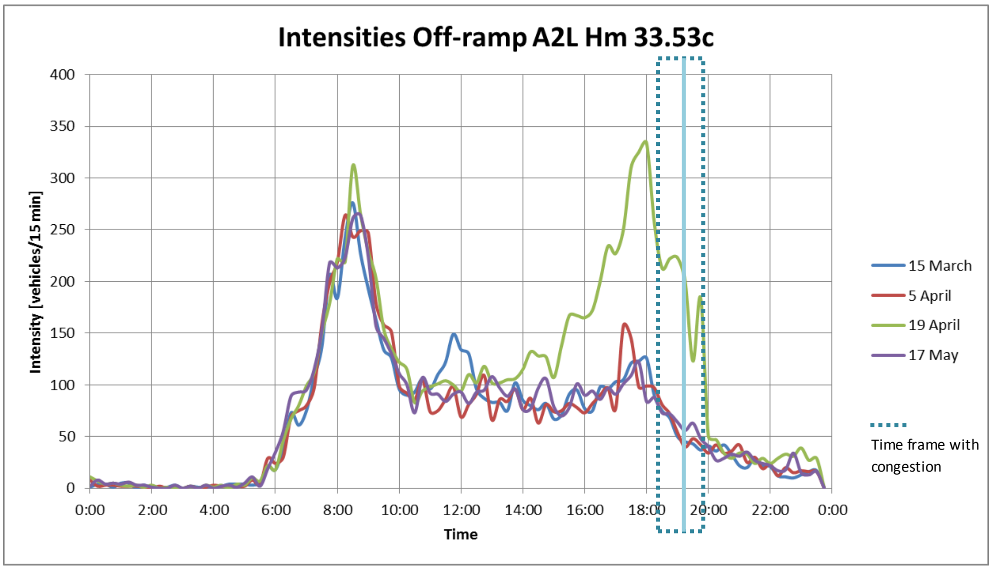
Figure 15: Intensities off-ramps A2L and A2R including event Netherlands-Romania on 26 March 2013

The figure shows 320 vehicles/15 minutes on A2L and 400 vehicles/15 minutes on A2R. The second reason is that the morning peak is even higher. This inflow did not lead to congestion.

4.5.4.3 *Intensity off-ramp A2 during inflow triple (ArenA, Ziggo Dome, HMH)*

On Friday 19 April 2013 three events started at 20:00 h. It led to a huge inflow with more than 12.000 *event vehicles* entering the area within 4 hours. This was the heaviest inflow of the last few years and lead to a big traffic jam on A2L, de highway from the south. Figure 16 shows the intensities on A2L and A2R. The speed-contour plots can be found in Appendix B: Empirical data analysis.

The congestion on highway A2 is caused by spillback from the secondary road network. There are three arguments for this statement. Firstly the maximum intensity measured at A2L during the inflow is lower than the maximum intensity during the inflow of Ajax-NEC on the same road which did not lead to congestion. Secondly if the maximum peak at 18:00 h would have led to congestion caused by the intersection, the throughput capacity would not have dropped so much.



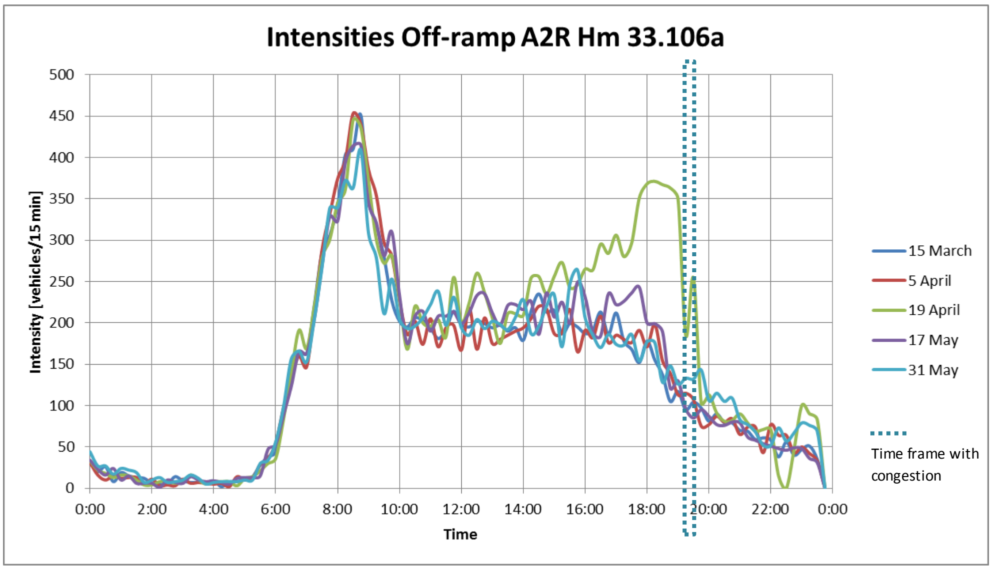


Figure 16: Intensities off-ramps A2L and A2R including event Triple on 19 April 2013

This argument can be explained by using Figure 17. Both off-ramps have a 'storage capacity' before the spillback will reach the main road. The detectors which measured the intensities are indicated with the yellow dot. This means that the detectors still can measure a high intensity while in the meantime spillback from set in coming from the intersections. At the moment that spillback reaches the location of the detector the intensity will drop to the throughput capacity of the bottleneck. However, this applies only if the vehicle supply taking that exit is the same or higher. This was the case for the triple on 19 April since the traffic jam was increasing till 19.15 hour (see speed-contour in appendix B: empirical data analysis). The blue line within the blue dotted line on Figure 16 shows this point of time. We can see that the inflow intensity using A2L was on average 210 vehicles per 15 minutes when congestion was increasing to the south. This is much lower than the peak of more than 300 vehicles per 15 minutes which is at least the capacity the off-ramp can handle.

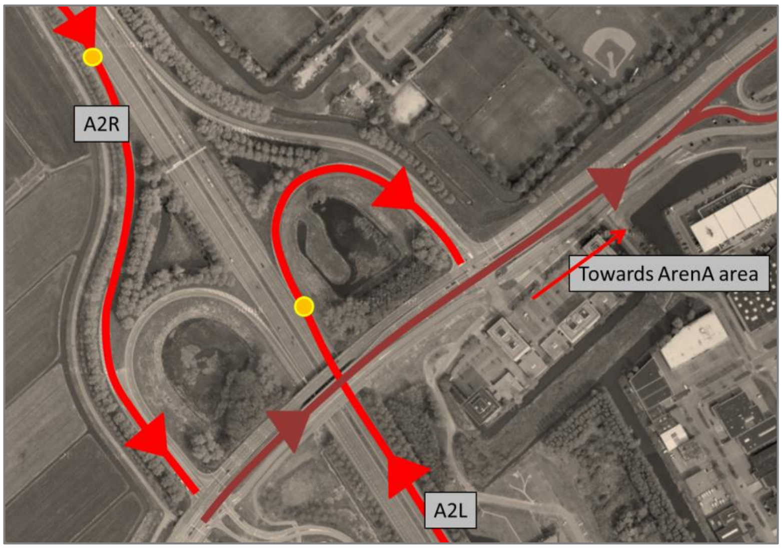


Figure 17: Routes from off-ramp A2 towards ArenA area
(Yellow dots are the locations of detectors)

The last argument that congestion was caused by spillback on the Burgemeester Stramanweg: congestion on A2R started more than 30 minutes later and dissolved earlier compared with the congestion on A2L. This can be explained by the fact that the 'storage capacity' for vehicles coming from the north is higher. When spillback comes from the parking facilities or intersections, it will first reach the intersection with A2L. Later in time it will reach the intersection with A2R. If congestion solves it will work the other way around. If the spillback on the Burgemeester Stramanweg decreases, the congestion on the A2R will be the first to solve since the off-ramp A2L is still blocked. This is the case during the inflow of the triple at 19 April.

4.5.5 Origin of traffic and distribution over off-ramps

This section shows several tables of the empirical data analysis which gives an overview of the distribution of event and regular traffic over the available off-ramps. The scenarios are input for the modelling part.

4.5.5.1 *Distribution event traffic during biggest peak hour*

The empirical data analysis gives output of the origin of event traffic and the distribution over the available off-ramps. Table 10, Table 11 and Table 12 show the output of the distribution during the maximum peak hour of the three scenarios. The values are rounded to steps of fifty. All information in the tables are derived from the off-ramp data. This means that the origins are not definitely sure. However the origin can be assumed since event traffic will probably not make huge detours to enter the ArenA area. As an example, the number of vehicles coming from A10-west is a summation of event traffic on off-ramp A2R, A10L-S111 and A10L-S112. The vehicles from A10-east are indicated by the vehicles on off-ramp A10R-S111 and A10R-S112. The other two origins are determined in the same way.

The information in the tables below are used as an input for the scenarios used in the modelling part of the strategy.

Table 10: Empirical trip distribution of scenario Ajax-NEC, peak 15:00 – 15:59 hour

	A2	A10-S111	A10-S112	A9-S111	A9-S112	total per origin:
A10-west	800	600	100	-	-	1500
A10-east	-	550	600	-	-	1150
A2-south	900	-	-	600	100	1600
A9-east	-	-	-	100	450	550
total	1700	1150	700	700	550	**4800**

Table 11: Empirical trip distribution of scenario Netherlands - Romania, peak 18:30 - 19:29 hour

	A2	A10-S111	A10-S112	A9-S111	A9-S112	total per origin:
A10-west	750	350	150	-	-	1250
A10-east	-	200	0	-	-	200
A2-south	950	-	-	500	150	1600
A9-east	-	-	-	150	150	300
total	1700	550	150	650	300	**3350**

Table 12: Empirical trip distribution of scenario Triple, peak 18.30 - 19.29 hour

	A2	A10-S111	A10-S112	A9-S111	A9-S112	total per origin:
A10-west	750	550	350	-	-	1650
A10-east	-	650	700	-	-	1350
A2-south	600	-	-	800	350	1750
A9-east	-	-	-	550	450	1000
total	1350	1200	1050	1350	800	**5750**

Congestion on highway A2 started at 19:00 h during the inflow of Netherlands-Romania and at 18:20 h during the inflow of the Triple. The scenarios Ajax-NEC and Netherlands-Romania show clearly that off-ramp A2 is used most often. The triple shows a huge inflow of 6.400 vehicles of event visitors in total. We can see that the distribution over the most common off-ramps regarding the route strategies of the municipality – A2, A9-S111 and A10-S111 – is nearly equal. If we look at the distribution of the inflow of the scenario Netherlands – Romania we can conclude that congestion on the A2 could have been less worse if event visitors would have used the off-ramps at the A9 and A10 more. The reason that the off-ramp at the A10 was less used is assumable due to the congestion on the A10 during the peak hours. The speed-contour plots can be found in the appendix.

4.5.5.2 *Distribution total traffic during biggest peak hour*

As can be observed from the previous tables, the number of vehicles during the biggest peak hour of Ajax-NEC was much higher than Netherlands-Romania but did not lead to congestion on the highway. The cause and effect of congestion are not only depending on event traffic, but on regular traffic as well. Figure 18 gives an overview of the total traffic that used the several off-ramps during the biggest peak hour and shows a comparison of the two scenarios.

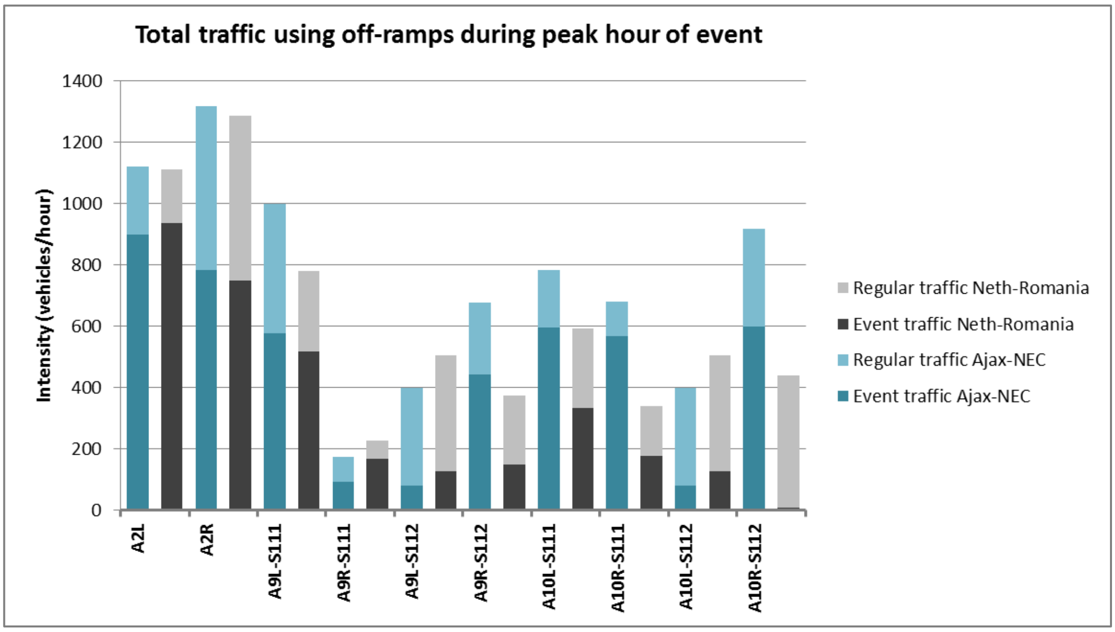


Figure 18: Comparison between Ajax-NEC and Netherlands-Romania inflow distribution during peak hour

The figure shows that not only event traffic is comparable on off-ramp A2L and A2R, but regular traffic is comparable as well. The assumption is made before that a match of the Dutch national team attracts more unfamiliar visitors and that this leads to congestion. Ajax supporters know better how to distribute themselves over the available parking facilities coming from off-ramp A2. Figure 18 makes this assumption stronger.

More output of the empirical data analysis regarding the distribution of traffic over the off-ramps can be found in appendix B.

4.5.6 Familiar and unfamiliar visitors

The hypothesis is made that familiar visitors are able to divide themselves more efficiently over the available network and parking facilities than unfamiliar visitors. The state of the art and the analysis of the current situation show a difference between the inflow of a Ajax match (familiar visitors) and a match of the Dutch national team (much more unfamiliar visitors). Familiar visitors know more about possible routes and parking facilities in the ArenA area and therefore know how to distribute themselves more efficiently. This leads in general to less spillback in the area. Because of this a distinction is made between familiar and unfamiliar visitors. Which part of the visitors is familiar and unfamiliar is based on the type of event.

For every scenario assumptions are made about the proportion familiar and unfamiliar visitors. These assumptions are used in the 'Parking choice model' in chapter 6. The proportions are given in Table 13. Ajax-supporters go to the matches of their favourite football club frequently. Therefor the percentage of familiar event visitors is estimated on 90. The matches of the Dutch national team have a much broader audience. Since these matches are on average three times a year the assumption is made that only 25% of the visitors is familiar. The last scenario (Triple) exists of an Ajax match and two concert in Ziggo Dome and Heineken Music Hall. The half of the total amount of event visitors contains of Ajax supporters. Therefore the familiar visitors are stated on 50% .

Table 13: Percentages familiar and unfamiliar visitors at three scenarios

Scenario:	% familiar visitors	% unfamiliar visitors
Ajax-NEC	90	10
Netherlands – Romania	25	75
Triple (Ajax, Pink, E. Izzard)	50	50

4.5.7 Conclusions empirical data analysis

The conclusions of this data analysis:

- Concerts at Ziggo Dome do not lead to congestion on the primary road network;
- The inflow of an event in the ArenA could lead to congestion on the A2;
- The inflow of a concert takes much longer than the inflow of a football match;
- A football match of Ajax generally does not lead to congestion on the A2;
- A football match of the Dutch national team leads in general to congestion on highway A2;
- The bottleneck of this area is mainly the secondary road network instead of the capacity of the off-ramps on the A2;
- It can be assumed that familiar visitors know how to distribute themselves more effectively over the available parking facilities than unfamiliar visitors;
- The number of vehicles entering the ArenA area is less than the capacity of the network for the majority of events. With other words, the network is not optimally used.

4.6 Aggregation of traffic dynamics

The previous sections in this chapter give a clear view of the bottlenecks in the area and the causes of delay in the ArenA area. Figure 19 on the next page shows a flow-diagram of these traffic dynamics in the area. The grey boxes show the network characteristics and the blue boxes give the opportunities to change the traffic dynamics within the scope of this research.

Delay in the Amsterdam ArenA area can occur in several ways. First of all when too many drivers choose the same parking lot or the same route within the same time. If the flow capacity of the parking facility or the intersection cannot handle the demand, a waiting queue begins. If demand stays higher than the flow capacity the waiting queue grows. When the waiting queue exceeds the storage capacity of the road, spillbacks occurs. This means that all vehicles using that particular road or route will be affected by the spillback. If the waiting queue will override the storage capacity of the secondary road network as well, the congestion spills back on the primary road network. This affects all vehicles on that part of the primary road network. As showed in the bottleneck analysis, congestion on the primary road network can also exists when too many drivers choose the same off-ramp at the same time.

To prevent delay from happening we can try to influence the reasons why there are too many vehicles on the same place at the same time. Drivers make four decisions when they bought a ticket for a football match or a concert for their trip to the event; what transport mode will I choose? At what time do I leave? Where do I park? And which route will I take? The first two options are mobility management and out of the scope of this research. The last two options are choices to influence and incorporated in the design criteria for the in-car strategy, described in the next chapter.

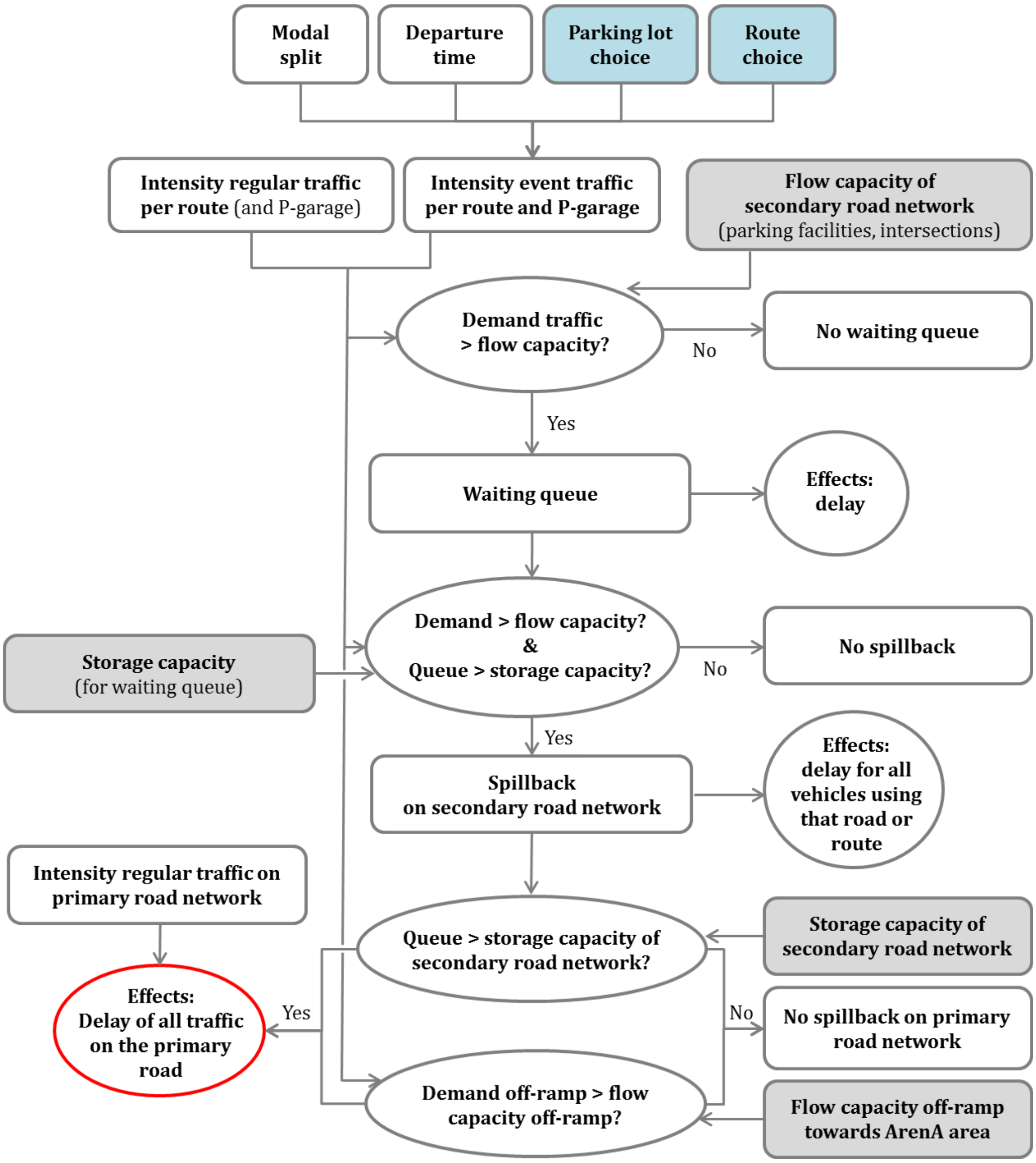


Figure 19: Flow-diagram of the cause of delay in the ArenA area
(grey boxes = network characteristics, blue boxes = possibilities to change with a strategy)

4.7 Overall conclusions

The current route strategies in the Amsterdam ArenA are only focused on roadside measures. The government (Rijkswaterstaat) is responsible for the information on the primary road network while the municipality of Amsterdam is responsible for the measures on the secondary road network. The route strategies consists of route information on DRIPs towards the ArenA (on primary road network) or towards parking facilities (secondary road network). Additionally the municipality can decide to close some lanes or parking facilities during the inflow of an event. The outflow of an event has a clear goal: guide people via the shortest path from a parking facility to the highway and prevent crossing traffic to reach a maximum outflow capacity.

The most commonly used static travel information towards "Amsterdam ArenA" leads a user to the off-ramp on the A2 towards the Burgemeester Stramanweg. Navigating to a parking facility will distribute event traffic more over the several off-ramps in the ArenA area. However, the main emphasis is still on the off-ramp of the A2.

The empirical data analysis shows that the inflow of a concert starts earlier than a football match in the ArenA. When the inflow of a concert takes approximately four hours, the inflow of a football match takes only 2.5 hour. In general, matches of Ajax in the Dutch competition or concerts in Ziggo Dome and Heineken Music Hall do not lead to congestion on highway A2 during the inflow. Matches of the Dutch national team however lead often to congestion. There is assumed that this is partly caused by the more unfamiliarity with the area in combination with the number of visitors of this type of football matches and the small inflow time period.

The bottlenecks analysis showed that the inflow is limited by the inflow capacity of parking facilities and the flow capacity of the intersections. If the demand gets higher than the flow capacity a queue will arise. This could lead to spillback and in the end to congestion on the primary road, depending on if demand stays higher than capacity. The flow capacity of the intersections at the end of the off-ramps at the A2 is limited as well. This is also a bottleneck if too many vehicles want to use this off-ramp within the same time.

Observations in practice showed that the inflow of certain parking facilities is relatively low because of the fact that a parking guide controls the inflow. For example by checking the parking reservations of visitors by hand. Since parking facilities are one of the bottlenecks during the inflow it is of importance to maximize the inflow capacity. The available parking capacity in the ArenA area is sufficient for the number of event visitors.

The conclusions of the analysis of the current situation are used for the design of the in-car strategy (chapter 5) and the design of the model (chapter 6).

5 Design of in-car strategy

After the literature study and the analysis of the current situation, a strategy is designed. The main goal of this strategy is to improve the current situation. This chapter describes the design. First of all the design criteria are provided based on the conclusions of the previous chapters. After that, the designed strategy will be explained. This includes an explanation of known strategies that are not suitable for this area.

5.1 Design criteria

This section describes the criteria for the design of the strategy. At first the criteria will be described from a traffic throughput point of view, since the goal of the strategy is focused on improving traffic throughput. Secondly the criteria from a traveler's point of view is described. Because of the fact that traffic information and advice does not force people to a route or parking facility, the strategy must be convincingly for people to comply to.

5.1.1 From the traffic throughput point of view

Goal of the strategy is to prevent spillback from occurring during the total inflow of an event. The flow-diagram in chapter 4 - Figure 19 - gives an overview how this spillback exists in the Amsterdam ArenA area. It shows that route choice and parking lot choice are the factors that can be influenced in the strategy (indicated by the blue colour in the figure).

Literature study showed that in-car travel advice has a higher compliance level than roadside measures when people are unfamiliar in an area. If we really want to steer travelers, we have to put the strategy inside the car instead of the current roadside strategies. Besides that, road side measures are applicable for every driver on that particular road or route. An in-car strategy gives the possibility to give every traveler a different advice. This can lead to a better distribution over the available road and parking capacity.

The design criteria based on literature and analysis of the ArenA area to decrease delay are well summarized in the four principles of integrated network management (INM). These four principles are: improve throughput, prevent congestion from occurring, if congestion is inevitable then at least control queue spillback and the last principle is to distribute traffic such that under all circumstances everyone is able to finish their trips at an acceptable cost (Integrated and Coordinated Networkmanagement - Reader CIE5804 TU Delft, 2012). The 'acceptable cost' can in the case of the ArenA area be described as 'make sure that every visitor will be in time for the start of the event'.

The analysis of the current situation in the previous chapter showed that the bottlenecks in the area are several intersections and the inflow capacity of parking facilities. Furthermore the ArenA area has a high inflow capacity, but in practice it is not used optimally. The inflow of an event occasionally leads to congestion on the primary road network. This mainly happens at highway A2 and there are two main reasons for this. First of all, the off-ramps of the A2 are used most often by event visitors during the inflow. Secondly the routes from off-ramp A2 to the parking facilities are very short. This together makes that spillback exists because of high demand and reaches the highway fast. This can be prevented by distributing vehicles more efficiently over the network. The conclusions of the previous chapter and the four principles of integrated network management lead to the following principles to improve traffic throughput in the ArenA area during the inflow of events:

1. Avoid crossing traffic
2. Steer people to a parking facility with sufficient capacity (parking facility and route)

The first statement provides maximum green times at the intersections in the direction of the parking facilities; the less demand from multiple streams the higher the green time of the main directions. The second statement controls the length of spillback. The users of the in-car strategy will not be responsible for making the queue longer than it is already. Furthermore the users of the system will not experience delay since they are led to spare capacity. If spillback is inevitable than this statement is less applicable.

5.1.2 From event visitor's point of view

The analysis of the current situation showed that people who are driving to Amsterdam ArenA do not have clear information about parking costs and estimated walking time from the parking facility to their final destination. Basically the current parking choice of unknown event travelers is based on traffic signs they see on their way to the ArenA or is based on the random parking advice that the current navigation systems can generate. A research showed that people who are driving to an unknown location want travel advice instead of only information (Dicke-Ogenia, 2013). This means that giving information about parking costs and walking distances alone is not enough; the information has to be turned into an advice. The less experienced the drivers are, the more they will comply to the given advice. This hypothesis is based on the Figure 6: The cycle of choice on page 14. Furthermore, the more valuable the advice is the more travelers will comply to the advice as well.

5.1.3 Overall

In summary, the strategy should distribute the event visitors over the available parking facilities and off-ramps in such a way that queues and spillback in the ArenA area will be prevented. To avoid crossing traffic green times can be maximized towards the parking facilities. Event visitors using the in-car strategy will get a route and parking advice. To adapt the information on their personal preferences, the chance they will comply is getting bigger. To distribute event visitors as good as possible over the network and the available parking lots it is important that the strategy is dynamic and personal. Dynamic means that the advice should be given at the last part of the trip based on the real-time situation (queues in front of a parking facility and available places). Personal information makes it possible to give drivers all a different advice. This ensures the distributing of vehicles over the network.

5.2 The designed in-car strategy

This section describes the designed strategy for event traffic towards the ArenA area, based on the design criteria from the previous section. First the design process is discussed with ideas that are not suitable for this area.

5.2.1 The design process

Several parties think about solutions for the inflow of event traffic. These parties have different interest and different goals. Tripticket.nl and onlineticket.nl are websites where a visitor can make a reservation for a parking lot. This approach is designed for the visitor; it takes unfamiliarity away and gives the visitor certainty. TNO has thought about reservations of parking places as well. In view of Amsterdam Practical Trial their goal is to distribute vehicles over the network. The fact that people will pay for their parking lot in advance has a great advantage; the probability that a visitor will listen to the given advice is rather high. A big disadvantage of the use of reserved parking places is that it is not dynamic. Firstly if many users arrive at the same time at the same parking facility they cannot be rejected because they already paid and spillback will occur. Furthermore the measurements in practice show that reserved parking places lead to a huge decrease of inflow capacity. Since this is one of the main bottlenecks in the area this must be prevented. Practice showed that people who reserved a parking place must show a printed ticket. The process takes so many time in practice that it decreases inflow from 300 vehicles per hour to 180 vehicles per hour per entrance.

The idea behind reserving parking lots is good; take the unfamiliarity of visitors away and give them certainty. Furthermore give visitors all a different route advice to increase the distribution over the network. However it is important to keep the strategy dynamic since we do not know when people arrive and which route and parking facilities non-users will take.

The goal is to distribute vehicles efficiently over the network conform system optimum. Social navigation (Van den Bosch & Van Arem, 2011) has that same goal. It claims to be the first approach to motivate drivers to choose their route from a system optimum point of view. Social navigation focusses on in-car travel time. It aims to let a driver change its route in favor of the travel time of other road users. However, for event traffic the utility of travel information regarding the preferences of the visitors are estimated higher than the disutility of visitors making a detour. First of all the ArenA area is a small area and therefore the detours are limited. Secondly it is assumable better to focus on utility than on disutility to increase level of compliance.

5.2.2 Personal preferences of event visitor

The personal preferences of the event visitor will be incorporated in the parking and route advice. As mentioned before, there is a lack in information about walking distance and parking cost. Since unfamiliar drivers want information that takes this unfamiliarity away, information about walking time and parking cost are incorporated in the strategy.

State-of-the-art shows that 'perfect' travel advice differs per individual traveler. This means that there is a difference in the preferences of travelers, and so in the preferences of event visitors. Some visitors are willing to pay for a small walking distance. On the other hand some people are willing to walk if this reduces their parking cost. To use these differences in the preferences of event visitors, the following strategy is designed. As an input for the route and parking advice, users are asked about their preferences.

There are three categories as shown in Figure 20. A high parking fee with a short walking time (category A), a low fee with a long walking time (category C) and an average option (category B).

Figure 20: Input for travel advice; the preferences of an event visitor with three possible options depending on walking time and parking cost.

The in-car device in Figure 20 is shown as a smartphone but it could be a built-in navigation device as well. As long it is in-car it satisfies the strategy.

In summary, parking cost and walking time are on the one hand types of information which gives the traveller certainty about – until now - rather unknown factors. Since the parking and route advice will be based on people's own preferences the compliance to the given advice will be high. If we can steer many visitors to a route and parking place we can reach the system optimum.

5.2.3 Classification of parking facilities

The three options that the strategy offers to event visitors regarding parking cost and walking time are connected to the parking facilities. Figure 21 shows this classification.

The colours are similar as the colours used on the smartphone screen on the previous page. The green parking facilities (P1, P6 and P-dome) are the closest to the ArenA and have a walking time of maximum 5 minutes. The blue facilities have a walking time with a maximum of 10 minutes and the red facilities (P10, P12, P22, P24 and P-Amstelborgh) are 15 minutes away from the ArenA. The coverage of the classes regarding number of parking facilities is as follows: green 28%, blue 51% and red 21%. These numbers are based on the total of 12.000 parking places within the scope of this research.

Figure 21: Classification of the parking facilities in the ArenA area regarding the designed strategy (Green (A)= high parking fee, max 5 min. walking time. Blue (B) = average parking fee, max 10 min. walking time. Red (C) = low parking fee, max 15 min. walking time)

5.2.4 Generation of parking and route advice

This part describes how the parking a route advice is generated. Figure 22 gives the overview in a flow-diagram. When an event visitor departs to the ArenA area by car and uses the in-car system he is asked to his preferences as shown in Figure 20. The system knows all characteristics of the network and the parking facilities. In the first part of the trip the user gets a basic route advice towards the ArenA area. Current in-car technology satisfies. Users will not get a parking advice yet since this is based on real-time information.

Part II of the trip starts when the vehicle enters the ArenA area. The current technology of GPS is able to detect the location of the vehicle. The ArenA area starts before the junctions on the primary road network. Therefore it is still possible to direct vehicles over multiple routes.

When the vehicle enters the ArenA area, the real-time situation is identified. Based on the preferences of the user, the real-time situation and the given advice to other users at the same time, the traveler gets a parking advice and a corresponding route advice.

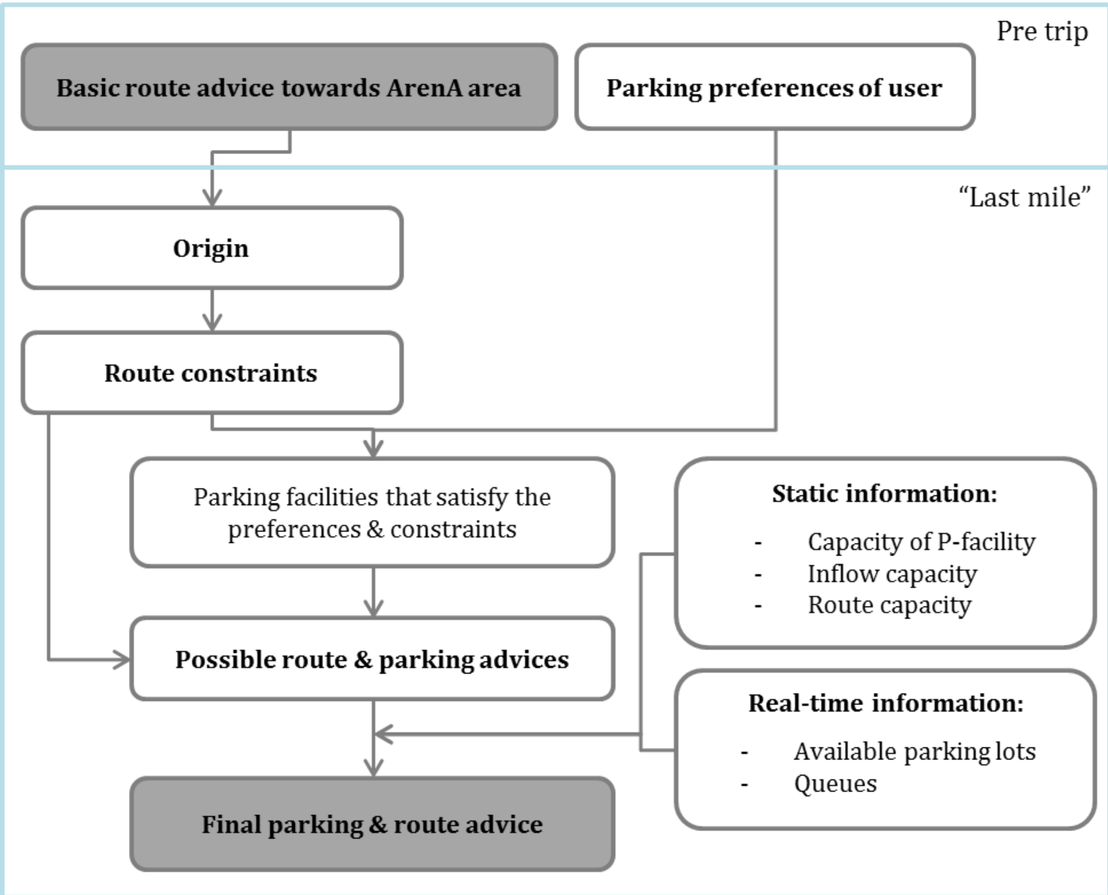


Figure 22: Flow-diagram of the generated route and parking advice following the designed strategy

The parking facilities which are not available are excluded from the advice. If a parking facility of the preferences of the road user is not available anymore or it will lead to a big detour for the traveler, the user will get a new pop-up in his screen with the two remaining categories.

There are route constraints as well to prevent that users receive a route advice with a large detour. A detour leads to more vehicles-kilometres and can be contradicting to the perception of the users of 'the right route'. Vehicles coming from A10-west and A10-east do not receive a route advice via highway A9. It is also the other way around; people coming from A2-south and A9-east will not receive a route advice via highway A10. The generated advice for a user has a sequence based on the shortest paths, parking capacity and possible effects of the given advice for traffic throughput. Table 14 shows the sequence of generated advice for vehicles coming from A10-west. If real-time information about number 1 shows that parking capacity is not sufficient anymore or there is a waiting queue on the route towards that parking facility, the advice of number 2 will be assigned. If number 2 is also not applicable, advice number 3 will be given. And so on. The sequences of the three categories are given in Table 14. The colours in the table are corresponding with the colours of the three categories again.

The sequences of parking and route advice are determined for every origin. They can be found in appendix D.

Table 14: Generation of parking and route advice coming from A10-west

A10-west	Destination:	Off-ramp:	Sequence:
Category A	P1-west	A2	1
€20,-	P-dome	A10-S111	2
< 5 minute walk	P6	A2	3
	P1-east	A10-S112	4
	Destination:	**Off-ramp:**	**Sequence:**
Category B	P2	A10-S111	1
€12,-	P-Endemol	A10-S111	2
< 10 minute walk	P3-P5	A2	3
	P18	A2	4
	P18	A10-S112	5
	P21	A10-S112	6
	Destination:	**Off-ramp:**	**Sequence:**
Category C	P10	A2	1
€5,-	P12	A2	2
< 15 minute walk	P-Amstelborgh	A10-S111	3
	P22	A10-S112	4
	P24	A10-S112	5

The possible parking facilities per origin are based on the same reasoning the basic routes are created in chapter 4. Prevent unnecessary detours and crossing traffic for event traffic to maximize traffic throughput. An example are parking facilities P3, P4 and P5. The bottleneck is the capacity of the roads that lead traffic to these parking facilities. Therefore it is important to use the existing infrastructure as efficient as possible. This can be reached by making certain routes.

The strategy is mainly designed for unfamiliar users since they are the biggest cause of inefficient distribution over the network. Familiar visitors (e.g. parking license holder) already know how to find their parking facility. The designed in-car system could give a route advice to parking license holder or other people that reserved a parking place in advance to their parking facility. However this would not be different than the current dynamic route navigation.

5.2.5 Expanding the function of the in-car device

The in-car device that includes the event strategy can be expanded to make it even more interesting for private parties and consumers. Nowadays a lot of different tools and apps exists for different functions. To combine these different functions into one tool or app it can be designed much more efficiently and attractive for consumers. Examples are given below.

First of all visitors traveling by car need to buy a parking ticket. They have to wait in a row and this takes time. The payment for the parking lot can be made digital using the in-car device. This saves time. Secondly the GPS function is able to save the location of the vehicle. This way the car can be found very easily when the user returns home. When the in-car strategy is incorporated in an smartphone application it can be combined with the application of the event as well. For example the Ajax app. Besides match results, characteristics of players and competition ranking, the supporters can be provided with travel advice as well.

6 Model based effectiveness assessment of the strategy

The previous chapters of this research show the current situation during the inflow of an event in the ArenA area, a state of the art of in-car systems is described and criteria are designed to improve traffic throughput during the inflow of an event. The conclusions led to a design of an in-car parking and route strategy for event traffic towards the Amsterdam ArenA. Before bringing this strategy into practice, an ex-ante evaluation is needed to show if the desired results can be achieved and which penetration level is needed to have a substantial effect on traffic throughput. The ex-ante evaluation is performed by using a model. This chapter describes this model, applies the designed in-car strategy and gives the results.

6.1 Model description

This section develops the content of the model. First of all the model criteria are explained. Secondly the indicators are described that indicate the network performances. Thirdly the structure of the model is described with the use of a flow-diagram. After that the model parts are discussed into detail.

6.1.1 Model criteria

A model is designed to cover the goal of the model. The goal of this research is to design a solution to improve traffic throughput in the ArenA area and to prevent congestion from happening on the primary road network. Therefore the output of the model should show these measures of performance as well.

The flow-diagram at the end of chapter 4 shows the causes and effects of congestion in the ArenA area. Congestion appears when flow (demand) is higher than capacity (supply). Both components are incorporated in the model to determine the effects on traffic throughput. The empirical data analysis in chapter 4 shows that only the off-ramp choice of event visitors is known for the three scenarios. The parking choice of event visitors must be estimated to determine every flow in the network and the inflow per parking facility. This parking choice is based on the characteristics of the network and parking facilities including the familiarity or unfamiliarity of the visitors. Secondly the capacity of the ArenA area must be determined. Chapter 4 showed that the intersections and the inflow capacity of parking facilities are the bottlenecks in the area. Therefore the focus of the model should be on those parts. Thirdly, one of the criteria is that the model must show if congestion appears on the primary road network or not. With this output the model can be calibrated and validated since this congestion on highway A2 is the only information we have about traffic throughput during the inflow of an event. After that the in-car strategy can be applied to the model to show its effectiveness with different penetration levels. The effect of the in-car strategy is only focussed on traffic throughput. It does not take the distribution of choice into account when we look at the three categories of the strategy (walking time versus parking cost). For now it is only designed to increase the compliance rate. Further research should show the ideal parking cost combined with the parking facilities.

The model is a macroscopic model. Macroscopic models describe the most important properties of traffic flows such as queues and shock waves based on speeds, volumes and densities (Traffic Flow Theory and Simulation, reader CIE4821). They are generally deterministic and less sensitive to small disturbances in the input. Macroscopic models are applicable in the development of dynamic traffic management and control systems and can be used to estimate average traffic flow operations. The characteristics of a macroscopic model suit the purpose of the model in this graduation research.

The model is designed with homogeneous flows over time during one single peak hour. First of all this makes the calculations in the model less complicated and more organized. Secondly the total traffic entering the ArenA area stays the same – if the flows are homogeneous or inhomogeneous – in time since it is determined from empirical data. In practice, the demand per [O,P] varies over time. A waiting queue may exist but can also resolve within a short time step. This would mean that after an hour there won't be a waiting queue. So the final results on traffic throughput after one hour however is the same. This statement creates the criteria to look at the result on traffic throughput after that one single hour (t=60).

6.1.2 Network description

The roads and parking facilities within the scope of this research are input for the model. Figure 23 shows a schematisation of the secondary road network of the ArenA area. The conclusion of the capacity and bottleneck analysis in chapter 4 is that several intersection and parking facilities are the main bottlenecks in the area. The most important intersections – intersections which are sensitive to high demand – are taken into account separately. Detailed information about the network characteristics (number of lanes, distances, number of turning movements, green times, saturation flows and parking characteristics) can be found in appendix A.

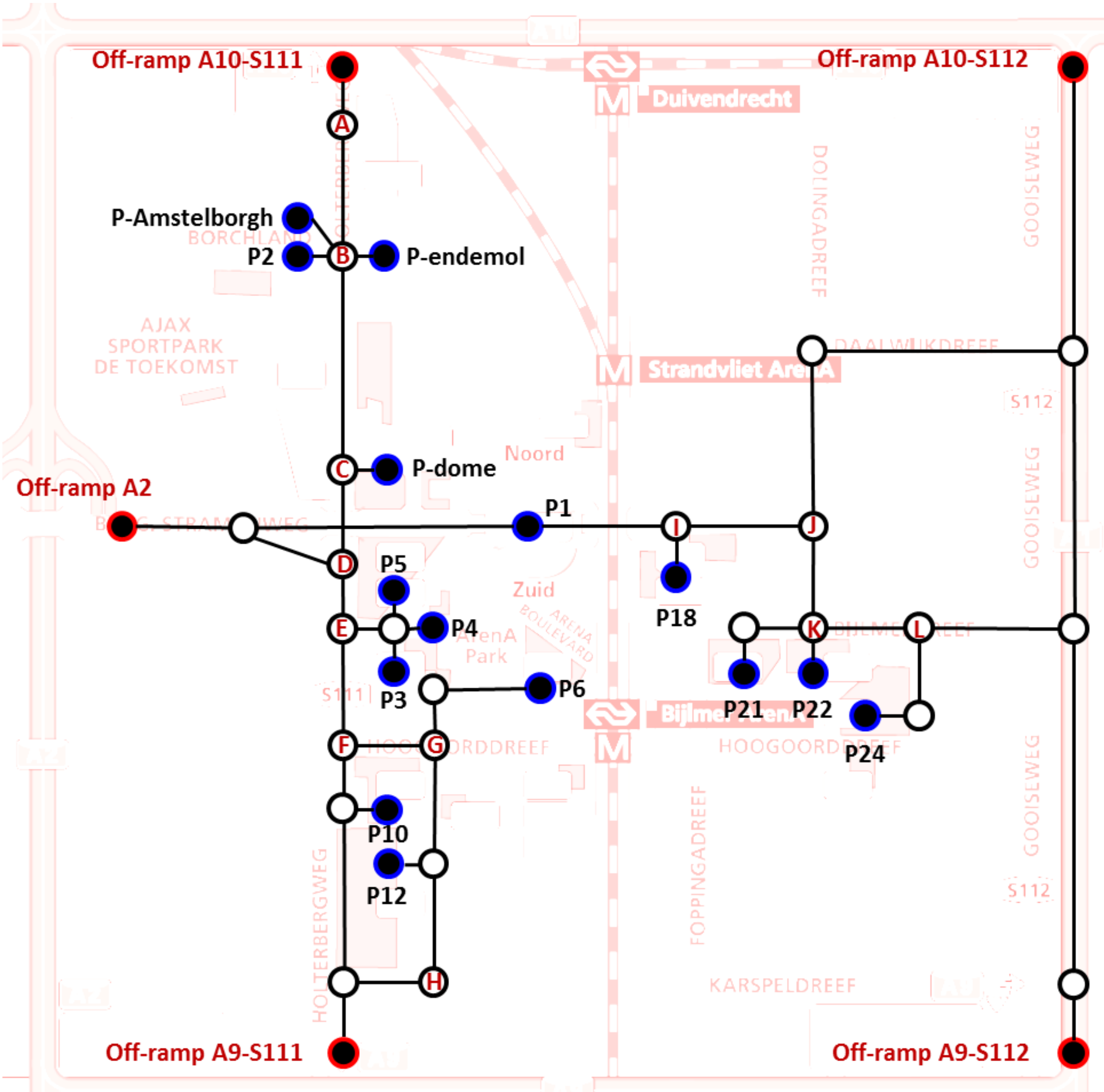


Figure 23: Schematization of the secondary road network

Figure 24 shows the selected routes from off-ramps to parking facilities within the scope of this research. It is stated unrealistic that every parking facility is reached from every off-ramp. This is due to the information on the road side information (for unfamiliar visitors) and the knowledge of the fastest route of familiar visitors. For example, people coming from off-ramp A9-S111 can park there car in P2-P12, P-dome, P-Endemol and P-Amstelborgh. The change that they park their car at the east of the ArenA is estimated as unlikely.

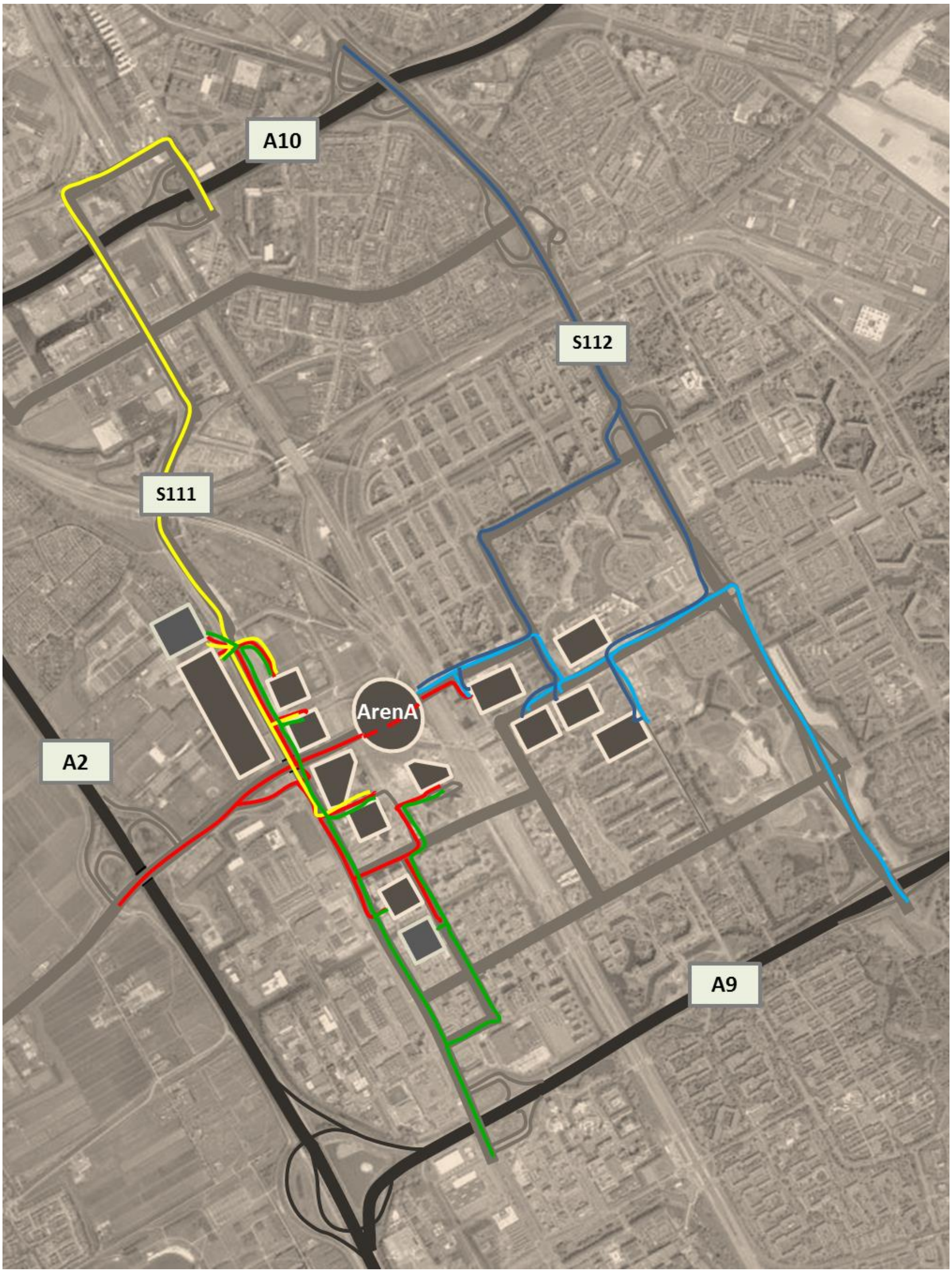


Figure 24: Selected routes from off-ramp to parking facilities for event traffic which do not use the in-car strategy - Parking choice model -

6.1.3 Indicators

Based on the model criteria and the available input for the model, three indicators are designed. In the end the indicators have to show the performance of the current network and the performance of the designed strategy.

6.1.3.1 *Indicator 1: total travel distance of event traffic*

The first indicator is the "total travel distance of event traffic". The strategy is designed to prevent congestion from happening. Therefore the users of the strategy will get an in-car advice that leads them to a route and parking facility with spare capacity. This might cause a detour for the users of and this increases the total travel distance. Generally this increases the travel time as well. This indicator is designed to show the effect of the strategy on the total travel distance.

6.1.3.2 *Indicator 2: shortage of capacity*

The second indicator is the "shortage of capacity". A shortage in capacity shows that a waiting queue will appear but it does not have to lead to congestion on the primary road network. However, the vehicles will still experience delay. If the model shows an output of 150 vehicles/hour, this means that there is a queue on the secondary road network with a minimal length of 1.5 km (based on an assumed density of 100 vehicles/km/lane). In the end the most ideal inflow of event traffic is that the outcome of this indicator is equal to zero.

6.1.3.3 *Indicator 3: congestion on highway*

The third and last indicator is "congestion on highway". An important goal of the designed strategy is to prevent congestion on the highway from happening at all time. This indicator shows if the designed strategy fulfils this goal. Besides that this indicator is used to calibrate the model. The empirical data analysis showed if congestion appeared on highway A2 or not. The model should generate the same output as the empirical data analysis showed. This indicator shows the time that spillback reaches the highway and the length of the waiting queue after one hour (t=60).

Factor travel time is not an indicator in this research. Indirectly it is taken into account since a decrease in shortage of capacity and congestion on highway leads to a decrease in delay as well. This means that the effects of delay are covered by other indictors.

6.1.4 Structure of the model

Based on the model criteria and the indicators the model is designed. The flow-diagram on the next page, Figure 25, gives an overview of the design. The following text explains the diagram. Event traffic can be divided into three categories; familiar visitors, unfamiliar visitors and users of the strategy that comply to a generated in-car advice. Familiar and unfamiliar visitors are together 100% of the total event traffic before the strategy is implemented in the model.

Chapter 4 stated that there is a difference in the familiarity of visitors going to an event. This has a different effect on traffic throughput as well. Familiar visitors make a parking choice based on their experience in the ArenA area while unfamiliar visitors base their choice more on the information they receive. The hypothesis is made that familiar visitors are able to divide themselves more efficiently over the available network and parking facilities. They know the area and have an alternative when a parking facility is full or if there is a queue in front of the parking facility. Besides that, familiar visitors such as Ajax supporters can be seen as 'regular traffic'. They go to an Ajax match at the ArenA every two weeks and have reached an equilibrium all together. The statement that familiar visitors know how to distribute themselves better than unfamiliar

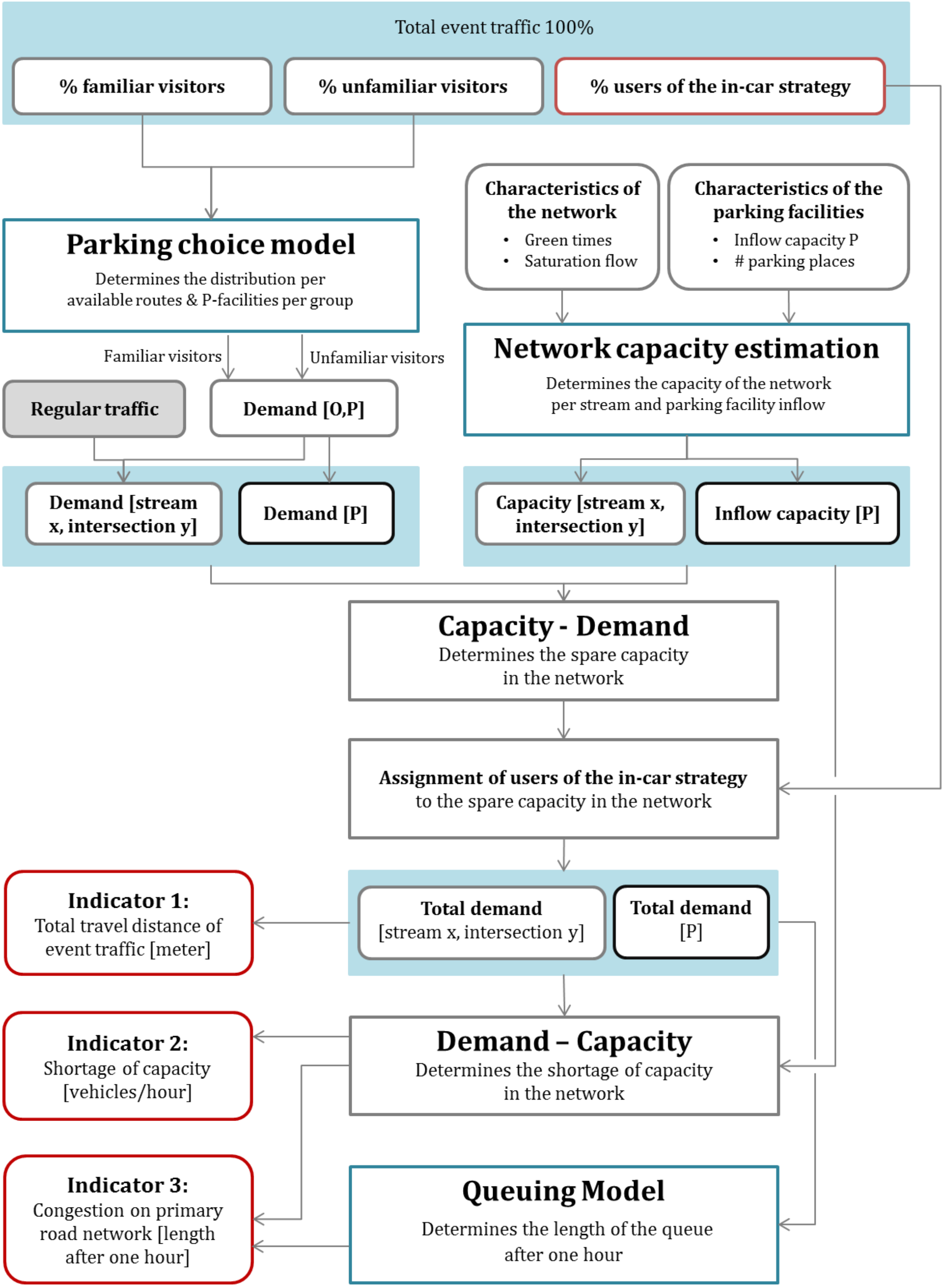


Figure 25: Flow-diagram of the complete model to test the effectiveness of the designed strategy

visitors means that the chance on spillback with more unfamiliar visitors will be higher. The absolute numbers, generated in chapter 4, of event traffic per off-ramp are input for the parking choice model. This input differs per scenario. The parking choice model is a gravity model that determines the distribution of event traffic per route and parking facilities. Input for this model are factors where visitors could base their parking facility and route on; distance from off-ramp to parking facility, number of turning movements, parking capacity and inflow capacity. The output is demand per off-ramp (origin) to a parking facility (destination) written as Demand [O,P]. The demand per P and the demand per stream on an intersection can be derived from this output. The bottleneck analysis in chapter 4 showed that the inflow capacity and the capacity of a few intersections are the bottlenecks of the ArenA area. That is the reason why flow per link does not have to be determined.

Regular traffic is added in the model as well. The assumption is made that regular traffic does not have a parking facility as final destination. That explains why regular traffic is only added to demand on an intersection. Regular traffic is based on the empirical data analysis as well and differs per scenario.

The output (demand) of the parking choice model will be compared with the output (capacity) of the network capacity estimation model. The capacity of the network is estimated based on green times, turning factors, number of lanes, inflow capacity of parking facilities and the number of parking places per facility. By subtracting the demand from capacity the spare capacity in the network is determined. When a part of event traffic uses the designed in-car strategy, this is the point in the model where the users are assigned to available routes and parking facilities. The output is the total demand in the network during the peak hour. When the number of users is equal to zero, the total demand is the same as the flow determined from the parking choice model including regular traffic.

Now it is time to generate final output. Indicator 1: total travel distance can be determined since every demand [O,P] is known. The total distance includes travel distance on the primary road network as well. Walking distance however is not included since extra walking distance will not lead to extra fuel consumption or less traffic throughput. Indicator 2: shortage of capacity can also directly be derived from the total demands. The shortage of capacity is the sum of all points in the network where demand is higher than capacity. So a negative value (too much capacity) is not taken into account. The last indicator 3: congestion on highway is determined by the use of a "queuing model". This queuing model incorporates the capacity of the network and the buffer distances to stall the vehicles standing in the queue. Based on densities and flows the speed of the queue downstream can be calculated for multiple parts of the network. In the end the speed of the queue on the highway can be estimated and so the length of the queue after one hour.

The different models (parking choice model, network capacity estimation model, queuing model) are explained into detail in the following sections.

6.1.5 Parking choice model

The first model is the parking choice model. It determines the distribution of event traffic over the parking facilities based on their origin (off-ramp), familiarity or unfamiliarity with the area and the characteristics of the network and parking facilities. Therefore an 'origin constrained trip distribution model' is used. The method is based on the gravity model and distributes the vehicles coming from off-ramp O over the available parking facilities.

6.1.5.1 *Input*

The input of the parking choice model exists of the following variables:

- Distribution familiar and unfamiliar visitors [%];
- Parking characteristics (parking capacity and inflow capacity);
- Number of event traffic entering the ArenA area during the peak hour per off-ramp;

The parking characteristics are similar for every event. The number of event traffic per off-ramp and the familiarity with the area however, are depending on the scenario and type of event. The number of event traffic per scenario is given in chapter 4. The distribution of familiarity is given in Table 13 in chapter 4.

6.1.5.2 *Origin constrained trip distribution model*

The origin constrained distribution model splits the given trip numbers over the available destinations to their relative accessibility and utility opportunity (Bovy, Bliemer, & Van Nes, 2006). In this research it means that the number of vehicles coming from an off-ramp are distributed over the available parking facilities based on the accessibility and attraction potential.

$$Demand\,[O,P] = a_O P_O X_P F_{OP}$$

Demand [O,P] = number of trips from off-ramp (O) to parking facility (P)
a_O = balancing factor
P_O = number of trip coming from off-ramp (O)
X_P = attraction potential of parking facility (P)
F_{OP} = accessibility of parking facility (P) from off-ramp (O)

The accessibility of parking facilities is based on in-car travel distances and number of turning movements from off-ramp to parking facility. The factor accessibility is more relevant for unfamiliar visitors since they will park in a parking facility close by.

Attraction potential [X_p] is based on the limitation of parking capacity or inflow capacity. The lowest value of both factors is leading. For example if a parking facility has two entrances (inflow capacity approximately 700 veh/hour) but has only 300 parking lots, then 300 is the value of the attraction potential.

Accessibility [F_{OP}] makes the difference between familiar and unfamiliar visitors. As stated before, unfamiliar visitors are less capable to distribute themselves over all available parking facilities compared to familiar visitors. The accessibility of a parking facility decreases when the distance and number of turning movement increases. The value of accessibility is determined by an exponential formula:

$$F_{OP} = \alpha_f * \exp(\beta_f * d_{OP} * tm_{OP})$$

α_f = parameter [-]
β_f = parameter [-]
d_{OP} = distance from off-ramp (O) to parking facility (P)
tm_{OP} = number of turning movements from off-ramp (O) to parking facility (P)

The graph on Figure 26 shows the output of the formula.

In the end, the balancing factor is used to equal the sum of Demand [O,P] to P_O. The distribution method is run through separately for familiar and unfamiliar part of the visitors.

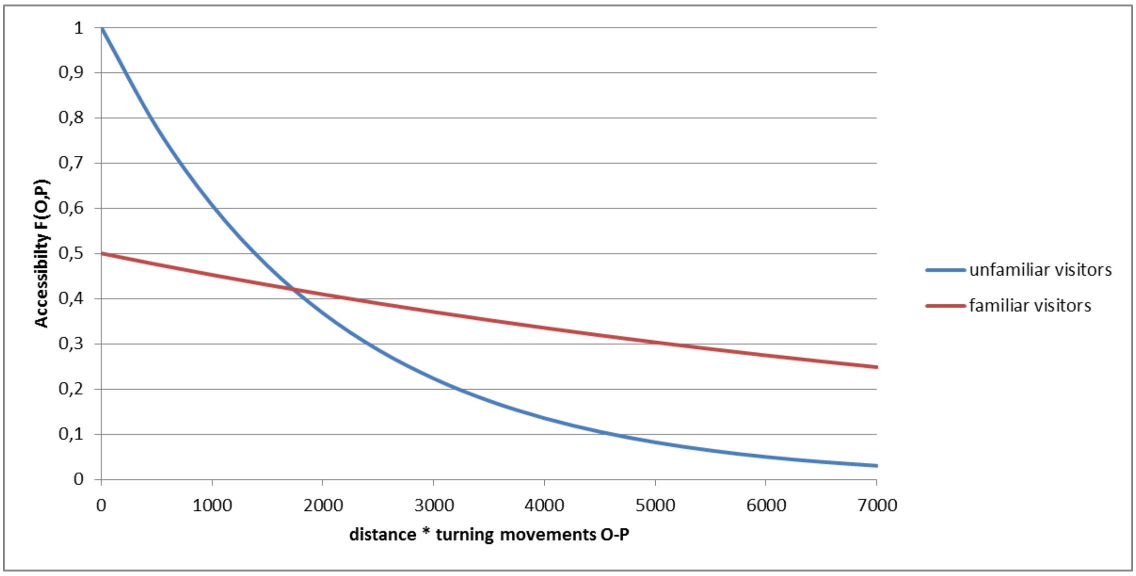


Figure 26: Exponential distribution function of accessibility [Fop].
Example α(familiar) = 0.5, α(unfamiliar) = 1.0 and β(familiar) = -0.0001, β(unfamiliar) = -0.0005

6.1.5.3 *Output*

The final output of the parking choice model is Demand [O,P]; the number of vehicles coming from off-ramp (O) going to parking facility (P). The bottlenecks in the ArenA area are the inflow capacity of parking facilities and the intersection on the secondary road network. Therefore these demands need to be derived from demand [O,P]. This is done with the following formulas.

Number of vehicles choosing parking facility (p_x) coming from every possible off-ramp (O):

$$Demand[p_x] = \sum Demand\ [O, p_x]$$

Number of vehicles using stream x on intersection y:

$$Demand\ [stream\ x, intersection\ y] = \sum Demand\ [o, r_{(stream\ x,\ intersection\ y)}, p]$$

6.1.6 Network capacity estimation

The 'network capacity estimation' part in the model estimates the capacity of the network per stream and parking facility inflow. It determines the maximum throughput in the total network.

Excel is used as software to carry out this model. The advantage of Excel is the numerical optimization add-in Solver. Based on the several constraints the Solver can optimize – maximize or minimize – the output of a certain target formula. The output is optimized by finding the optimal combination of the variables in the formula. For this capacity estimation model the optimizing value is the summation of the total throughput. With other words; to maximize the capacity per hour. The constraints in this model are based on the capacity per route (lanes per link, turning factor, assumed green times), inflow capacity of parking facilities and the number of parking lots. This is the same approach as the capacity and bottleneck analysis in chapter 4. The advantage of this model is that routes can easily overlap by adding an extra constraint to the model.

In summary, Excel contains a matrix with all possible routes from the off-ramps to the parking facilities. There are many constraints to the capacity per flow. The objective function is the maximization of the traffic flow entering the ArenA area within an hour (vehicles/hour). The decision variables are the characteristics of the network as described above. Based on the constraints and decision variables the maximum traffic throughput (objective function) is determined.

6.1.6.1 *Output network capacity estimation*

The output of the capacity estimation model is shown in the next three tables. Table 15 shows the output of the capacity of the ArenA area without the in-car strategy. The optimum distribution of vehicles leads to an inflow capacity of 7.612 vehicles/hour. This is only valid for the first hour when no parking places are occupied.

Table 15: Capacity of the ArenA area [veh/h]

Off-ramp:	[veh/h]
A2	2980
A10-S111	1208
A9-S111	1268
A10-S112	2156
A9-S112	
Total	**7612**

Table 16 shows the capacity of the network if the in-car strategy is applied to 100% of the visitors. The most optimum distribution is found taken categories A – C into account. Category A contains parking facilities with a small walking distance and high parking cost. Category C contains parking facilities with a large walking distance and low parking cost. The capacity of the ArenA area is 6.577 vehicles/hour at the first hour. This is lower than the maximum capacity without the strategy. The in-car strategy is designed to prevent crossing traffic. Therefore less routes are available compared to the network without the strategy and this causes the decrease in capacity.

Table 16: Capacity of the ArenA area with 100% penetration and compliance of the in-car strategy [veh/h]

Off-ramp:	Total [veh/h]	category A	category B	category C
A2	2649	1050	603	996
A10-S111	1325	350	625	350
A9-S111	738	0	738	0
A10-S112	1865	700	450	715
A9-S112				
Total	**6577**	**2100**	**2416**	**2061**

The output shows the possible distribution over the three categories as well. 32% of the routes and parking facilities is available for category A, 37% for category B and 31% for category C.

The empirical data analysis showed that congestion of highway A2 occasionally occurs during the inflow of an event. If this happens, the strategy provides an advice that will lead the user to a different off-ramp (as long as there is no congestion at that other off-ramp). Table 17 shows the capacity of the first hour when highway A2 is not generated in the given advice. It shows an inflow capacity of 5745 vehicles/hour. This number is still based on not-occupied parking facilities. This is not realistic but it shows the decrease of capacity if one highway could not be used.

Table 17: Capacity of ArenA area when A2 not taken into the generated advice - with 100% penetration rate of in-car strategy [veh/h]

Off-ramp:	Total [veh/h]	category A	category B	category C
A2	0	0	0	0
A10-S111	1325	350	625	350
A9-S111	2264	350	918	996
A10-S112	2156	700	741	715
A9-S112				
Total	**5745**	**1400**	**2284**	**2061**

6.1.7 Queuing model

The 'queuing model' is used to generate indicator 3: congestion on the primary road network. The output is given in the length of a waiting queue after the peak hour (t=60). Important input for this section is the flow-diagram given in chapter 4. This flow-diagram shows the cause of delay in the ArenA area and the multiple reasons for congestion on the primary road network. This diagram compares the flow (demand) with capacity (supply) combined with the length of the queue and the available storage capacity. The next section will explain the queuing model more into detail. In the end we aim to determine:

1. time t_1 at which the waiting queue in front of the bottleneck has exceeded the buffer capacity;
2. time t_2 when spillback exceeds the storage capacity on the secondary road network;
3. time t_3 when the queue exceeds the storage capacity on the off-ramp;
4. and at last: the length of the queue on the primary road network at t_4=60

Since we assume continue flows and look at one hour, the waiting queue starts immediately at t_0=0.

This queuing model is based on the macroscopic traffic flow characteristics (Traffic Flow Theory and Simulation, reader CIE4821). The kinematic wave model (or first-order model) assumes that the traffic volume can be determined from the fundamental relation between density and speed (q=ku). Besides this model the shock wave theory is used to find analytical solutions to kinematic wave theory. The speed of the shock equals:

$$w = \frac{q_2 - q_1}{k_2 - k_1}$$

w = speed of wave [km/h]
q_1 = flow upstream [veh/h]
q_2 = flow downstream [veh/h]
k_1 = density upstream [veh/km]
k_2 = density downstream [veh/km]

This formula is applied in the model of this research to determine the speed of the queue downstream. Since the geometric characteristics of the network (e.g. distances, number of lanes) are known, the time can be calculated that a waiting queue exceeds the buffer capacity of the specific road when the speed of the wave is known.

However, this network consists of more than just one single road so it is more complicated to calculate all different flows, densities and speeds. The next explanation of the expansion of a waiting queue and the consequences to the rest of the network is based on Figure 19. When flow (demand) at a certain point in the network is higher than capacity (supply) a waiting queue occurs. The queue will expand downstream when demand stays higher than capacity. If the waiting queue exceeds the storage capacity in front of the bottleneck, the spillback will affect other streams (or flows) as well. Other parts of the network will be less accessible and this means that more vehicles will be affected by delay. The queue will still be moving downstream when demand stays higher than capacity. In the end it leads to spillback on an off-ramp and finally to congestion on the primary road network.

To make the determination of congestion on the primary road network possible, the network is divided into several blocks. The next blocks are distinguished:

1. Block 1: waiting queue in front of the bottleneck
2. Block 2: spillback on secondary road network
3. Block 3: spillback on off-ramp
4. Remaining: congestion on the primary road network

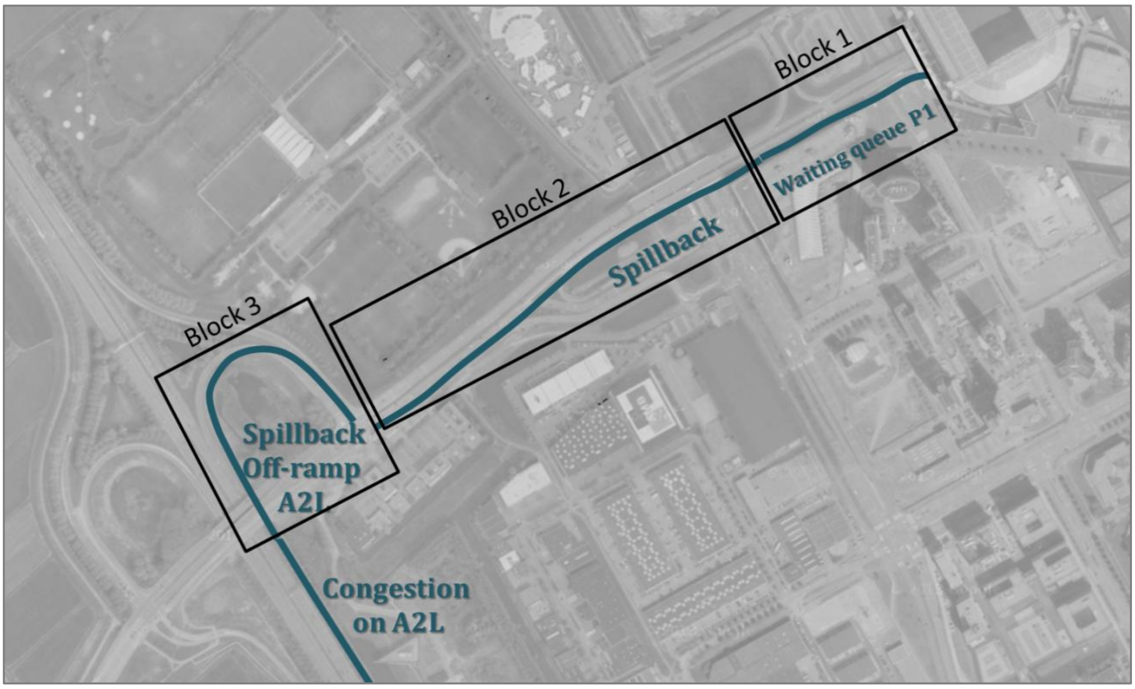


Figure 27: Schematic overview of blocks to calculate the congestion on the highway (example bottleneck P1)

Figure 27 shows the location of the blocks based on an example. The example is the situation when congestion on highway A2L appears, caused by a bottleneck at parking facility P1.The speed w of a subsequent block depends on the previous block. Every block has different distances (storage capacity of vehicles) and flows (q_{inflow}). The assumption is made that density in congestion k_c = 100 veh/km, free flow speed on secondary road network $v_{f,s}$ = 40 km/h and free flow speed on primary road network is 80 km/h. It is possible that in real-life the number of lanes in a block fluctuates over the length. For this model the blocks are simplified. Assumed is that every block has only one lane. This overrates the speed of the wave (w) because the calculated $k_{downstream}$ is higher compared with the real situation. However, the distance d is determined by length * number of lanes. So in the end the time that a block exceeds is comparable with the situation in practice, since the number of lanes and speed w are directly proportional to each other. The off-ramp A2R is the only off-ramp with two lanes. This is taken into account with the calculation of the speed w on the highway.

6.1.7.1 *General formulas*

The next formulas are used to determine the speed of the queue downstream and the time that the length of the queue exceeds a certain block. In the end the distance of congestion on the highway can be estimated.

Density downstream [veh/km]:

$$k_{downstream} = \frac{q_{downstream}}{v_{freeflow}}$$

Speed of queue [km/h]:

$$w = \frac{q_{downstream} - q_{upstream}}{k_{downstream} - k_{upstream}}$$

Time that the length of the queue exceeds a certain block [minutes]:

$$t_{block\ exceeds} = \frac{d}{w/60} + t_{previous\ block\ exceeds}$$

Distance of congestion on highway [km]:

$$d_{congstion\ highway} = \frac{w_{block\ 3}}{60} * (60 - t_{block\ 3})$$

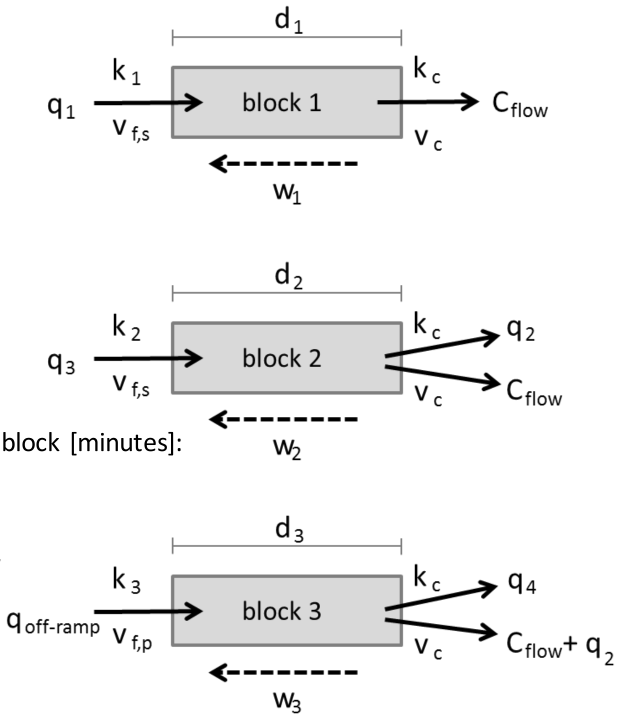


Figure 28: schematic overview of queuing model and its several blocks

The challenging part of the determination of w is that a part of the vehicles from block 2 and block 3 will not pursue their trip in block 1 and/or block 2. They will leave the queue since they have a different destination. The schematic overview of the blocks, Figure 28, shows this with q_2 and q_4. Because there are vehicles standing in congestion in a block, the fact is that q(inflow) ≠ q(outflow). If the inflow is equal to outflow, there would not be congestion. The flow leaving the queue is estimated as a proportion of vehicles of q(inflow) that do not have the next block as destination, multiplied by the flow leaving the next block. A schematic overview is given in Figure 29. The red vehicles drive towards the bottleneck while the green vehicles have a different destination.

To be more precise, the determination of q_2 [veh/h] leaving block 2:

$$q_2 = \frac{q_3 - q_1}{q_3} * C_{flow}$$

Formula to determine q_4 [veh/h] leaving block 3:

$$q_4 = \frac{q_{off-ramp} - q_{going\ to\ block\ 2}}{q_{off-ramp}} * (C_{flow} + q_2)$$

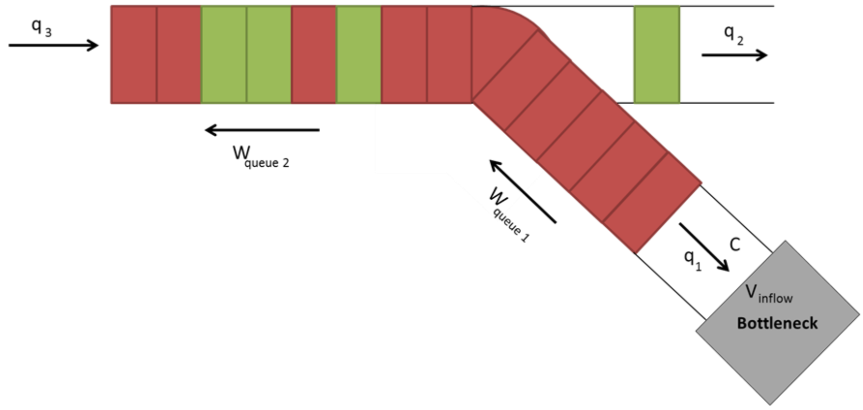


Figure 29: Schematic overview of vehicles (green) leaving the queue before the bottleneck. The red vehicles have a destination behind the bottleneck, the green vehicles do not.

The outflow from block 3 to block 2 is not similar to the total inflow in block 2. This is caused by the fact that a highway has two off-ramps. The inflow of block 2 is coming from both off-ramps. This also affects the speed of the wave on the off-ramp (block 3). The assumption is made that half of q_3 exists of vehicles coming from off-ramp L and the other half exists of vehicles coming from the other off-ramp. In the real situation this depending on the traffic light but since there is no information available, this assumption is made. This leads to the following formula of the speed of the wave w on an off-ramp:

$$w_3 = \frac{q_{off-ramp} - q_4 - \frac{1}{2}(C_{flow} + q_2)}{k_3 - k_c}$$

6.1.7.2 *Fundamental diagram*

Figure 30 shows the fundamental diagram which is used for the secondary road network of the ArenA area. The given $k_{downstream}$, $q_{downstream}$ and $q_{upstream}$ in the diagram are examples. It depends on the bottleneck and traffic demand which value they have. $K_{upstream}$ is fixed and stated at 100 veh/km/lane. The diagram shows the speed of the vehicles upstream, speed of the vehicles downstream and the speed of the wave downstream.

6.1.7.3 *Output of the queuing model*

The final output of the queuing model is if spillback reaches the primary road network. If it does, then the length of queue on the highway after one peak hour is estimated.

A disadvantage of the model is that the waiting queue determined on the highway by indicator 3 only exists of vehicles that want to use the off-ramp. However, such a waiting queue will affect regular traffic on the highway as well. The effect depends on the total intensity on the highway.

This research did not take regular traffic on the primary road network into account. This means that the effect on congestion is not determined as a realistic situation and so the output of indicator 3 cannot be compared with congestion from empirical data. Nevertheless, what we can say using indicator 3 is if spillback reaches the primary road network or not. Besides that we can also mention the possible severity of the congestion; the longer the queue, the higher the severity of congestion.

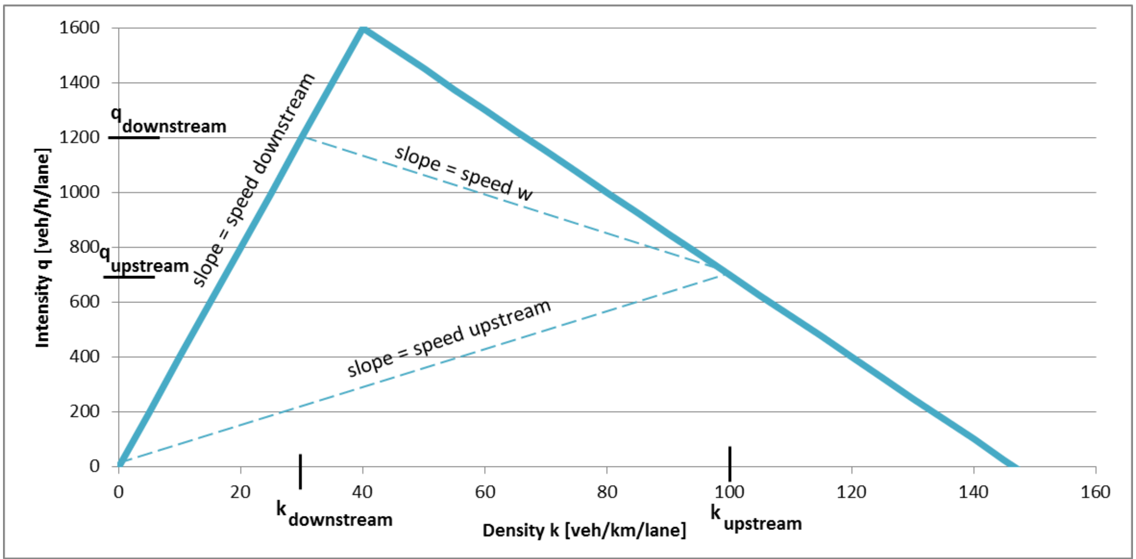


Figure 30: Fundamental diagram for the secondary road network of the ArenA area

6.2 Calibration, validation and sensitivity analysis

Now the model is designed, the model can be applied. First of all the model is calibrated. The empirical data analysis provided insight in the number of vehicles entering the ArenA area during the inflow (input) and showed if congestion appeared on the primary road network (output). The model should generate the same output as the empirical analysis in chapter 4 shows. After the model is calibrated, the model is validated. The determined parameters should be applicable for all three scenarios. In the end of this section a sensitivity analysis of the model is carried out to determine the sensitivity of the chosen parameters.

6.2.1 Calibration

Calibration maximizes the goodness of fit of the model. For this model the calibration is focussed on the parameter β in the parking choice model. The parameters of the model are estimated to generate an output that is comparable to the conclusions of the empirical data analysis.

The model is calibrated on scenario Ajax-NEC and Netherlands-Romania. Input for the model are the number of vehicles entering the ArenA area within the peak hour and the percentages familiar and unfamiliar visitors. The value β determines the accessibility of a parking facility coming from a certain off-ramp. The closer β is to zero the more all parking facilities have a comparable accessibility. This will lead to more distribution of vehicles over the available facilities. If β gets less close to zero, the difference in accessibility becomes larger and so the distribution decreases. A first value of β suits the hypothesis about familiar visitors and the second β suits the one for unfamiliar visitors. Table 18 shows the values of β's that are estimated by the calibration.

Table 18: The calibrated parameters β of the accessibility formula

β (familiar)	β (unfamiliar)
-0.0002	-0.001

The output of the model showed spillback on highway A2 during the inflow of scenario Netherlands – Romania, but did not show congestion during the inflow of Ajax-NEC. This is the same output as the empirical data showed.

Figure 31 shows the effect of parameter β on the shortage of capacity in the network. Remark: shortage of capacity indicates a waiting queue on the secondary road network but does not necessarily have to lead to congestion on the primary road network. Values of β smaller than -0.001 are not taken into account of the analysis since this would mean that visitors will only choose 2 or 3 parking facilities. This is stated as unrealistic.

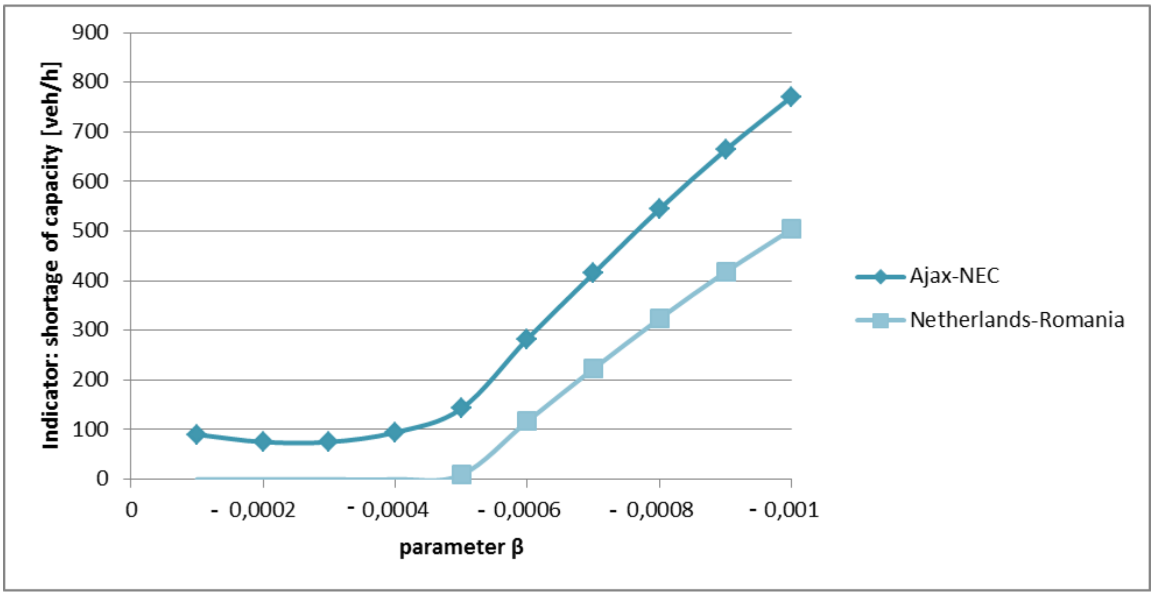


Figure 31: Effect of parameter beta on the shortage of capacity of two scenarios

6.2.1.1 *Parking facilities P3-P5*

During the calibration the output of the model showed that many visitors were distributed to parking facility P3-P5. This is due to the characteristics of the three parking facilities. The distance and number of turning movements are limited compared to the other parking facilities. Besides that, the parking facilities have a large capacity (± 2900 vehicle) and have five entrances in total. These factors together make the attraction and accessibility of these three parking facilities very high. However, the infrastructure around these parking facilities is not designed to handle large traffic flows. There is only one lane for vehicles coming from the northern part that wants to go to P3-P5. The capacity estimation model indicates the capacity of this stream on 662 vehicles/hour (1 lane * 0.92 turning factor *1800 sat. flow *0.4 green time). This is much less than the 2900 parking places and the inflow capacity of 1750 veh/hour (350*5 entrances).

To limit the number of vehicles going to P3-P5, the attraction potential of these parking facilities is decreased in the model. Instead of 1750 vehicles the attraction potential is decreased till 800 vehicles per hour. There are two arguments to do so. First of all, the queue will exists very fast. In practice the parking facilities will become less attractive since people will pass the queue and look for another parking spot. Secondly, observations in practice during the inflow of a concert in the ArenA area showed that P3-P5 was closed down during the peak hours. In all likelihood due to the same reason that the attraction potential in this model is decreased; the route to P3-P5 is sensitive to spillback. Since we do not have the information if certain parking facilities were closed down during the peak hours or not, this could not be taken into account in the model.

6.2.2 Validation

The model is validated on the hour before the main peak hour of scenario Triple. It could not be validated on the main peak hour since the model is only suitable when the begin situation has no congestion on the primary road network. The input of the model is empirical data from the off-ramps. When there is congestion on the primary road network, only the congested flow (vehicles/time) is counted (the location of the detection loops is at the beginning of the off-ramps). This means that demand is not measured and so it is unknown how many vehicles wanted to use the off-ramp of the A2 during the main peak hour, since there was congestion from t=0.

However, the main peak hour is still used as an input for the model to evaluate the strategy. This is because the other off-ramps are used intensively. The questions are: 1. Lead this high intensity on the off-ramps during the main peak hour to a shortage of capacity in the ArenA area? 2. Is this shortage of capacity preventable by a better distribution of vehicles? 3. What is the spare capacity on the routes from the other off-ramps to decrease demand on off-ramp A2?

Table 19 is the input for validation. The proportion of familiar/unfamiliar visitors is 25%/75%. This is different compared to the main peak hour. The conclusion of the empirical data analysis in chapter 4 is that the inflow of a concert starts earlier than a game of Ajax. The inflow of the triple consists of concert visitors of Pink and Eddy Izzard and supporters of Ajax. Assumed is that the inflow during 17.30 – 18.29 hour mainly consists of concert visitors and they are more unfamiliar than Ajax supporters.

Table 19: Empirical trip distribution of scenario Triple, time 17.30 - 18.29 hour. Input for validation.

	A2	A10-S111	A10-S112	A9-S111	A9-S112	Total per origin:
A10-west	600	200	100			900
A10-east		250	200			450
A2-south	800			350	100	1250
A9-east				100	50	150
total	1400	450	300	450	150	**2750**

The output of the model shows congestion (1.4 km) on highway A2L at 18:29 hour. Spillback did not reached highway A2R yet. This is equal to the output of the empirical data. Hereby there can be concluded that the model suits for its goal, namely to show if congestion occurs on the primary road network or not. Chapter 8: Discussion discusses the quality of the model. The main discussion is about the fact we do not know nothing about the real distribution and road side traffic information is not taken into account.

6.2.3 Sensitivity analysis

A sensitivity analysis is carried out for the different parts of the model. This analysis gives insight into the sensitivity of the output of the model parts based on a change in the input. The conclusions of a sensitivity analysis are needed to determine the consistency of the total model. The conclusions show us also the relation between input and output. This analysis should lead to uncertainty reduction; if the output is sensitive to a certain input variable, then the value of this variable should be argued very well. The different model parts are discussed separately.

6.2.3.1 *Parking choice model*

The sensitivity analysis of the parking choice model is based on the input; percentages familiar and unfamiliar visitors. This approach is chosen because the formula of the gravity model exists of fixed values for accessibility and attraction potential, except for β and the percentages familiar and unfamiliar visitors. The calibration of this model is based on β, so the last variables remain. The following figure shows how indicator 2 - shortage of capacity – changes when the proportion familiar and unfamiliar visitors changes. The characteristic of familiarity is that visitors are able to distribute themselves more equally over the available parking facility than unfamiliar visitors ($\beta_{familiar}$ = -0,0002 vs. $\beta_{unfamiliar}$ = -0,001). The less vehicles are distributed well, the bigger the chance on a shortage in capacity. This explains the gradient of the graph.

The sensitivity analysis is carried out for all three scenarios. Besides familiarity/unfamiliarity of visitors, the shortage of capacity also depends on the number of vehicles entering the area per off-ramp. If demand is higher than total capacity in the first place, there will be a shortage of capacity anyway. Figure 32 shows the output of the sensitivity analysis.

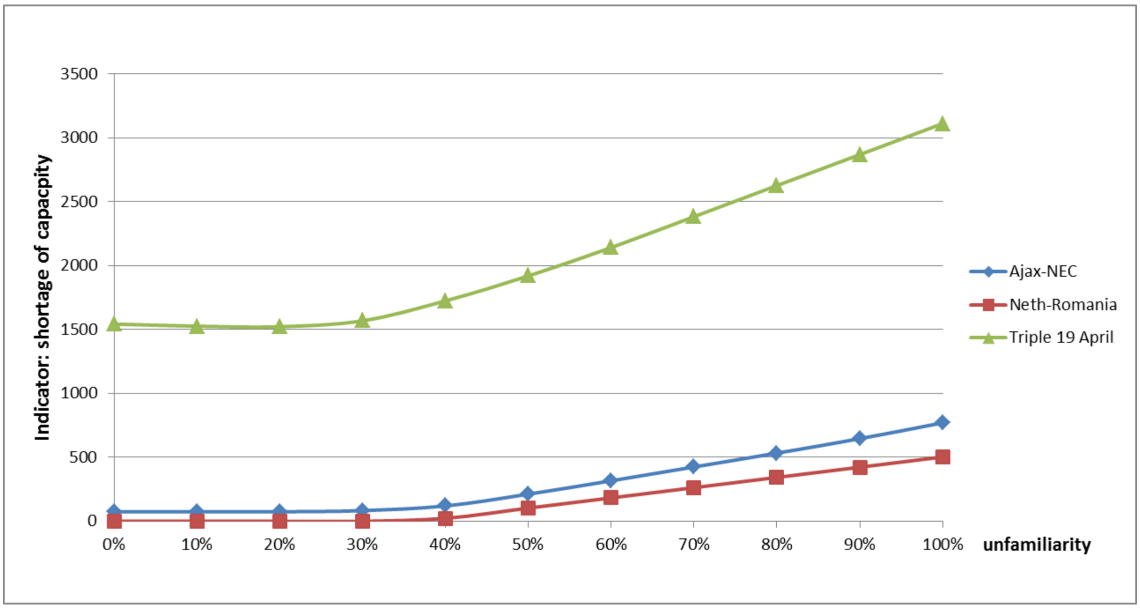


Figure 32: Sensitivity analysis of 'parking choice model': variable familiarity versus unfamiliarity

The figure shows that the shortage of capacity stays almost the same between 0% and 30% unfamiliarity of the visitors. From an unfamiliarity percentage of 40% of the visitors the shortage of capacity starts to increase. The slope of the graph of Triple 19 April is steeper than the graph of Netherlands-Romania. This is due to the total number of event traffic during the inflow.

The capacity of the ArenA area is approximately 7.600 vehicles per hour with a total parking capacity of 12.000 vehicles. The inflow of the Triple counts 6.700 vehicles in the peak hour. However, the graph shows a shortage of capacity of more than 1.500 vehicles/hour. This is due to the fact that vehicles enter the 'wrong' off-ramps. When the 6.700 vehicles would be distributed over the different off-ramps more efficiently the shortage of capacity could be minimized to zero. That is why the designed in-car strategy starts to distribute vehicles from their origin.

The output of the model turned out to be completely insensitive to α_f in the accessibility formula. This is caused by the balancing factor a(o).

6.2.3.2 *Network capacity estimation*

The variables of the network capacity estimation are the green times per direction, the saturation flow and the inflow capacity of parking facilities. The assumed values of the variables are argued in chapter 4. The green times are estimated on 0.6 * total time for straight going traffic and left turning traffic. The green times of right turning traffic is estimated on 0.4 * total time. The saturation flow is indicated on 1800 vehicles per hour. The inflow capacity of parking facilities differs per type of parking facility but is mainly stated on 350 vehicles/hour/entrance. The output of the network capacity estimation model is the maximum throughput in one hour.

The graph in Figure 33 shows the output of the sensitivity analysis. It shows the relative change in maximum throughput of the network when the variable is multiplied with a value between 0.5 and 1.2. Higher and smaller values are out of scope since it generates unrealistic low or high values for the input.

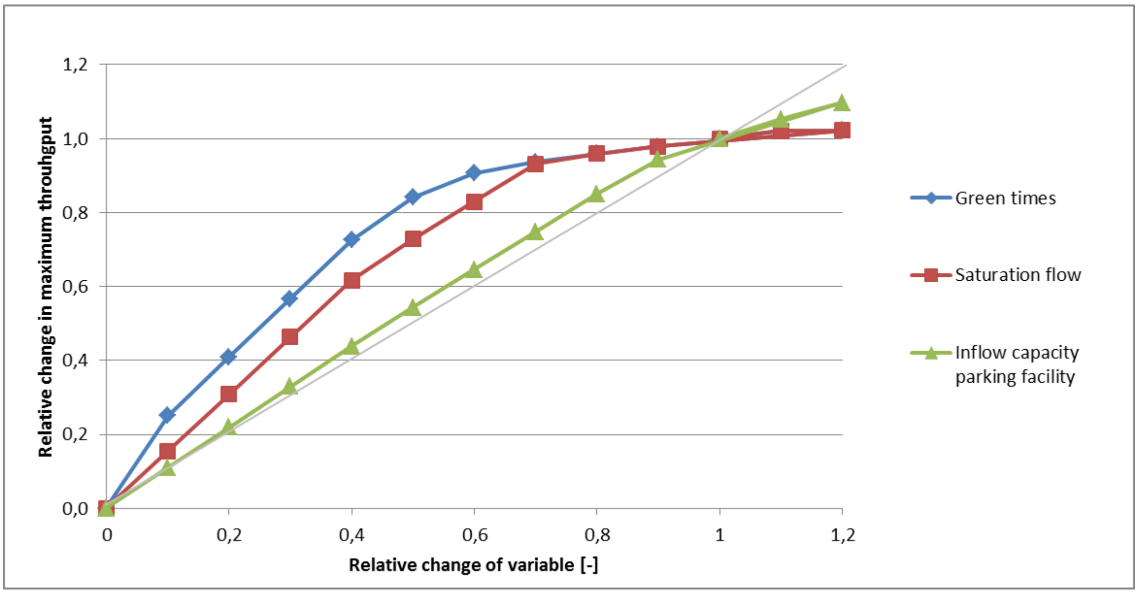


Figure 33: Sensitivity analysis of 'network capacity estimation model'

The result shows that green times and the saturation flow provide a limit sensitivity in the model. The assumed value for the inflow capacity of parking facilities is much more sensitive. This shows the correlation between the maximum throughput of the network and the limited inflow capacity of the parking facilities. When the inflow capacity decreases with 50% then the total throughput will drop with almost 50% as well. The argument to assume the inflow on 350 vehicles/hour/ entrance is based on observations in practice. The inflow however could be limited by a barrier or traffic guider. Since the model shows that the maximum throughput is sensitive to limitation of the inflow of parking facilities, it is a recommendation to restrict this limitation.

6.2.3.3 *Queuing model*

The output of the queuing model is the length of congestion on the highways. A few assumptions are made to determine the output, namely the free flow speed on secondary road network, free flow speed on primary road network and the density upstream. Free flow speed on the secondary road network is stated on 40 km/h, free flow speed on primary road network on 80 km/h and density upstream – so in congestion state – on 100 vehicles/km.

Figure 34 shows the output of the sensitivity analysis of the queuing model. It shows that an increase of the speeds has hardly any influence the output of the model. If the values for free flow speed are twice as low the congestion on the highway will be approximately 30% longer. Most sensitive variable in the queuing model is the density upstream. When the density upstream is 80 vehicles/km/lane the length of the traffic jam is almost twice as high.

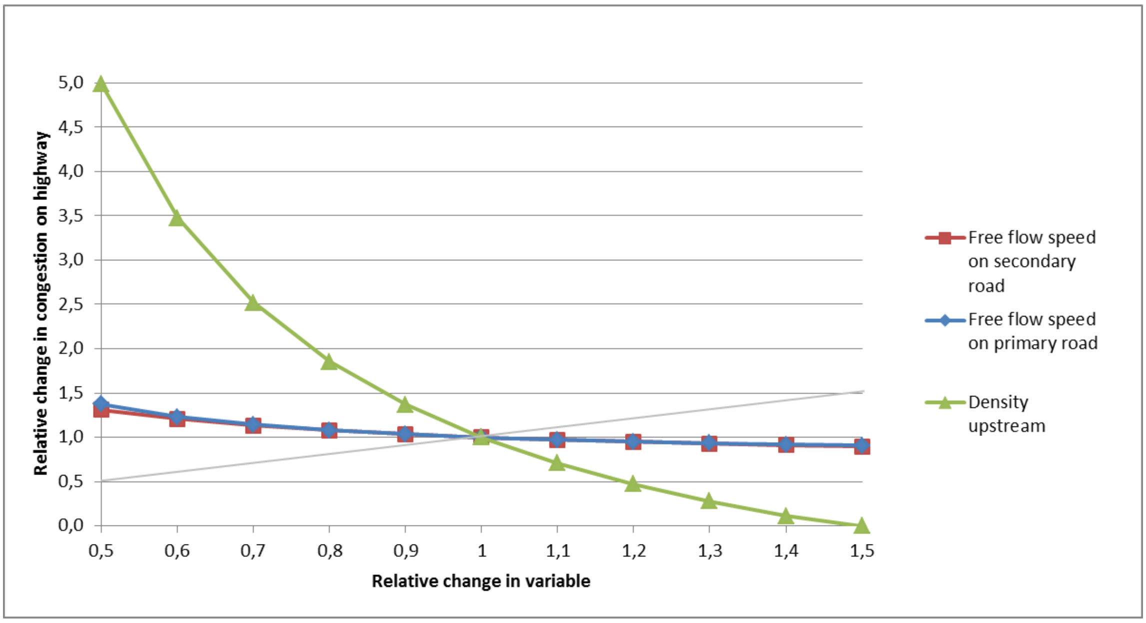


Figure 34: Sensitivity analysis of 'queuing model'

The argument to choose the value 100 vehicles/km is based on the fundamental diagram in this chapter; the speed upstream is assumed on 7 km/h.

6.3 Implementing the designed in-car strategy

Now the model is up and running the model will be used where it is designed for; to show the effectiveness of the designed in-car strategy. This sections describes the robustness analysis of the designed in-car strategy, the application to the event visitors and generated output. As mentioned before compliance is equal to the penetration level.

6.3.1 Robustness analysis

The in-car strategy is applied to the three scenarios to test its robustness. The three scenarios – Ajax-NEC, Netherlands-Romania and Triple 19 April – are three different type of events and led to varied traffic circumstances. The first scenario (Ajax-NEC) did not lead to congestion on highway A2. The second (Netherlands-Romania) had less number of vehicles entering the ArenA area during the peak hour but led to congestion in both directions on the highway. The third scenario (Triple 19 April) was rare and extraordinary. Three events started at exactly the same time. This led to a total inflow more than 10.000 vehicles of which 5.750 vehicles entered the ArenA area during the main peak hour. It led to a large traffic jam on highway A2L from southern direction. To test the strategy on three different type of events the robustness of the in-car strategy can be determined.

6.3.2 Penetration rate

The strategy is applied with various penetration levels. This indicates the effects of different penetration levels. Furthermore it indicates which penetration level is needed to prevent congestion on the primary road network from happening and to improve traffic throughput.

The penetration rate is assumed to be equal to the compliance rate. Practice shows that many road users do not comply to traffic advice, or at least not completely. However, the designed strategy has a main focus on compliance. It is designed to fit the preferences of the users. They give their own preferences regarding walking time and parking cost. Based on this a personal advice is generated for them. If someone uses the system is assumed that this person will comply to the given advice.

Furthermore the in-car strategy is designed to give the users information about parking cost and walking time; information that is unknown for mainly the unfamiliar visitors. Because of this the strategy is firstly applied to the unfamiliar visitors. The next tables show the proportions and absolute number of the three type of event traffic regarding different penetration levels. After all unfamiliar visitors use the in-car strategy, the strategy is also applied on familiar users.

Table 20: Percentages of type of event traffic. Scenario 1: Ajax-NEC (total 4800 vehicles)

% users of the strategy	% familiar visitors	% unfamiliar visitors
-	90% (4320)	10% (480)
10% (480)	90% (4320)	-
25% (1200)	75% (3600)	-
50% (2400)	50% (2400)	-
75% (3600)	25% (1200)	-
100%	-	-

Table 21: Percentages of type of event traffic. Scenario 2: Netherlands – Romania (total 3350 vehicles)

% users of the strategy	% familiar visitors	% unfamiliar visitors
-	25% (838)	75% (2513)
10% (335)	25% (838)	65% (2178)
25% (838)	25% (838)	50% (1675)
50% (1675)	25% (838)	25% (838)
75% (2513)	25% (838)	-
100%	-	-

Table 22: Percentages of type of event traffic. Scenario 3: Triple 19 April (total 5750 vehicles)

% users of the strategy	% familiar visitors	% unfamiliar visitors
-	50% (2875)	50% (2875)
10% (575)	50% (2875)	40% (2300)
25% (1438)	50% (2875)	25% (1438)
50% (2875)	50% (2875)	-
75% (4313)	25% (1438)	-
100%	-	-

6.3.3 Preferences of the users

This research does not include a research about the preferences of event visitors regarding parking costs and walking time. Therefore there is assumed that proportion of preferences is equally divided; every category is chosen by 33,3% of the users of the strategy. Further research should be carried out to know the real proportions and if it differs per event. Parking cost can be adapted to increase the chance on equal distribution over the different categories and so improve traffic throughput.

6.3.4 Output

The distribution of vehicles towards an event is assigned in the model after t=60. This is not according to reality, but since flows in the model are homogenous over time the 'real-time situation' - where the advice is based on – does not change. Because of homogeneous flows a queue exists at t=1. The assignment of the users of the strategy happens in the sequences described in chapter 5. It describes the sequences of different advices based on origin and preference of the user.

6.4 Results

This section describes the results of the model by applying the designed in-car strategy. The results are generated for the three selected scenarios. Different penetration levels of the in-car strategy are applied to show its effects.

6.4.1 Scenario 1: Ajax-NEC

The first table shows the results of scenario 1: Ajax-NEC of time frame 15.00 -15.59 hour and with 4800 vehicles.

Table 23: Model results of applying the strategy on scenario Ajax-NEC (4.800 vehicles)

	Indicator 1		Indicator 2	Indicator 3
Penetration level:	Total in-car distance [km]	Total walking distance[9] [km]	Shortage of capacity [veh/h]	Congestion on highway [m]
0%	20.060	2.772	75	0
10%	20.043	2.747	0	0
25%	19.907	2.705	0	0
50%	19.657	2.642	0	0
100%	19.555	2.557	0	0

During the inflow of this event (penetration level 0%) there was no congestion on the highways. However indicator 2 'shortage of capacity' shows 75 vehicles/hour. This is caused by intersection A on Figure 23; the first intersection after off-ramp A10-S11. The capacity for vehicles coming from highway A10 going to S111 is limited on 1325 vehicles/hour. This is due to green time for left turning traffic and the limited space where vehicles can wait in front of the traffic lights.

[9] Total walking distance is based on an occupancy of one person per vehicle. In practice this will be higher.

A penetration level of 10% during this peak hour can prevent the waiting queue at intersection A from occurring. People that wanted to use off-ramp A10-S111 are guided to off-ramp A2 or off-ramp A10-S112, depending on their origin and preferences. An higher penetration level of the in-car strategy does not lead to a shortage of capacity and therefore does not lead to congestion on the primary road network. The results show that when the penetration level of the strategy increases, the total in-car and walking distances decreases. This is due to the sequences of the given advice.

6.4.2 Scenario 2: Netherlands-Romania

Table 24 shows the results of scenario 2: Netherlands-Romania in time 18.30-19.29 hour with 3350 vehicles.

Table 24: Model results of applying the in-car strategy on scenario Netherlands-Romania (3.350 vehicles)

	Indicator 1		Indicator 2	Indicator 3			
Penetration level:	Total in-car distance [km]	Walking distance [km]	Shortage of capacity [veh/h]	Congestion A2L [km]	t	Congestion A2R [km]	t
0%	13.000	1.663	304	3.4	17	1.3	27
10%	13.012	1.709	183	1.9	25	0.6	39
25%	12.991	1.743	3	0	0	0	0
50%	12.756	1.767	0	0	0	0	0
75%	12.647	1.762	0	0	0	0	0
100%	12.698	1.659	0	0	0	0	0

The output of a penetration level of 0% shows that congestion on A2L started on t=17 and had a length of 3.4 kilometre at t=60. The congestion on A2R started 10 minutes later and reached a length of 1.3 kilometre after an hour. The shortage of capacity of 304 vehicles after one hour. This shortage is mainly caused by the inflow capacity of P1. Too many people coming from off-ramp A2 choose to park in P1. The table does not show congestion on highway A9 and A10 since there wasn't any.

A penetration of the in-car strategy for 10% of the visitors – all unfamiliar visitors – decreases the shortage of capacity and the length of congestion on highway A2. The users of the system got an advice that did not lead them to the west entrance of P1. The queue before P1 was also taken into account in the advice, so no advice towards off-ramp A2 was given since there was chance on spillback.

A penetration level of 25% provides a congestion free highway. After one hour only 3 vehicles are waiting in front of P1. This does not lead to spillback. Therefore an travel advice via off-ramp A2 was one of the possibilities. Since this is the shortest path from A10-west and A2-south the total in-car distance decreased. Penetration levels of 50%, 75% and 100% show no shortage of capacity and so no congestion on highways. The total walking distance decreases when penetration level increases. Total in-car distance decreases but a penetration level of 100% shows a small increase compared to a penetration level of 75%.

6.4.3 Scenario 3: Triple 19 April

As mentioned in section 6.2.2 Validation the evaluation of the strategy at the main peak hour of the Triple is carried out differently. The model is only suitable for situations when there is no queue at t=0. At the start of the main peak hour of the Triple (18.30 h) there is already congestion on highway A2L. The focus of the strategy is to show the possibilities of distributing vehicles over the other four off-ramps. The challenge is to make sure that the users of the strategy do not experience delay and that congestion on the highways does not increase during the main peak hour. The questions that need to be answered by applying the strategy to the main peak hour are:

1. Lead the high intensity on the off-ramps of the A9 and A10 during the main peak hour to a shortage of capacity in the ArenA area?
2. Is this shortage of capacity preventable by a better distribution of vehicles by the use of the in-car strategy?
3. What is the spare capacity on the routes from the other off-ramps to decrease demand on off-ramp A2?

The results are shown slightly different compared to previous scenarios. This due to the fact congestion can exist on highway A10 and A9 as well. The empirical data analysis showed that congestion on highway A2L still increased during 18.30 – 19.29 hour (the main peak hour). As explained before, the total demand could not be counted by the detector loops since there was congestion. This means that only the flow is detected. The increase of the traffic jam leads to the assumption that there is high demand during the main peak hour, so people with the in-car strategy will receive an advise that leads them to highway A9 or A10. Depending on their origin and preferences. This approach is applied till a penetration rate of 75%. It is assumed that the remaining 25% can use off-ramp A2 without increasing the traffic jam, since traffic in the jam still moves forward.

In summary, the starting point for the main peak hour of scenario Triple includes congestion on highway A2L, almost congestion on highway A2R and parking facilities that are partly occupied by event traffic that arrived before the main hour peak. Therefore highway A2 is not taken into account in the generated in-car advice.

The given advice by the in-car strategy prevents crossing traffic and is based on the origin of visitors and their preferences regarding parking cost and walking time. Since we do not know the preferences of the users we assumed an equal distribution of the three categories over the vehicles coming from the same origin. Table 25 shows the results of indicator 1 and indicator 2 of the main peak hour (18.30 -19.29 h) with 5.750 vehicles.

Table 25: Model results of applying the in-car strategy on scenario: Triple (5.750 vehicles) - indicator 1 and 2

	Indicator 1		Indicator 2 [veh/h]		
Penetration level:	Total in-car distance [km]	Total walking distance [km]	Shortage of capacity	shortage of infrastructure	shortage of parking capacity
0%	24.634.720	3.438.546	1282	360	922
10%	24.742.057	3.403.107	889	244	645
25%	24.807.140	3.420.973	925	584	341
50%	24.987.080	3.293.050	553	340	213
75%	25.423.190	3.282.175	1467	1175	292
100%	24.537.200	3.148.800	831	635	196

The results show that there always will be a shortage of capacity. The shortage of capacity is divided into 'shortage of infrastructure' and 'shortage of parking capacity'. The strategy is designed to give an advice to an available parking lot. However, this shifts the shortage of capacity from 'shortage of parking capacity' to 'shortage of infrastructure' when the penetration level increases. In practice this means long waiting queues in front of a parking facility. Remarkable is the increase of shortage at a penetration level of 75 percent (4.313 vehicles). This is due to that all users of the strategy are guided to an other off-ramp than off-ramp A2. The capacity of the network based on the in-car strategy (routes and preferences) is not sufficient to decrease the shortage of capacity.

Taking the pressure of highway A2 has consequences for the traffic situation on highway A9 and A10. Table 26 shows the results of indicator 3: the length of a queue on the primary road network.

Table 26: Model results of applying the in-car strategy on scenario: Triple (indicator 3)

Indicator 3: Length queue on highway on t=60 [km]						
Penetration level:	A2L	A2R	A10L-S111	A10R-S111	A9L-S111	A9R-S111
0%	x	x	0	0	0	0
10%	x	x	0	0	0	0
25%	x	x	1.4	0.2	0.9	0
50%	x	x	1.2	0	1.5	0
75%	x	x	2.6	0	1.7	0
100%	x	x	0	0	3.4	0

Since the model is not suited to calculate the increase of the traffic jam on highway A2 it is not taken into account in the results. The results show that the distribution of vehicles leads to congestion on highway A10 and A9. At a penetration level of 100% there is no congestion any more on highway A10. This is due to that the congestion at A2R was not severe at t=0. Therefore still 700 users of the system could be advised to travel via off-ramp A2R. Since congestion on A2L at t=0 was heavy the advice to take off-ramp A2L was still not taken into account. Therefore the congestion on A9L increased. In other words; taking the pressure of highway A2 leads in this case to congestion on the other highways.

These are the answers to the questions asked at the beginning of this paragraph. The high intensities on the off-ramps of highway A9 and A10 lead to a shortage of capacity in the main peak hour. The shortage of capacity cannot be prevented by a better distribution by the designed in-car strategy. The capacity of the network and parking facilities is not sufficient. This means that there is no spare capacity when we follow the in-car advice regarding preferences. The shortage of capacity can be reduced when preferences of the users are not taken into account anymore and if we only focus on spare route and parking capacity. However when people do not get the advice of their preferences, the compliance probably decreases. Modelling the in-car strategy of this scenario did not change the 33,3% distribution of the three categories. However this could be included in the design as well. Besides the changing preferences the in-car strategy could include more routes than it does now to increase the capacity.

The inflow during this main peak hour was extremely high. The network capacity estimation model showed that 5.745 vehicles can enter the ArenA area within an hour when off-ramp A2 is not taken into account in the advice. Unfortunately this number is based on free parking facilities. Before the main peak hour a lot of parking lots where occupied already so this number is not realistic. Moreover the inflow of the main peak hour asked for capacity of 5.750 vehicles. This is already more than the 5.745 vehicles/hour, so a shortage of capacity is inevitable.

6.5 Overall conclusions

The model described in this chapter is able to evaluate the effects of the designed in-car strategy. The conclusion of the results of the effectiveness of the in-car strategy is divided into three parts, namely advantage of the strategy, disadvantage of the strategy and the findings of the sensitivity of the network.

6.5.1 Advantage of the strategy

The results show that the strategy is able to distribute the users over available routes and parking facilities for most events. This distribution leads to a decrease in shortage of capacity and therefore can prevent congestion from occurring. The higher the penetration level of the strategy the higher traffic throughput. Additionally the results show that the in-car strategy does not lead to a detour for the users.

6.5.2 Disadvantage of the strategy

The strength but also the constraints of the in-car strategy are the preferences of the users and the limited number of routes to prevent crossing traffic. For an average event in the Amsterdam ArenA this would not lead to a problem. However, when total demand approaches capacity it is a disadvantage since these constraints limit the capacity. If demand exceeds capacity then the in-car strategy can only shift congestion or a waiting queue from one point to another. This happens when the strategy is applied to an event similar to scenario Triple.

6.5.3 Sensitivity of the network

The model shows the sensitivity of the infrastructural network as well. The maximum traffic throughput in the area is sensitive to the inflow capacity of the parking facilities. Besides that the first intersection after off-ramp A10-S111 has a limited capacity. Also the route on S111 from the north to parking facilities P3-P5 has a limited capacity and can easily create spillback.

There can be concluded that the designed in-car strategy is suitable for the ArenA area. It distributes vehicles in such a way that congestion and spillback can be prevented. However the strategy has also its limitations. These limitations are in particular important when total demand approaches capacity.

7 Discussion

This chapter discusses this research. It shows the strengths of the research but also the room for improvement. This is done to show the consequences of assumptions that are made during this research. Distinction is made between the sections in-car strategy, research & measurements and results.

7.1 Designed in-car strategy

7.1.1 Strategy towards a system optimum

In the introduction we stated that a system optimum reduces total travel time by 10-20% compared to a user equilibrium. The literature study shows that an in-car route advice has an higher compliance level than roadside information. Therefore an in-car travel advice conform system optimum leads presumably sooner to a system optimum than roadside information. Unfortunately system optimum means that some drivers have to make a detour. For this research area the detour is negligible, especially compared to the total trip, since the distances in the area are short. Nevertheless it is important that people do not all choose the shortest path, because this leads to a user equilibrium instead of the desired system optimum. The literature study describes another approach to reach the system optimum, namely 'social navigation'. Social navigation also likes to reach a system optimum by in-car travel advice. It only focuses on in-car travel time and therefore it makes people aware that they have to sacrifice their own travel time to decrease the travel time of others. The question here is if humans are really that social. Overall we are rather selfish. The strength of this designed strategy is that it puts the emphasis on the utility that a user can achieve by using the in-car system instead of the disutility. Moreover it takes the total trip into account instead of only the in-car trip.

7.1.2 Actors

Many actors profit from this designed in-car strategy. The authorities are helped by distributing the vehicles over the available network and prevent congestion from occurring. Their strategies can be incorporated in the in-car strategy as well. Event locations and organizations profit since the strategy is based on the preferences of the visitors; their goal is to assist their visitors to have a pleasant visit and encourage visitors to return in the future. Residents and companies located in the ArenA area profit because their homes and companies are more accessible when spillback is prevented. The owners of parking facilities are the only one that may not profit from this strategy. First of all since the faraway parking facilities are expected to decrease their parking fee to € 5,-. Secondly the goal of the strategy is to distribute vehicles to prevent waiting queues. To make profit, owners of parking facilities want as much customers as possible. Since the municipality of Amsterdam is owner of the majority of the parking facilities the disadvantage of losing profit may be limited. The municipality can carry out a social cost-benefit analysis to conclude if the reduced waiting queues compensates the lost in incomes. Another option is to increase all parking fees, but retain the differences in parking cost per category.

7.1.3 Parking cost

The preferences of the designed strategy regarding parking cost are distinguished into three categories, namely € 20, €10 and €5. These parking cost are fictive to create this distinction. This research did not include a study about the willingness to pay and walk of event visitors. Further research should demonstrate if the three categories are equally chosen by the users regarding the available capacity per category. The parking fees can be adapted to these conclusions.

Another option is to make parking fees demand-dependent. If a category reaches its capacity the parking fee can be increased to make the category less attractive.

7.1.4 Results

The model shows the effectiveness of the designed in-car strategy. The results are as expected. The strategy is able to distribute the vehicles over the available routes and parking facilities more efficiently than the current inflow. It can prevent congestion from happening. The model shows that the total in-car travel distance does not increase. This is against the expectations. The shortest path to the Amsterdam ArenA is a route via off-ramp A2. Drivers that use the in-car system are often guided to a different off-ramp. Therefore the expectation is that the in-car travel distance increases. The reason that this is not the case is that options of assigned parking facilities are limited after taking an off-ramp.

7.1.5 Applicability for other event areas

The in-car strategy is designed for the Amsterdam ArenA area, but the question is if the solution is applicable on other event areas as well. The strategy is designed to distribute vehicles over the available network and parking facilities. Therefore the new event area must satisfy the following conditions:

- there must be sufficient route alternatives;
- there must be enough parking options;
- demand must be lower than the maximum traffic throughput

If the area and number of vehicles does not satisfy the conditions, the vehicles cannot be distributed over the network and/or waiting queues are inevitable.

7.1.6 Possible effect of an improved traffic situation

An improved traffic situation has a downside as well. It attracts more vehicles. One effect can be that event visitors decide to shift mode from public transport to car. Another effect can be that the broad inflow peak becomes smaller. Both possibilities lead to more vehicles in a single time frame. An higher demand leads to a greater chance on waiting queues again. This will always stays the challenge of traffic.

7.2 Research and measurements

This second section describes the limitations and consequences of the assumption that are made.

7.2.1 Analysis of the current situation

7.2.1.1 *Available data*

There is limited data available about speeds and intensities in the ArenA area. Therefore it was a challenge to get insight in the current situation. Only data of the primary road network could be used. Unfortunately there was no data available of the off-ramp of highway A10R to the S112. The assumption is made that the intensities using that off-ramp are similar to the intensities at off-ramp A9R-S112 at that same time frame. It is likely that off-ramp A10R-S112 is not one of the most used off-ramp by event traffic during the inflow of an event. The DRIPS lead event traffic towards the S111 instead of S112. Furthermore interviews with the municipality does not provide a reason to think that this off-ramp leads to problems. The consequences to the final results of this research of using the traffic counts of A9R-S112 for A10R-S112 is therefore negligible.

The capacity and bottleneck analysis in this research shows that the bottlenecks of the ArenA area are located on the secondary road network rather than the primary road network. We do not have speed data and intensities of the secondary road network so a determination which exact bottleneck causes congestion during the inflow of an event cannot be easily answered. Furthermore busses, pedestrians and cyclists are not taken into account to determine the capacity of the network. If we would include these vehicles and travelers it would mean that the green times of traffic light in favor of event traffic decreases. The sensitivity analysis of the network capacity shows that 60% of the assumed green time leads to a decrease of 10% in the maximum throughput. This means that the overall throughput in the ArenA area mainly depends on the characteristics of parking facilities instead of the green time at intersections. The decrease in throughput is limited, so the effect of adding pedestrians, cyclist and busses is negligible and it has no serious consequences for traffic throughput.

7.2.1.2 *Congestion on primary road network caused by regular traffic*

This research does not take congestion on the highways A2, A9 and A10 that is caused by regular traffic into account. This congestion probably has consequences for the route choice of event traffic. Furthermore the text on the DRIPs (route information towards the ArenA) is unknown and there is not looked into the consequences for event traffic if they receive a route advice that lead them to a congested road.

Nevertheless it does not change the effectiveness of the strategy during the main peak hour. The speed-contour plots of highway A10 in the appendix show that congestion caused by regular traffic ended around the start of the main peak hour. This applies for events organized during the week. It means that the users of the system still receive a travel advice without leading them into congestion. Congestion of highway A2 started after congestion on highway A10 was resolved. Most events start around 20.00 hour. Earlier is not recommended because of the evening peak of commuters on the primary roads.

7.2.1.3 *Inflow capacity of parking facilities*

We assume an inflow capacity of parking facilities of 350 vehicles per entrance per hour. This assumption is motivated by different arguments. However the arguments are based on a rather smooth inflow and competent traffic guiders that improve the inflow capacity towards its maximum. The sensitivity analysis of the network capacity estimation model shows that the network is sensitive to the inflow of the parking facilities. The measurements in practice at P-dome shows a low inflow caused by ticket control at the entrances. On the other hand the inflow at P2 is organized very smoothly. The research did not look into detail how the inflow of parking facilities is organized. Since a decline of the inflow capacity is almost proportional to the total inflow capacity of a network, further research is recommended to optimize throughput at a parking facility. The expectation is that many parking facilities do not have their optimal inflow yet, so that this can be improved to optimize traffic throughput in the ArenA area.

The designed strategy focuses on distributing vehicles over spare parking and route capacity, therefore a lower inflow capacity would not change the strategy. However a lower inflow capacity means a lower network capacity and therefore high demand leads to inevitable waiting queues. A higher penetration rate of the strategy is be needed to lead vehicles to spare capacity and so decrease the waiting queues.

7.2.1.4 *Parking capacity*

Only parking facilities which are included on the parking map of the ArenA area are included in this research. However there are also less familiar parking places where event traffic is able to park during an event. For example on-street parking and the parking spots of a company nearby. This results in a total parking capacity higher than 12.000. The bottleneck and capacity analysis shows that the parking capacity limits the total inflow capacity during an event. More parking facilities means that the capacity of the network is higher as well.

7.2.2 Cause of congestion on highway A2

The research contains a comprehensive analysis to the cause of congestion on the primary road network during the inflow of an event. The analysis shows that the bottlenecks on the secondary road network are the cause for congestion and that this leads to spillback on the primary road network. The empirical data analysis of multiple events in 2013 shows that the main peak hour of scenario Ajax-NEC and scenario Netherlands-Romania are comparable. The second scenario leads to congestion on highway A2 and the first scenario does not. The hypothesis which is based on this analysis states that familiar visitors are able to distribute themselves more efficiently than unfamiliar visitors. The assumption is made that a match of Ajax attracts more familiar visitors than a match of the Dutch national team. This explains the occurrence of congestion during the inflow of the last match. The hypothesis about the familiarity of event visitors is not studied. This can be studied by gathering data about the familiarity of visitors, with the help of surveys, and their off-ramp and parking choice. In this way the relation between familiarity and route & parking choice can be shown.

In combination with the limited available data there can be other causes of spillback. These are given below.

7.2.2.1 *Parking facilities*

The research shows that the maximum throughput is sensitive to the (inflow) capacity of parking facilities. It can be that during the week there are less parking places and/or parking facilities available than during the weekend when Ajax plays its games. Less available parking places and facilities means a greater change on waiting queues and spillback. Another option is that during a match of the Dutch national team more people make use of reserved parking places. As shown in this research, checking the reservation of event visitors takes time and this leads to a decrease of the inflow capacity of parking facilities.

7.2.2.2 *Outflowing traffic*

The ArenA area houses many companies. Mainly during the week this leads to attraction and production of traffic. This research only takes traffic into account that make use of the off-ramp to the ArenA area during the peak hours. Outflowing traffic is not taken into account.

Firstly outflowing traffic means more traffic on the secondary traffic than assumed. When a waiting queue in front of a parking facility exists and this leads to spillback, the presence of outflowing traffic on that road increases congestion even more. Secondly outflowing traffic provides more pressure on intersections. Green times of traffic lights have to be divided over more streams compared with a situation where only event traffic uses the intersection. The sensitivity analysis shows that maximum throughput does not depend on green times that much. However, the intersections which are indicated as a bottleneck are sensitive to a decrease of green times.

If congestion is not caused by the proportion familiar and unfamiliar visitors, the current parking choice model is not suited to model the current situation. The following section describes the content of the model. In the end of this chapter there is a recommendation to improve the model to incorporate the other possible causes of congestion

7.2.3 Model

This section describes a discussion about the model choice and the suitability for this research.

7.2.3.1 *Parking choice model*

The parking choice model uses a gravity method to model the route and parking choice of the visitors. It distributes the total demand of vehicles over the parking facilities. To calculate the accessibility (F_{OP}) of a parking facility (P) coming from a certain off-ramp (O), the next formula is used:

$$F_{OP} = \alpha_f * \exp(\beta_f * d_{OP} * tm_{OP})$$

With α and β as parameters, d_{op} as distance from off-ramp to parking facility and tm_{OP} as number of turning movements. The idea is that accessibility decreases when distance and turning movements increase. This multiplication of distance and number of turning movements is not theoretically well founded. The general exponential formula used for accessibility is α * exp(β *cost) based on the Gravity law of Newton. However it is not theoretically well founded, it has no big influence on the final results. The reason for that is that the value of parameter β would have been different if the number of turning movements is not taken into account. The parameter β is calibrated on a distribution of visitors of two scenarios and the corresponding output of indicator 3 'congestion on highway'.

Furthermore the parking choice model is not dynamic. The model assumes that people only base their choice on the characteristics of the network and parking facilities instead of including the current traffic situation. In practice a route and parking choice is based on the real-time situation as well. If there is a huge waiting queue in front of a parking facility, people assumable choose a different parking spot. Another part that is not incorporated into the choice model is the route strategy of the road authorities. Chapter 4 describes the current route strategies of the authorities; these use DRIPs to show a route advice to the event visitors and occasionally use road blockades. Besides that there are also the normal fixed road signs with parking information. The parking choice model does not take this information into account.

The parking choice model is calibrated on the proportion of familiar and unfamiliar visitors. The proportion per scenario is an assumption. So this means that this assumption has major consequences of the output of the model. The output of the complete model shows an output that is comparable with the empirical data (congestion on highway A2), but the output of parking choice model can be much more improved. A research should be carried out on the real route and parking choice of event visitors.

Another room for improvement in the parking choice model is the incorporation of route strategies of the road authorities. The gravity model takes distance, number of turning movements and the characteristics of parking facilities into account. It does not take roadside information into account and the possible closedown of certain roads. The road authorities lead vehicles to parking facilities close by and all these route options are incorporated in the current choice model. The attraction of certain parking facility though, could be different than only gravity based. Besides this a closedown of a certain road changes the accessibility in the area and decreases (or increases) the chance on spillback. The closedown of the road towards parking facilities P3-P5 for example decreases the chance on spillback. The network capacity analysis shows that the road towards those parking facilities has a very low capacity and therefore spillback easily occurs.

The gravity model suits the model for its purpose. It shows that the current distribution of event vehicles over the network is not optimal. However, to improve the choice model the dynamic element should be taken into account and so the roadside route information as well.

7.2.3.2 *Network capacity estimation model*

The network estimation model is based on the information that is available of the network and a simplification of it. Although it does not incorporated all roads and intersection, the model is capable to show a plausible maximum throughput and plausible bottlenecks. The sensitivity of the input of this part of the model is discussed earlier in this chapter, namely the assumption about the inflow capacity of a parking facility. This model can easily generate a new overview of the bottlenecks and capacity if the input changes.

7.2.3.3 *Queuing model*

The queuing model is only applicable to calculate an increase of the queue. It is not able to calculate the speed of a queue that resolves. Therefore it is not suitable to model the main peak hour of scenario Triple since there was already congestion on highway A2. The effectiveness of the designed in-car strategy for scenario Triple is therefore evaluated by excluding highway A2 from the travel advice. Because this advice is excluded, vehicles receive an advice to other highways. High demand leads to congestion on highway A10 and A9. If the model is able to demonstrate the resolving of a queue, a travel advice towards the highway A2 might have been possible.

The sensitivity analysis shows that this part of the model is sensitive for the assumption about the density upstream. The density $k_{upstream}$ is assumed on 100 vehicles/km/lane. The higher this density the lower the chance on congestion. The assumption is based on the fundamental diagram. Since this part of the model is sensitive to this assumption the recommendation is to measure the density upstream in practice to validate the model.

The queuing model does not take the intensities of regular traffic on the highways into account. This has consequences on the increase of congestion on those highways. The more regular traffic on the highways the greater the impact on the length of the queue, vehicle delay, environmental damage and economic losses. To gain insight in the effect of spillback on the primary road network the intensities of regular traffic should be taken into account as well. The reason that it is not incorporated in this model is that the goal of this research is to prevent congestion from occurring, instead of showing all consequences of congestion.

7.2.3.4 *Application of the model for other areas*

The model can be applied on other areas. It gains insight in the maximum throughput of an area including the bottlenecks and is able to show the possible effectiveness of distributing vehicles.

7.2.3.5 *Possible improvements of the model*

The previous pages show an overview of the weakness of the model and the assumptions. Therefore a recommendation is given to improve the model. The hypothesis about the familiarity and unfamiliarity of visitors is not proven. There is a possibility that this is not the main cause of congestion. Therefore the model must be made less dependent on the percentage of familiarity. Outflowing traffic should be taken into account and there must be looked into the real inflow capacity of different parking facilities. In addition, the route strategies of the road authorities and the fixed road signs can be modeled as well. The gravity model seems realistic; the greater the distance the less attractive a parking facility becomes. However, the choice of a driver also depends on the roadside information he receives and the real-time traffic situation.

Not only the main peak hours must be modeled, but the total inflow of an event must be taken into account. This gains more insight in the consequences of the traffic situation which is created before the main peak hour and takes the occupied parking facilities into account as well. A traffic situation changes over time; queues increase but also resolve. Therefore the model should be able to take resolving waiting queues into account. This means that the model must be made dynamic. If insight in the effects of congestion on the primary road network is needed, this must developed as well.

The improvement of the complete model leads to a better founded cause of congestion on the primary road network. Taken the route information of roadside measures into account improves the choice model. Furthermore, the dynamic part of the model provides a dynamic route advice of the in-car system as well.

In the end the current model is able to demonstrate the current situation of the scenarios and the possible effectiveness of the strategy. However, an improved model gains more insight in the real cause of congestion and the dynamic possibilities and effectiveness of the strategy.

8 Conclusions and recommendations

This chapter describes the conclusions and recommendations. Firstly the conclusions are given by answering the research questions. The recommendations are divided in recommendations for practical application and recommendations for further research.

8.1 Conclusions

The conclusions are described by answering the research questions. Before answering the main research question, the sub questions are answered.

Infrastructure

What is the capacity [vehicles/hour] of the exits, secondary road network, and parking facilities near the ArenA?

The capacity of the total network is estimated on 7.612 vehicles per hour. This estimation is based on parking capacity [number of parking lots], geometric design of the ArenA area [distances, number of lanes] and assumptions about green times at intersections and inflow capacity of parking facilities. The capacity of the ten exits to the ArenA area varies from 662 vehicles/hour (off-ramp A9L-S112) till 1836 vehicles/hour (off-ramp A10L-S112). The most common used off-ramp at highway A2 has a capacity of 1325 vehicles/hour coming from the south (A2L) and 1656 vehicles/hour coming from the north (A2R). The capacity of the parking facilities varies from 228 parking lots (P22) till 2.400 parking lots (P1). The total parking capacity in the ArenA area is around 12.000. This number is without on-street parking places and the parking lots of companies.

Current situation

What are currently the frequent bottlenecks during the inflow of event traffic in the ArenA area?

The bottlenecks in the ArenA area are several intersections and the limited inflow capacity at parking facilities. An capacity and bottleneck analysis shows that the main bottlenecks of the ArenA area are mainly the limited inflow capacity of P1 and the intersection towards parking facility P3-P5. The capacity of the network is also limited by the parking capacity of certain parking facilities. In general, the bottlenecks are located on the secondary road network and not on the primary road network.

What are the current route strategies in the ArenA area during the inflow of an event?

The current route strategies in the Amsterdam ArenA are only focused on roadside measures. The government (Rijkswaterstaat) is responsible for the information on the primary road network while the municipality of Amsterdam is responsible for the measures on the secondary road network. The route strategies consist of route information on DRIPs towards the ArenA (on primary road network) or towards parking facilities (secondary road network). Additionally the municipality can decide to close some lanes or parking facilities during the inflow of an event. The outflow of an event has a clear goal: guide people via the shortest path from a parking facility to the highway and prevent crossing traffic to reach a maximum outflow capacity.

In particular unfamiliar visitors use an in-car navigation device when they travel to an unknown destination. The most commonly used static travel information towards "Amsterdam ArenA" leads a user to the off-ramp on the A2 towards the Burgemeester Stramanweg. So static information does not lead to a distribution of vehicles over the available off-ramps.

What are the characteristics of the current inflow of multiple events in the ArenA area?

The empirical data analysis of multiple events in the ArenA area shows that concerts in Ziggo Dome and Heineken Music Hall and football matches of Ajax in the ArenA in general do not lead to congestion on the primary road network. Football matches of the Dutch national team however lead often to congestion on highway A2 during the inflow. The number of event traffic for an event in the ArenA varies between 5.000 and 8.000 vehicles. Furthermore the analysis shows that the inflow of a concert takes longer (± 4 hour) than the inflow of a football match (± 2.5 hour). The number of vehicles entering the ArenA area within a peak hour is less than the capacity of the network for the majority of events. With other words, the network (capacity of 7.612 vehicles/hour and more than 12.000 parking lots) is not optimally used when the inflow of an event leads to congestion on the primary road network.

Strategy

Which criteria are of importance in the design of route guidance strategies for the inflow of event traffic at the ArenA area, from a traffic point of view and a traveller's point of view?

From traffic point of view it is important to distribute the vehicles over the available parking facilities and routes. The goal of this criteria is to prevent spillback and congestion from occuring. Additionally the strategy must be dynamic and personal. Dynamic is important since the high inflows during an event can change the traffic situation in the area within short time. Personal travel advice provides the possibility to distribute the vehicles.

The first criteria from a traveller's point of view is that unfamiliar visitors would like to get a travel advice instead of only information. Furthermore they would like to receive a travel advice that takes the unfamiliarity away. The assumption is made that if travellers receive an advice regarding their preferences of parking costs and walking time the chance they will comply increases.

Which method is appropriate to show the possible effects of the route strategy on traffic throughput in the Amsterdam ArenA area ex-ante?

The method must show the current situation. This means 1. the capacity of the network and parking facilities, 2. the route and parking choices of event traffic (demand) and 3. the effects on the traffic situation when waiting queues occur (demand exceeds capacity). The maximum throughput in the network capacity can be estimated by optimizing a matrix with all network constraints. Demand is modelled by the use of a gravity model. The number of trips towards a certain parking facility increases when the distance decreases and/or the parking capacity increases. Distinction is made between familiar and unfamiliar visitors. The effect on the traffic situation is determined by the use of a queuing model and first-order traffic flow theory. The different road sections of the secondary road network are divided into blocks. When the length of the first block exceeds by the length of a waiting queue, this has effect on the second block. Not only vehicles towards the bottleneck have delay, but other traffic is now affected as well. This other traffic ensures that the speed of the queue downstream increases. The blocks are simulated until the primary road network.

The complete method shows as output 1. the total travel distance, 2. the shortage of capacity (i.e. if waiting queues occur or not) and 3. the length of the queue on the primary road network after an hour. This method is able to show the effectiveness of the designed in-car strategy.

For which level of compliance has the route strategy a positive effect on the throughput?

The designed in-car strategy has a positive effect on traffic throughput from the beginning. The higher the penetration level the more people can be steered to the optimal distribution. However, this only applies when demand per origin and per parking preferences is less than the capacity that the in-car strategy provides.

Main research question
Which route strategy during the inflow of an event leads to a higher throughput at the ArenA area Amsterdam for most events?

An in-car route strategy that generates travel advice to distribute vehicles over the available routes and parking facilities based on the real-time traffic situation improves the traffic throughput in the ArenA area for most events. The advice is conform a system optimum and contains not only in-car travel time but walking time and parking costs as well. The distribution can be accomplished by in-car information since all travellers can receive a personal travel advice. To increase compliance, the travel advice is based on the preferences of the users itself. They are assigned to a parking facility which complies to their preferences regarding parking costs and walking time. The generated travel advice of the in-car strategy is based on the origin and preferences of the traveller and the real-time traffic situation in the ArenA area. Moreover the generated routes prevent unnecessary detours and crossing traffic to improve throughput and limit the effects of spillback. This designed in-car strategy provides a travel advice conform system optimum and increases the utility for the users as well.

8.2 Recommendations for further research

This section describes the recommendations for further research based on the total research.

8.2.1 Research and measurements

Congestion on highway A2 during the inflow of an event is caused by an inefficient distribution of vehicles over the available routes and parking facilities. The hypothesis is made that this inefficient distribution is caused by the unfamiliarity of the visitors. The discussion of this research shows that there can be other causes besides the unfamiliarity. The designed strategy is focussed to take the unfamiliarity away and help users to take a route that leads to optimal distribution. However, if the cause of congestion is the outflowing traffic, the limited available parking facilities or congestion on other roads, this has its influence on the effectiveness of the strategy. Less available parking facilities limit the possibilities to distribute traffic by the in-car strategy. Congestion on other roads could limited the distribution as well or decrease compliance since most travellers try to avoid congestion. The recommendation is to study the cause of congestion more into detail and the effects of those causes on the effectiveness of the in-car strategy.

The willingness to pay for the different parking categories is not studied during the research. It is assumed that the preferences of visitors regarding the three categories are divided equally. If all visitors would have the same preferences than demand is not equally divided and this leads to a higher chance on waiting queues. The in-car strategy is designed that people are asked for another category if the category of their preference has no sufficient capacity. This shall prejudice the design and also the compliance rate. A recommendation for further research is to study the willingness to pay. In this way the parking prices can be adapted that the chance that people have different preferences increases.

The inflow capacity of parking facilities is assumed on 350 vehicles per hour per entrance. The inflow capacity is determined as one of the bottlenecks in the ArenA area during the inflow of an event. If the inflow capacity in practice is lower, this would mean that the inflow capacity of parking facilities becomes the main cause of spillback. It decreases the estimated throughput in the ArenA area. It does not affect the strength of the designed strategy, but the chance on waiting queues in the area is higher. Further research should be carry out to determine the real inflow capacity. Additionally it is a recommendation on practical level as well; improve the inflow capacity of the parking facilities since this could be the main bottleneck and therefore the cause of congestion.

8.2.2 Model

The output of the parking choice model is dependent on the proportion familiar and unfamiliar visitors. As mentioned above, the hypothesis about the familiarity and unfamiliarity of visitors is however not proven. Furthermore the road side information is not incorporated in the choice model. An improved choice model provides more insight in the factors that are of importance of the route and parking choice of event visitors. This provides more insight in the cause of congestion and therefore also in the effectiveness of the designed in-car strategy.

The current model only models the main peak hour. It assumes that there is no waiting queue at the beginning of the main peak hour. Modelling the total event inflow of an event provides insight if this assumption is realistic. A traffic situation changes over time; queues increase but also resolve. Therefore the model should be able to take resolving waiting queues into account. This means that the model must be dynamic. If insight in the effects of congestion on the primary road network is needed, this must developed as well. The improvement of the complete model leads to a better founded cause of congestion on the primary road network. Taken the route information of roadside measures into account improves the choice model. Furthermore, the dynamic part of the model provides a dynamic route advice of the in-car system as well.

8.2.3 In-car strategy

The generated travel advice for event visitors is based on the real-time traffic situation. The state of the art shows that current technology is able to make travel time predictions. This is partly determined by using historical data. Events in the ArenA area are less often than the regular traffic situation on the primary road network in the Netherlands. This makes it more difficult to predict. Therefore further research should show if these travel predictions are reliable for this situation and can be generated in a short time period. In addition the traveller should get the advice before the junction in the ArenA area. In this way the traveller is still able to switch routes.

The in-car strategy is designed to prevent crossing traffic. It means that the number of possible routes is limited and so this limits the maximum throughput in the area. Further research should show more possible routes to increase the flexibility of the advice. It is of importance that the extended route options does not affect maximum throughput.

The in-car strategy does not only take the in-car trip into account but also looks at other parts of the trip, namely parking costs and egress time. This approach is already incorporated in travel advice for public transport, so why is it not incorporated in the advice for travelling by car? It would not have large influence on travel behaviour towards a destination with sufficient parking places close by, but travel advice for a trip towards a busy city centre or an event could be improved. Further research should show the effect of incorporating access time, egress time and direct costs on the perception of the driver and on the possible influence of steering people to an optimal distribution.

8.3 Recommendations for practical application

This section describes the recommendation for the practical application of the designed in-car strategy. It also gives recommendations for the Amsterdam Practical Trial, the reason for this study.

8.3.1 In-car strategy

Waiting queues and congestion can be inevitable in the ArenA area when demand approaches capacity. Therefore there must be decided where waiting queues and congestion are acceptable. This decision must be incorporated in the generated travel advice.

The designed in-car strategy makes a distinguish in different parking fees. To put the designed strategy into practice agreements should be made with the parking owners of category 3; low parking prices. The strategy shows a parking fee of €5,- for faraway parking facilities. Currently the parking price is €10 – €13,50 there during an event.

The route strategies of the municipality and the police of Amsterdam differ per event. These strategies, but also closed roads and closed parking facilities should be incorporated in the in-car strategy.

Observations in practice showed that the inflow of the parking facility is often limited by parking guards who check people's (possible) reservations. The bottleneck analysis shows as well that the inflow capacity of parking facilities in the ArenA area is a weak point for the traffic throughput. To encourage throughput in the area it is important to use the inflow capacity as efficient as possible;

The strength of the strategy is the efficient distribution over available parking facilities and routes. This leads to the constraint that sufficient routes and parking facilities must be available to distribute the traffic. If too many parking facilities and routes are not available, the effectiveness of the strategy is limited.

8.3.2 Amsterdam Practical Trial

The reason for this research is the Amsterdam Practical Trial. This research provides insight in possible improvements and so there are the following recommendations:

The first event selected for the in-car track of the Amsterdam Practical Trial is a concert of Lady Gaga in Ziggo Dome. The data analysis in this research shows that there is no congestion on the primary road network during the inflow of an event in the Ziggo Dome. The data analysis shows also that the inflow of a match of the Dutch national team always causes congestion on highway A2. The biggest challenge of Amsterdam Practical Trial is to prevent this congestion from occurring. Therefore, the recommendation is to apply the strategy on every match of the Dutch national team during the execution of Amsterdam Practical Trial to the test the effectiveness of the strategy in practice.

This research shows the lack of knowledge of compliance to travel information of travellers that are unfamiliar in an area. Amsterdam Practical Trial is the ideal platform to carry out a research about this topic. GPS-signals can track the route of a vehicle. The real-time situation on the road and the information showed on the DRIPs is known by the road authorities. The users of the in-car device that tracks their GPS-location, are asked to fill in a questionnaire. Stated preferences and/or data analysis provides insight in the compliance of event traffic to different travel information.

9 Literature

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Appendices

Appendices

The appendices are divided into five parts, namely A. Research area: the ArenA area, B. Empirical data analysis, C. Model approach, D. Model input and E. Model output.

A. Research area: the ArenA area

Details about the research area can be found in this section.

A.1. Characteristics of parking facilities

Table 27: Characteristics of parking facilities

Parking Facility	Organisation	Capacity	€ (event)	Address:
P1	Amsterdam	2.400	€ 20	Burgemeester Stramanweg 130
P2	Amsterdam	2.010	€ 12	Borchlandweg
P3	Amsterdam	366	€ 12	De entrée 228
P4	Amsterdam	1.248	€ 12	De entrée 7
P5	Amsterdam	1.354	€ 12	De entrée 7
P6	Amsterdam	399	€ 12	De corridor 15
P10	Amsterdam	814	€ 12	Herikerbergweg 288
P18	Amsterdam	291	€ 12	Fraijlemaborg 131
P21	Qpark	450	€ 13,50	Bijlmerdreef 91
P22	Qpark	228	€ 13,50	Bijlmerdreef 125
P23	Qpark	381	€ 13,50	Bijlmerdreef 400
P24	Qpark	487	€ 13,50	Flierbosdreef
Dome-garage	Amsterdam	550	€ 20	Passage 88
Endemol	Endemol	350	€ 13	MediaArenA 2

Figure 35: Overview of the location of parking facilities in the ArenA area

A.2. Interview with municipality of Amsterdam (in Dutch)

Ingevuld. Gesprek Daniel van Motman – Dienst Infrastructuur Verkeer & Vervoer
Locatie: pand gemeente Amsterdam, DIVV, Dijksgracht.
Datum en tijd: 3 juli 2013, 16.15 – 18.00 uur

Huidige situatie – problemen

1. Wat zijn de huidige problemen met het evenementverkeer in het ArenAgebied?
   Antwoord: Veel mensen nemen afslag 1 vanaf de A2. De entree vanaf de S111 richting P3,P4,P5 is een probleem. Ook de afwikkeling van de parkeergarage duurt te lang. Bij P1 bijvoorbeeld staan er mannetjes die vragen of de bestuurder een pashouder is van P1 of een eenmalige gebruiker. Dit duurt lang.
2. Wat zijn de knelpunten?
   - parkeergarages; ja
   - spreiding over afritten; ja
   - VRI's; met verlengen van groentijden wordt er goed omgegaan met VRI's. Dit gebeurt echter statisch, dus er is ruimte voor verbetering.
   - Kruisend verkeer; wordt met de scenario's met name bij de uitstroom voorkomen. Kruisend verkeer vormt volgens Daniel van Motman op dit moment niet het probleem.
   - instromend/uitstromend verkeer. Instroom = uitstroom
3. Zijn er verschillende problemen waarneembaar bij verschillende evenementenverkeer? Elke keer anders? Of altijd dezelfde problemen? Is het bij voetbalwedstrijden anders?
   Antwoord: Over het algemeen zijn dezelfde punten elke keer weer dezelfde problemen; afslag 1, A2, en de Entree naar P3, P4, P5. Bij voetbalwedstrijden zie je dat er veel gewoonterijders zijn met veel ervaring; ze weten waar ze gratis kunnen parkeren, ook al moeten ze 15 minuten lopen. Gewoonterijders komen echter nog steeds via afslag 1, A2 en komen ook steeds later. Omdat ze weten dat het goed geregeld is. Daardoor zie je bij de aanvang van een wedstrijd nog een kleine file op de Burg Stramanweg staan.
4. Waarom moet de situatie verbeterd worden? Directe/indirecte effecten?
   Antwoord: Het is een belangrijk economisch gebied. Mensen moeten ten alle tijden het gevoel hebben dat het gebied bereikbaar is, o.a. zodat ze ook de volgende keer terugkomen. Daarnaast moet het reguliere verkeer (winkelen, wonen) hun bestemming in het gebied kunnen bereiken ten tijde van een evenement.
5. Wat is het effect van het evenementenverkeer op het reguliere verkeer? Bewoners? Winkelende mensen? Zakelijk verkeer?
   Antwoord: Mensen die naar de woonboulevard gaan ten tijde van de instroom een groot evenement, staan in dezelfde file op de Burgemeester Stramanweg als de bezoekers van een evenement.
6. Hoeveel regulier verkeer is er tijdens de instroom en de uitstroom van een evenement [# of %]? -
7. Wat is het effect van file op de autosnelwegen op de knelpunten van het OWN? -

Parkeren

1. Waarom laten de PRIS de tekst "vol/vrij" zien? En geen # vrije plekken?
2. Antwoord: Beleidspuntje.
3. Welke parkeergarages worden er gebruikt ten tijde van een evenement?
   Antwoord: Denk hierbij ook aan Johan Football parking.

4. Hebben alle parkeergarages een slagboom?
   Antwoord: Ja waarschijnlijk wel
5. Welke parkeergarages zijn van Gemeente Amsterdam en welke van 'bedrijven'? -
6. Wat is het gebruik (# auto's) van de parkeergarages tijdens evenementen?
   Antwoord: Vertrouwelijke data. Daniel gaat er achteraan.
7. Zijn er veel bezoekers die hun auto op een totaal andere plek neerzetten dan de daarvoor bedoelde parkeergarages van de gemeente?
   Antwoord: Dat is vooral merkbaar bij voetbalwedstrijden omdat Ajaxsupporters de weg kennen. Mensen die het gebied niet kennen gaan eerder op de borden af.

Spreiding afritten

1. Hoe is de huidige spreiding over de afritten? Elk evenement anders? Of nagenoeg gelijk?
2. Wat is de capaciteit [auto's/min of VRI cyclus] per afrit?
   Antwoord: Volgens Daniel is er genoeg capaciteit bij afslag 3, A9 en afslag S111, A10, om de klap op te vangen die zich nu voordoet op de A2.

Regelscenario's

1. Hoe zijn de regelscenario's die gebruikt worden voor grote evenementen ontworpen? Modellen? Logica? Ervaringen?
   Antwoord: Gewoon logica.
2. Worden deze regelscenario's geëvalueerd? Zo ja, hoe?
   Antwoord: Na elk evenement vindt een korte vergadering plaats met de actoren. Hoe is het gegaan? Goed/niet goed.
3. Hoe is de samenwerking m.b.t. verkeer tussen de actoren?
   Antwoord: Voor elk evenement vindt een korte briefing plaats waarin alle afspraken weer helder worden gesteld. Als zo'n briefing niet plaats vindt, gaan de afhandelingen van het verkeer een stuk minder goed.

Verleden

1. Wanneer zijn de DRIP's op de rijkswegen ingevoerd? Is de tekst daarop in de loop van de tijd veranderd?
   Antwoord: 2010 of 2009
2. Wanneer zijn de PRIS (vol/vrij) in werking gegaan in het ArenA-gebied?
   Antwoord: Bij de opening van de ArenA in 1996?
3. Wanneer zijn de regelscenario's van Gemeente Amsterdam ingevoerd?
   Antwoord: zomer van 2009
4. Welke effecten zijn er sinds de invoer van deze middelen geconstateerd? En is hier wetenschappelijk onderzoek naar gedaan?
   - DRIP's autosnelwegen?
   - PRIS ArenA-gebied?
   - Regelscenario's?

   Antwoord: Er is geen wetenschappelijk onderzoek gedaan naar de DRIP's en PRIS. Volgens Daniel was de uitstroom vijf jaar geleden nog 2,5 uur waar het nu in 45 minuten gedaan is. De regelscenario's zijn wel gesimuleerd in een model van Goudappel. De uitkomsten lieten zien dat de regelscenario's een positief effect hadden op de bereikbaarheid. De DRIPs konden helaas niet gesimuleerd worden in dit model.

Toekomstige situatie

1. Wat gaat er de komende jaren veranderen in het ArenA-gebied en op de autosnelwegen rondom het gebied?
   Antwoord: De scenario's worden in de Scenariomanager gezet zodat het meer automatisch gaat. Ook wordt er een basic draaiboek geschreven. Nu is het nog elke keer een beetje anders. Daarnaast komen er pijl/kruissystemen (matrixborden boven de weg die aangeven met een pijl of een kruis of de weg te gebruiken is of niet. De ruimte voor verbetering ligt ook zeker in het dynamisch maken van het scenario. Vooruit denken en VRI/DRIPs/PRIS eerder aansturen om congestie te voorkomen.
2. Wat is uw/de verwachting van in-car technologie op het evenementenverkeer richting/in het ArenA-gebied?
   Antwoord: Het begeleiden van voertuigen van de bank thuis naar een parkeerplek bij het evenement is het doel. Naast het vergroten van de bereikbaarheid is het belangrijk dat de beleving van mensen sterk vergroot wordt.

B. Empirical data analysis

The next section of the appendices is the empirical data analysis.

B.1. Measurements inflow of parking facilities

To get insight in the maximum inflow of the parking facilities measurements are carried out in practice. On Sunday the 8th of September 2013 the artist Roger Waters gave a concert in the Amsterdam ArenA. A condition of measuring the maximum inflow is that the inflow is saturated. This was difficult to measure on different location, since the peak of the inflow only last for approximately an hour. Two parking facilities are measured, namely P2 and P-dome. The number of vehicles that past the entrance are counted per minute. The results are given in two tables on this page.

Table 28: Counts of saturated inflow at P-dome

Minute:	Number of Vehicles:
1	3
2	3
3	1
4	3
5	2
6	3
7	3
8	P-dome closed

Table 28 shows the counts at P-dome, the parking facility near Ziggo Dome. Currently this facility only sells parking tickets in advance, via onlineticket.nl. During the inflow the tickets are checked manually. This causes the limited inflow of 3 vehicles per minute. The measurement of one vehicle at minute 3 was for example caused by the fact that there was something wrong with the ticket that the person had who was first in line. With this approach of ticket controlling at P-dome, the average inflow is 3 vehicles per minute. This makes 3*60 = 180 vehicles/hour.

Table 29: Counts of saturated inflow at P2

Minute:	Number of Vehicles:
1	15
2	13
3	14
4	14
5	12
6	13
7	10
8	13
9	12
10	13

Table 29 shows the results of the measurement at P2, a big asphalt area at the S111 with a capacity of 2.010 vehicles. The inflow was very well organized since the inflow was continuing at (almost) the whole time. The average inflow is 13 vehicles/minute, so 13*60 = 780 vehicles/hour.

B.2. Methodology to determine intensities on an off-ramp without detectors

There are ten off-ramps within the scope of this research. Unfortunately, not all off-ramps have sufficient data during the year. Some off-ramps do not have detectors and some detectors on off-ramps are defect during (a part of) the year. To determine the distributions of the vehicles over the off-ramps, the intensities on the off-ramps need to be estimated. This is done in the following way:

$$Intensity_{Off-ramp} = Intensity_{Highway\ before\ off-ramp} - Intensity_{Highway\ after\ off-ramp}$$

The intensities are determined per 5 minutes. It is carried out for the following off-ramps:

- A2L towards Burgemeester Stramanweg (see figure)
- A9L towards S111
- A10L towards S112
- A10R towards S112

To validate this approach, the estimated off-ramp data is compared to the real data off-ramp data for the A2L. Figure 36 shows the results. The blue line is estimated data and the green line is the real data. The shape of the lines is comparable but the estimated intensities are in general lower than the real data.

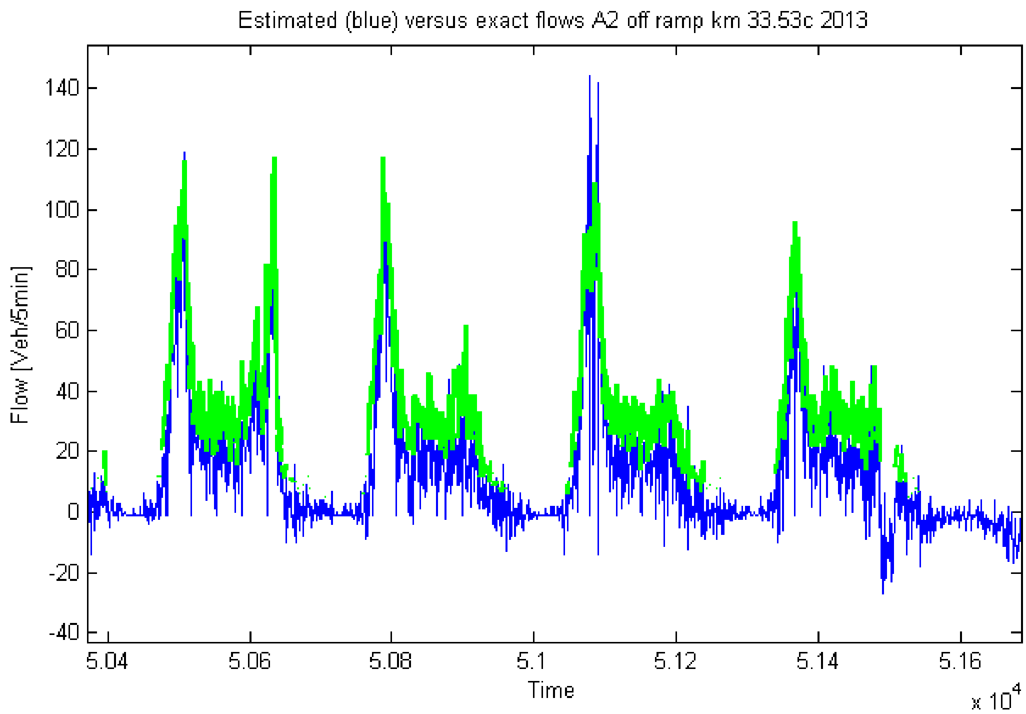


Figure 36: Validation real off-ramp data (green) and estimated off-ramp data (blue)

Those differences could be caused by several reasons. First of all, the method is applied with a delay of 5 minutes between the first measure point and the second measure point. Secondly it could be that one of the detectors was temporarily defect. The last argument is the fact that it is unknown if all four lanes where having a detector to measure the total intensity. The tables on the next page show the differences in absolute numbers. Table 30 shows the absolute numbers of event traffic going from the A2L to the Burgemeester Stramanweg during the inflow peak hours. As explained in the main report, event traffic is determined by the total traffic minus the 'regular traffic' during the event peak. This means that event traffic is already an indication. The estimated data however, is determined in the same way. The deviation of the estimated data compared to the off-ramp data is given in the right column.

Table 30: Event traffic using off-ramp A2L towards ArenA, determined by off-ramp data and estimated data

Event:	Date:	Congestion A2?	Off-ramp data	Estimated data	Deviation
Toppers on Friday	24-5-2013	no	2012	1758	14%
Ajax-NEC	31-3-2013	no	1308	1243	5%
Ajax-Willem II	5-5-2013	no	1547	1199	29%
Ajax-ADO	24-2-2013	no	1085	888	22%
Ajax-Heracles	7-4-2013	no	1484	1275	16%
Neth-Romania	26-3-2013	yes	1918	1976	-3%
Mumford & Sons (ZD)	30-3-2013	no	1064	1029	3%
One Direction (ZD)	3-5-2013	no	752	707	6%
Ajax-Pink-Eddie Izzard	19-4-2013	yes	2296	2188	5%

Table 31 shows the total traffic on an event day that are using A2L towards the Burgemeester Stramanweg during the peak hours of the event. Deviation of the estimated data is also given.

Table 31: Total traffic using off-ramp A2L towards ArenA, determined by off-ramp data and estimated data

Event:	Date:	Congestion A2?	Off-ramp data	Estimated data	Deviation
Toppers on Friday	24-5-2013	no	3392	2615	30%
Ajax-NEC	31-3-2013	no	1945	1583	23%
Ajax-Willem II	5-5-2013	no	2380	1763	35%
Ajax-ADO	24-2-2013	no	1955	1486	32%
Ajax-Heracles	7-4-2013	no	2212	1710	29%
Neth-Romania	26-3-2013	yes	3047	2589	18%
Mumford & Sons (ZD)	30-3-2013	no	1916	1436	33%
One Direction (ZD)	3-5-2013	no	2158	1523	42%
Ajax-Pink-Eddie Izzard	19-04-2013	yes	3641	3001	21%

There can be concluded that there is a deviation in the estimated data compared to the real off-ramp data. The deviation has a wide range between -3% and +42%. Since there is no other data available for the off-ramps without detectors, this method will still be applied.

The assumption is made that the other off-ramps with estimated data have the deviation as well. That is why the average deviations, **+11%** for event traffic and **+29%** for total traffic, is applied to other estimated data as well.

B.3. Output speed-contour analysis of multiple events in 2012 and 2013

B.3.1. Selected events in 2012

Event:		Date:	start:	A2R			A2L		
Football Ajax				Time:	Duration (h):	Max. Length:	Time:	Duration (h):	Max. Length:
Ajax-PSV	su	5-8-2012		no			16:15-17:15	1,00	3,5
Ajax-AZ	su	12-8-2012		no			no		
Ajax-NAC Breda	sa	25-8-2012		no			no		
Ajax-RKC Waalwijk	sa	15-9-2012		no			no		
Ajax-FC Twente	sa	29-9-2012		no			no		
Ajax-FC Utrecht	su	7-10-2012		11:45-12:15	0,5	>1	11:40-12:30	0,80	2,5
Ajax-Vitesse	sa	3-11-2012		18:00-18:20	0,25	0,8	17:20-18:20	1,00	4,0
Football Ajax CL									
Real Madrid	wed	3-10-2012		no			19:10-20:00	0,80	3,0
Manchester	wed	24-10-2012		no			no		
Borussia Dortm	wed	21-11-2012		19:30-20:30	1	>1	18:30-20:30	2,00	4,5
Football National Team									
Neth-Turkey	fr	7-9-2012		19:30-20:00	0,5	>1	19:15-19:45	0,50	2,0
Neth-Germany	wed	14-11-2012		19:45-20:30	0,75	>1	18:55-20:30	1,50	3,5

B.3.2. Selected events in 2013

Event:		Date:	start:	A2R Time:	A2R Duration (h):	A2R Max. Length (km):	A2L Time:	A2L Duration (h):	A2L Max. Length (km):
Football Ajax									
Ajax-Feyenoord	su	20-1-2013	14:30	13:00 - 14:15	1,25	>1	12:45 - 14:15	1,5	4,25
Ajax-Roda JC	su	10-2-2013	14:30	13:20 - 14:10	0,8	>1	13:20 - 13:35	0,25	1,5
Ajax-ADO Den Haag	su	24-2-2013	14:30	no			no		
Ajax-AZ	we	27-2-2013	20:45	no			no		
Ajax-PEC Zwolle	su	10-3-2013	14:30	13:30 - 13:50	0,33	1	no		
Ajax-NEC	su	31-3-2013	16:30	no			no		
Ajax-Heracles	su	7-4-2013	16:30	no			no		
Ajax-Willem II	su	5-5-2013	12:30	no			no		
Football National Team									
Neth-Italy	we	6-2-2013	20:30	19:10 - 20:30	1,3	>1	19:00 - 20:30	1,5	3,5
Neth-Estonia	fr	22-3-2013	20:30	19:25 - 20:05	0,7	>1	19:00 - 20:30	1,5	4
Neth-Romania	tu	26-3-2013	20:30	19:20 - 20:00	0,7	>1	19:00 - 20:00	1,0	3
Concerts ArenA									
Toppers on Friday	fr	24-5-2013	20:00	no			no		
Toppers on Saturday	sa	25-5-2013	20:00	no			no		
Toppers on Sunday	su	26-5-2013	20:00	no			no		
Concerts Ziggo Dome									
Mumford and Suns	sa	30-3-2013	20:00	no			no		
Beyoncé	su	21-4-2013	20:00	no			no		
One Direction	fr	3-5-2013	19:30	no			no		
Triples									
Ajax-Pink-E. Izzard	fr	19-4-2013	20:00	19:15 - 19:30	0,25	1	18:20 - 19:50	1,5	5

B.4. Output off-ramp analysis – absolute numbers and percentages

B.4.1. Event traffic absolute numbers

Event:		Date:	Peak Hours:	Peak Duration:		A2	A9-S111	A9-S112	A10-S111	A10-S112	Total traffic
Concerts ArenA											
Toppers on Friday	fr	24-5-2013	16:00-20:15	4,25	N	3956	1232	396	1674		7258
Toppers on Saturday	sa	25-5-2013	16:00-20:15	4,25	N	3302	755	823	1729	1070	7679
Toppers on Sunday	su	26-5-2013	16:00-20:15	4,25	N	4413	841	946	2198	1406	9805
Football Ajax											
Ajax-Feyenoord	su	20-1-2013	12:00-14:30	2,5	Y	1794	1849	1322		1647	6613
Ajax-NEC	su	31-3-2013	14:00-16:30	2,5	N	2283	591	614	886	832	5206
Ajax-Willem II	su	5-5-2013	09:00-12:30	3,5	N	3160	1353	1024	1805	362	7704
Ajax-ADO	su	24-2-2013	11:30-14:30	3,0	N	2464	1126	479		492	4562
Ajax-Heracles	su	7-4-2013	13:30-16:30	3,0	N	3233	1251	963			5447
Football National Team											
Ned-Estonia	fr	22-3-2013	18:00-20:30	2,5	Y	3183	1837	699	900	374	6993
Ned-Romania	tu	26-3-2013	17:00-20:30	3,5	Y	3579	1589	542	839	496	7045
Ned-Italy	we	6-2-2013	18:00-20:30	2,5	Y	2877	1196	361	900		5334
Concerts Ziggo Dome											
Mumford and Sons	sa	30-3-2013	16:00-20:30	4,5	N	1718	147	110	217	0	2192
Beyoncé	su	21-4-2013	16:00-20:30	4,5	N	2326	302	177	262	311	3377
One Direction	fr	3-5-2013	16:00-20:30	4,5	N	1178	11	278	233		1700
Triple											
Ajax-Pink-Eddie Izzard	fr	19-4-2013	16:00-20:00	4,0	Y	4378	2729	1327	1896	1756	12086

B.4.2. Event traffic percentages

Event:		Date:	Peak Hours:	Peak Duration:		A2	A9-S111	A9-S112	A10-S111	A10-S112	Total traffic
Concerts ArenA											
Toppers on Friday	fr	24-5-2013	16:00-20:15	4,25	N						
Toppers on Saturday	sa	25-5-2013	16:00-20:15	4,25	N	43%	10%	11%	23%	14%	100%
Toppers on Sunday	su	26-5-2013	16:00-20:15	4,25	N	45%	9%	10%	22%	14%	100%
Football Ajax											
Ajax-Feyenoord	su	20-1-2013	12:00-14:30	2,5	Y						
Ajax-NEC	su	31-3-2013	14:00-16:30	2,5	N	44%	11%	12%	17%	16%	100%
Ajax-Willem II	su	5-5-2013	09:00-12:30	3,5	N	41%	18%	13%	23%	5%	100%
Ajax-ADO	su	24-2-2013	11:30-14:30	3,0	N						
Ajax-Heracles	su	7-4-2013	13:30-16:30	3,0	N						
Football National Team											
Ned-Estonia	fr	22-3-2013	18:00-20:30	2,5	Y	46%	26%	10%	13%	5%	100%
Ned-Romania	tu	26-3-2013	17:00-20:30	3,5	Y	51%	23%	8%	12%	7%	100%
Ned-Italy	we	6-2-2013	18:00-20:30	2,5	Y						
Concerts Ziggo Dome											
Mumford and Sons	sa	30-3-2013	16:00-20:30	4,5	N	78%	7%	5%	10%	0%	100%
Beyoncé	su	21-4-2013	16:00-20:30	4,5	N	69%	9%	5%	8%	9%	100%
One Direction	fr	3-5-2013	16:00-20:30	4,5	N						
Triple											
Ajax-Pink-Eddie Izzard	fr	19-4-2013	16:00-20:00	4,0	Y	36%	23%	11%	16%	15%	100%

B.4.3. Total traffic – absolute numbers

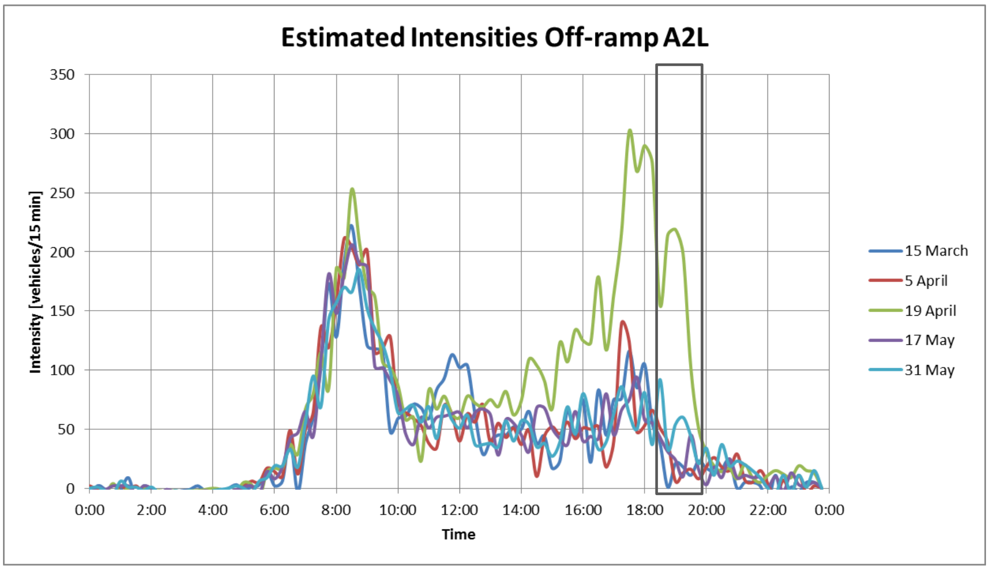
Event:		Date:	Peak Hours:	Peak Duration:		A2	A9-S111	A9-S112	A10-S111	A10-S112	Total traffic
Concerts ArenA											
Toppers on Friday	fr	24-5-2013	16:00-20:15	4,25	N	8176	2822	3841	4473		19312
Toppers on Saturday	sa	25-5-2013	16:00-20:15	4,25	N	6325	2547	3052	3622	4110	19656
Toppers on Sunday	su	26-5-2013	16:00-20:15	4,25	N	6569	2317	2836	3573	4039	19335
Football Ajax											
Ajax-Feyenoord	su	20-1-2013	12:00-14:30	2,5	Y	4304	3952	2447		4372	15075
Ajax-NEC	su	31-3-2013	14:00-16:30	2,5	N	4322	2343	2026	2349	2966	14006
Ajax-Willem II	su	5-5-2013	09:00-12:30	3,5	N	5218	2961	1956	3252	809	14196
Ajax-ADO	su	24-2-2013	11:30-14:30	3,0	N	5183	3331	1979		4003	14496
Ajax-Heracles	su	7-4-2013	13:30-16:30	3,0	N	5616	3299	2615			11530
Football National Team											
Ned-Estonia	fr	22-3-2013	18:00-20:30	2,5	Y	5097	2794	2125		2857	12874
Ned-Romania	tu	26-3-2013	17:00-20:30	3,5	Y	6674	2728	2947	2629	4287	19265
Ned-Italy	we	6-2-2013	18:00-20:30	2,5	Y	4696	2017	1668			8382
Concerts Ziggo Dome											
Mumford and Sons	sa	30-3-2013	16:00-20:30	4,5	N	4528	1780	2350	2233	3135	14026
Beyoncé	su	21-4-2013	16:00-20:30	4,5	N	4206	1645	2247	1976	2780	12855
One Direction	fr	3-5-2013	16:00-20:30	4,5	N	5635	1774	3158	2944		13511
Triple											
Ajax-Pink-Eddie Izzard	fr	19-4-2013	16:00-20:00	4,0	Y	8352	4345	4359	4590	5817	27463

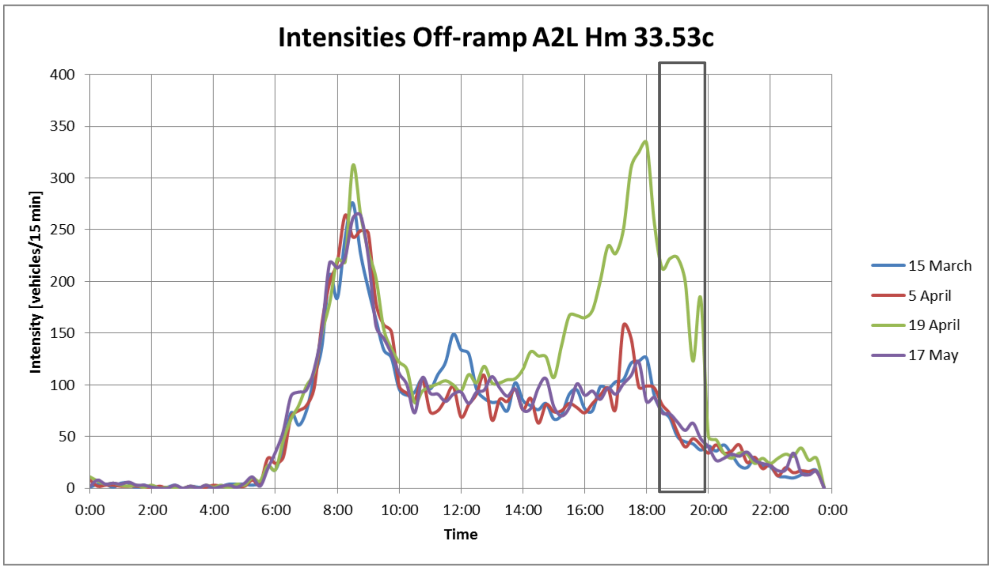
B.4.4. Total traffic – percentages

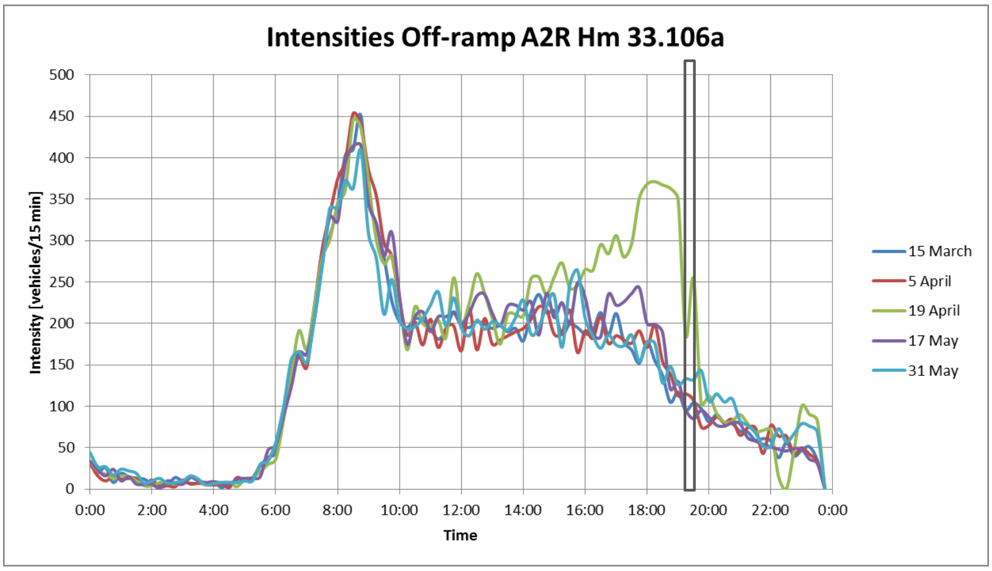
Event:		Date:	Peak Hours:	Peak Duration:		A2	A9-S111	A9-S112	A10-S111	A10-S112	Total traffic
Concerts ArenA											
Toppers on Friday	fr	24-5-2013	16:00-20:15	4,25	N						
Toppers on Saturday	sa	25-5-2013	16:00-20:15	4,25	N	32%	13%	16%	18%	21%	100%
Toppers on Sunday	su	26-5-2013	16:00-20:15	4,25	N	34%	12%	15%	18%	21%	100%
Football Ajax											
Ajax-Feyenoord	su	20-1-2013	12:00-14:30	2,5	Y						
Ajax-NEC	su	31-3-2013	14:00-16:30	2,5	N	31%	17%	14%	17%	21%	100%
Ajax-Willem II	su	5-5-2013	09:00-12:30	3,5	N	37%	21%	14%	23%	6%	100%
Ajax-ADO	su	24-2-2013	11:30-14:30	3,0	N						
Ajax-Heracles	su	7-4-2013	13:30-16:30	3,0	N						
Football National Team											
Ned-Estonia	fr	22-3-2013	18:00-20:30	2,5	Y	40%	22%	17%	0%	22%	100%
Ned-Romania	tu	26-3-2013	17:00-20:30	3,5	Y	35%	14%	15%	14%	22%	100%
Ned-Italy	we	6-2-2013	18:00-20:30	2,5	Y						
Concerts Ziggo Dome											
Mumford and Sons	sa	30-3-2013	16:00-20:30	4,5	N	32%	13%	17%	16%	22%	100%
Beyoncé	su	21-4-2013	16:00-20:30	4,5	N	33%	13%	17%	15%	22%	100%
One Direction	fr	3-5-2013	16:00-20:30	4,5	N						
Triple											
Ajax-Pink-Eddie Izzard	fr	19-4-2013	16:00-20:00	4,0	Y	30%	16%	16%	17%	21%	100%

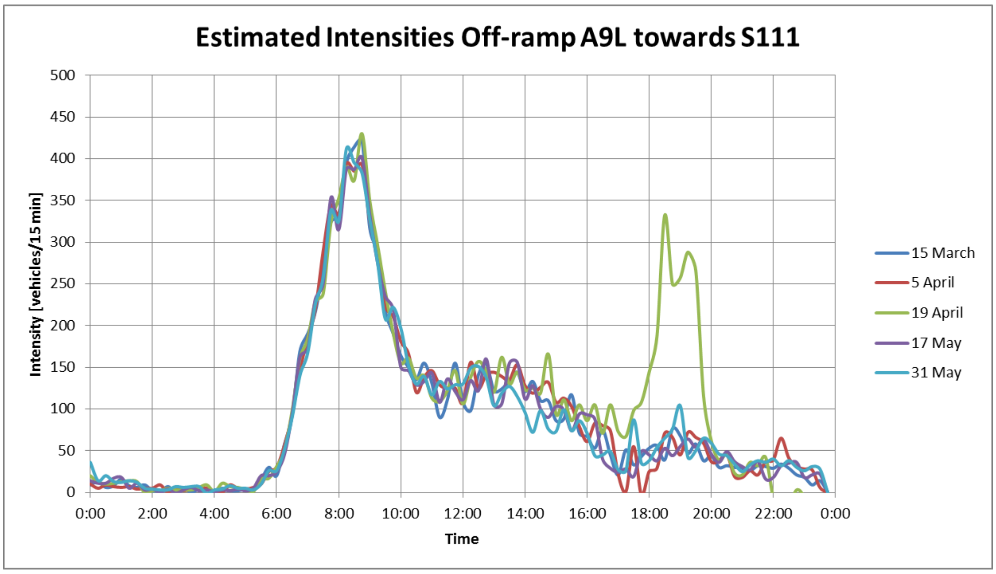
B.5. Graphs intensities off-ramps on event day of three scenarios

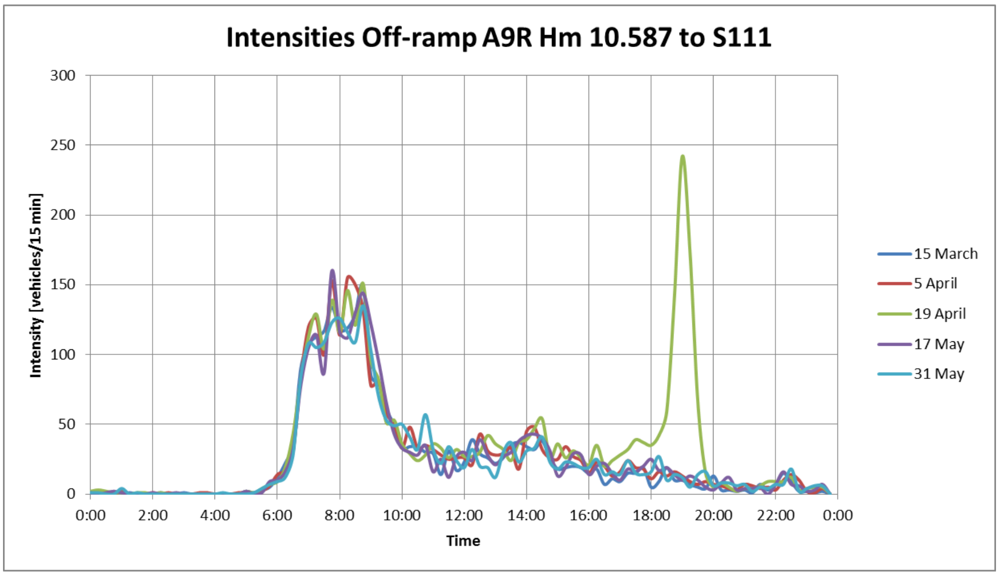
B.5.1. Triple ArenA on Friday 19 April 2013

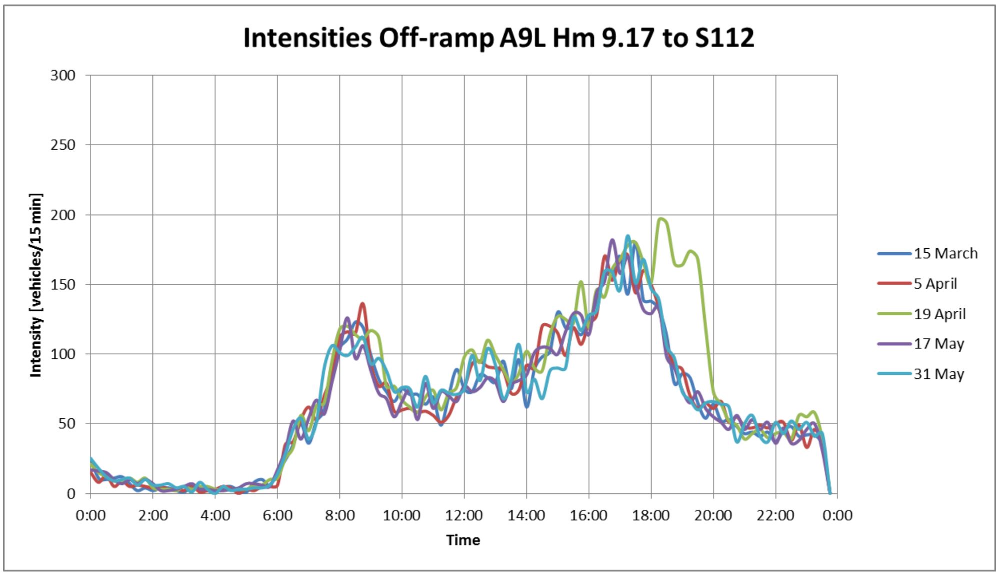




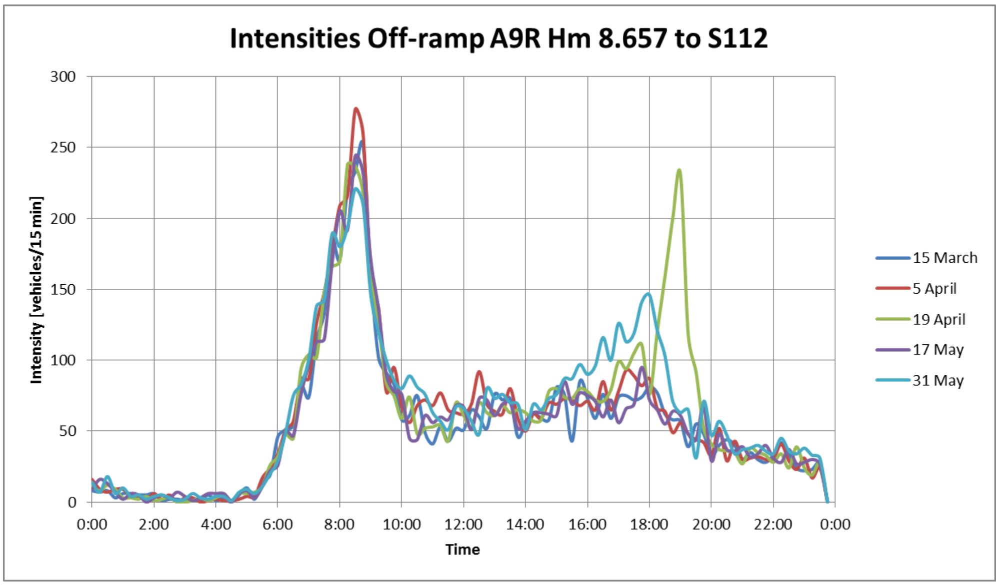



Estimated Intensities Off-ramp A9L towards S111
Intensity [vehicles/15 min]
500
450
400
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
15 March
5 April
19 April
17 May
31 May

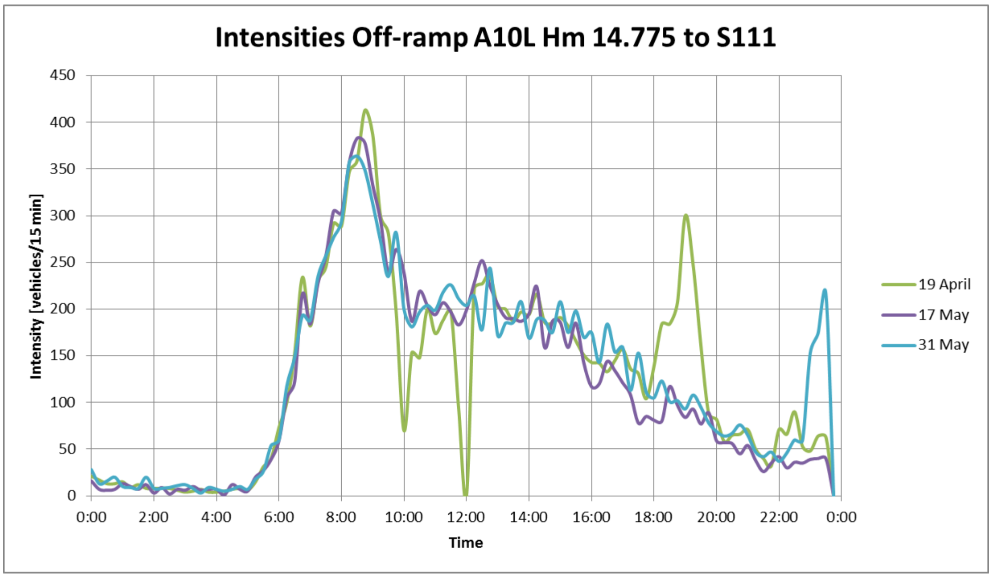

Intensities Off-ramp A9R Hm 10.587 to S111
Intensity [vehicles/15 min]
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
15 March
5 April
19 April
17 May
31 May

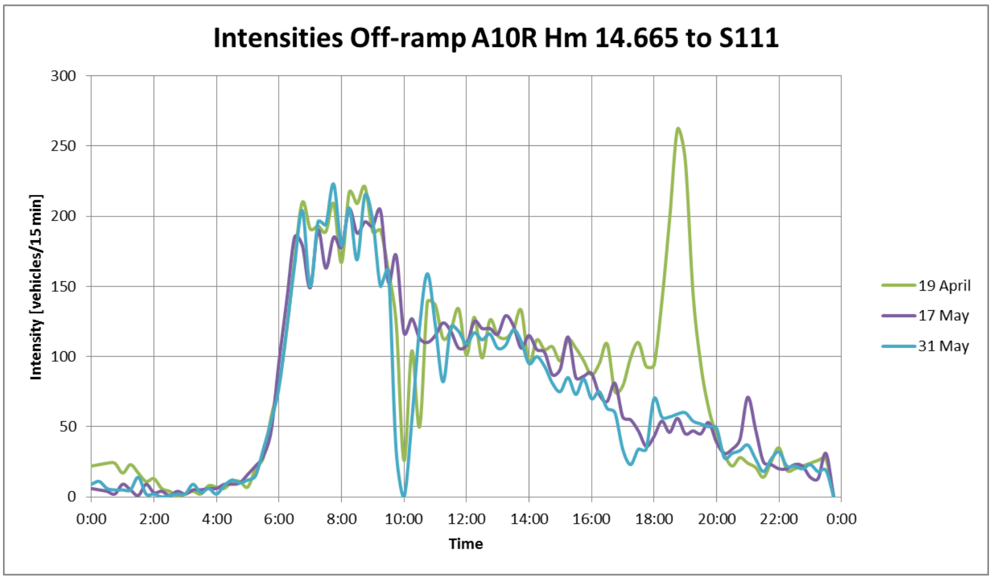


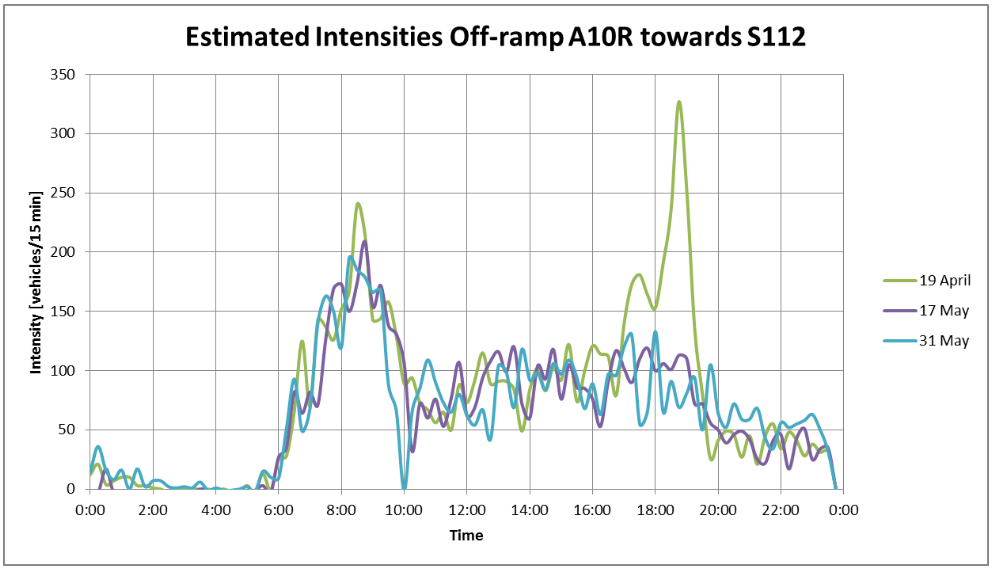
Intensities Off-ramp A9L Hm 9.17 to S112
Intensity [vehicles/15 min]
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
15 March
5 April
19 April
17 May
31 May

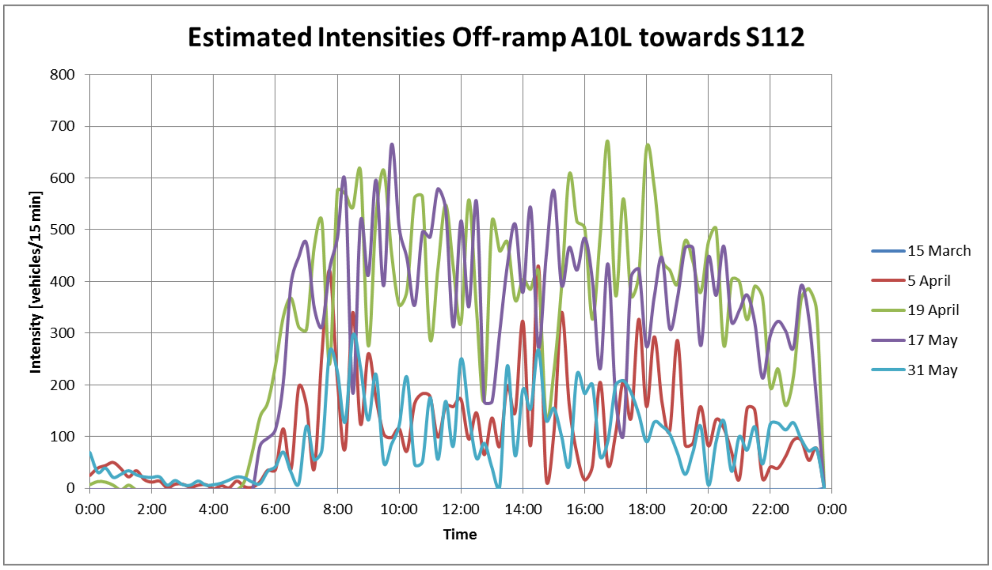


Intensities Off-ramp A9R Hm 8.657 to S112
Intensity [vehicles/15 min]
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
15 March
5 April
19 April
17 May
31 May

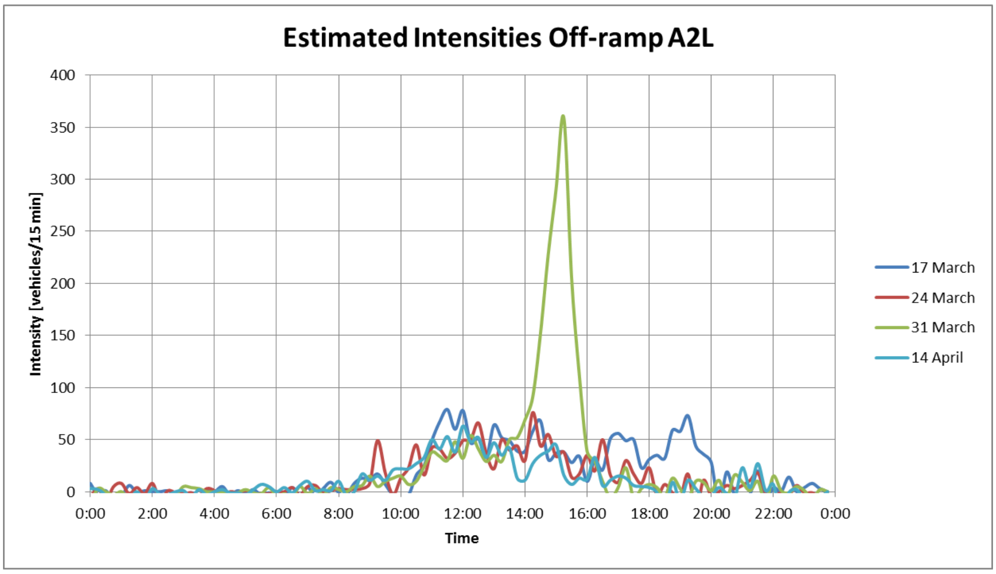

Intensities Off-ramp A10L Hm 14.775 to S111
Intensity [vehicles/15 min]
450
400
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
19 April
17 May
31 May

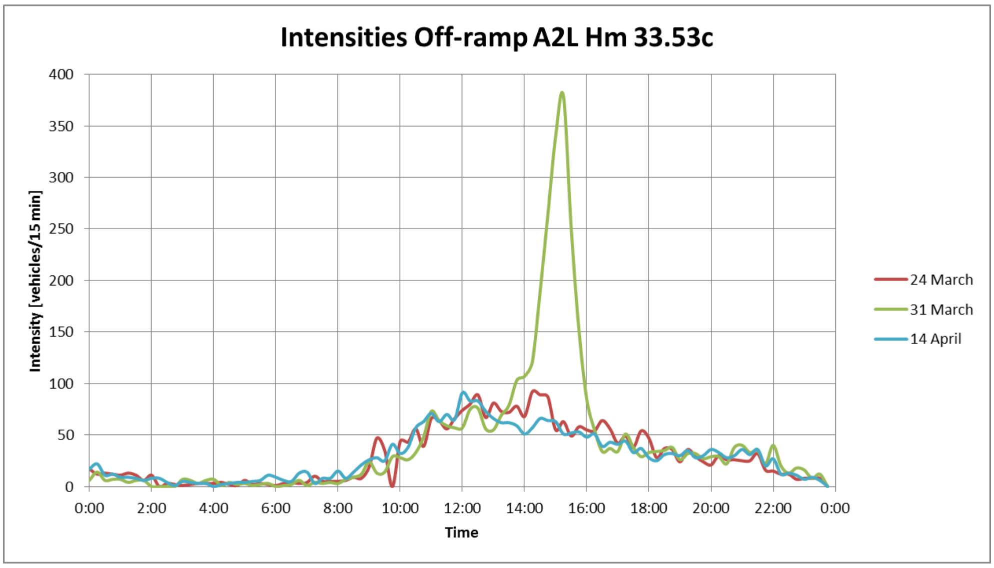

Intensities Off-ramp A10R Hm 14.665 to S111
Intensity [vehicles/15 min]
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
19 April
17 May
31 May

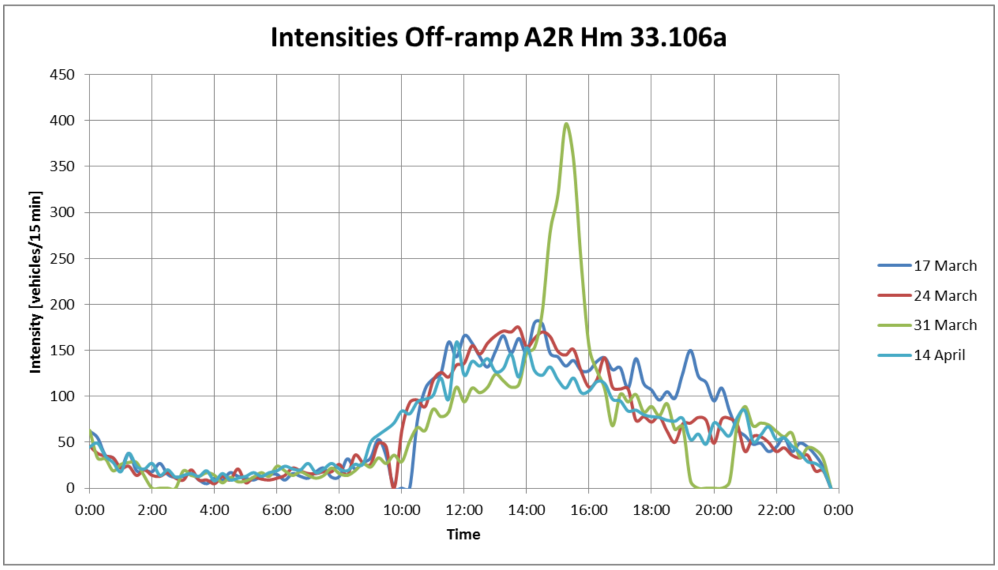

Estimated Intensities Off-ramp A10R towards S112
Intensity [vehicles/15 min]
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
19 April
17 May
31 May

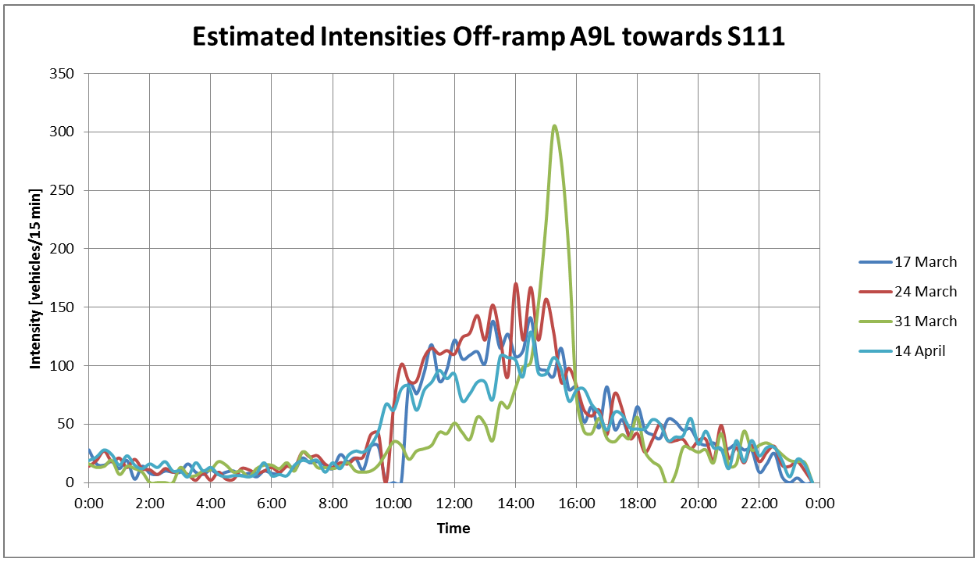

Estimated Intensities Off-ramp A10L towards S112
Intensity [vehicles/15 min]
800
700
600
500
400
300
200
100
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
15 March
5 April
19 April
17 May
31 May

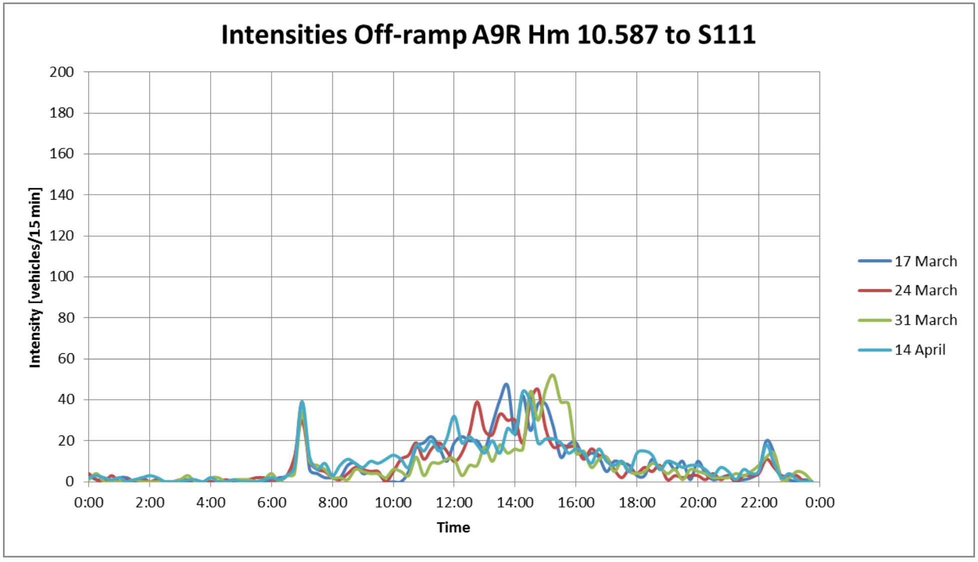
B.5.2. Ajax-NEC – on Sunday 31 March 2013

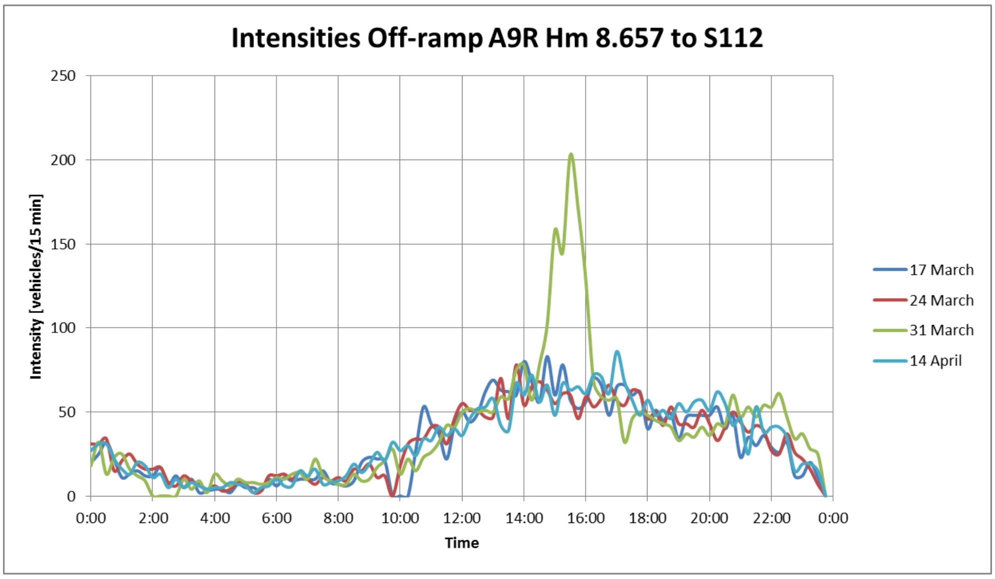


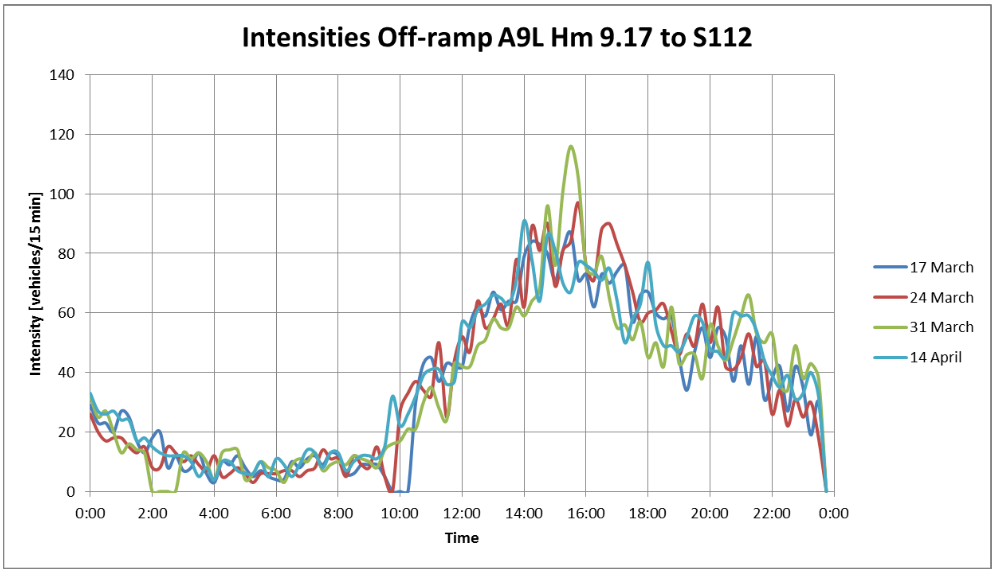


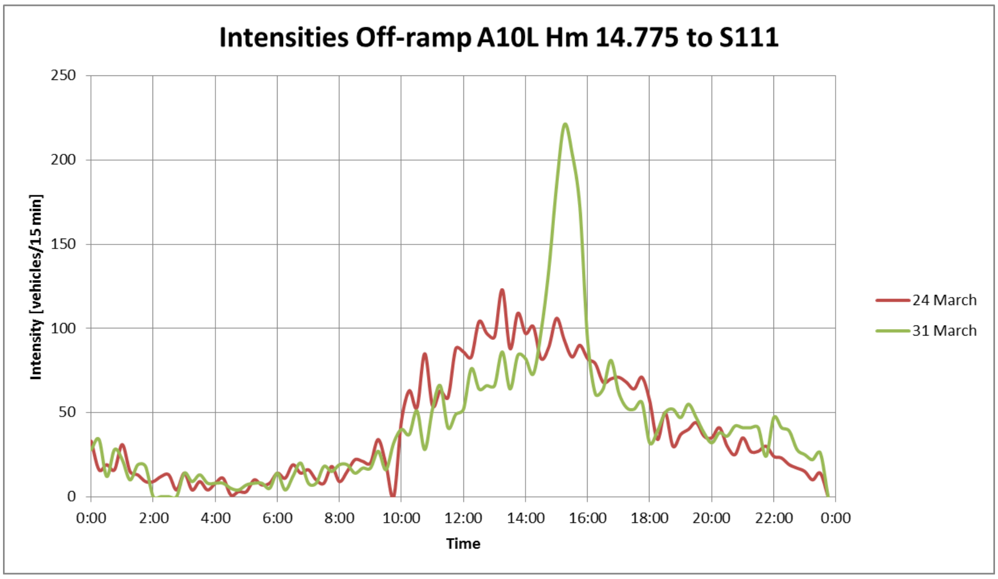


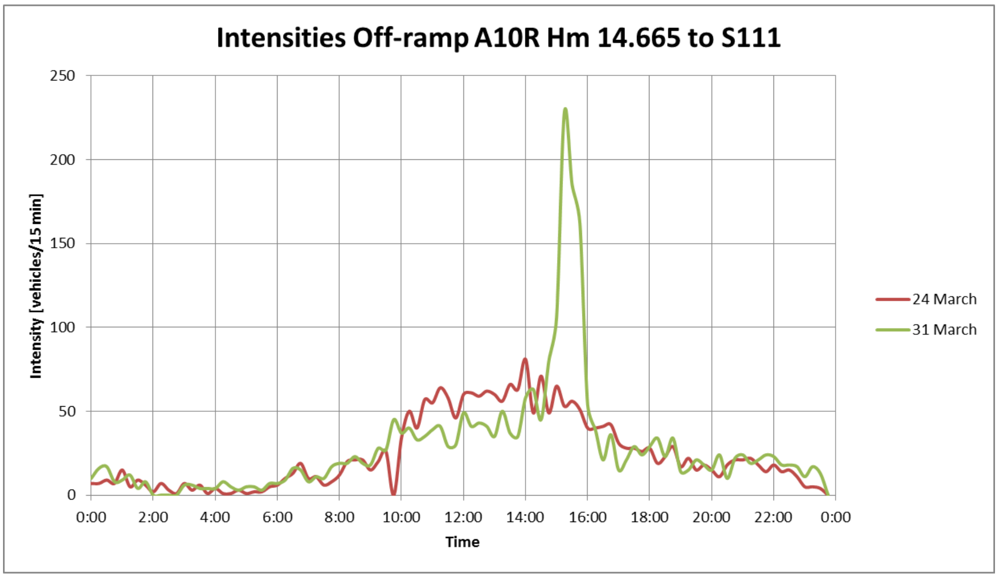

Estimated Intensities Off-ramp A9L towards S111
Intensity [vehicles/15 min]
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
17 March
24 March
31 March
14 April

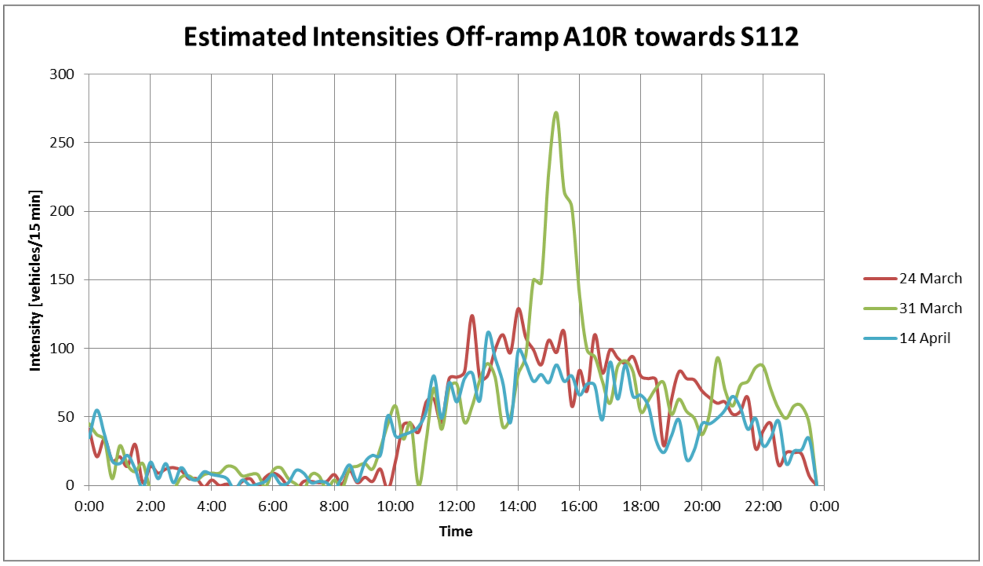

Intensities Off-ramp A9R Hm 10.587 to S111
Intensity [vehicles/15 min]
200
180
160
140
120
100
80
60
40
20
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
17 March
24 March
31 March
14 April

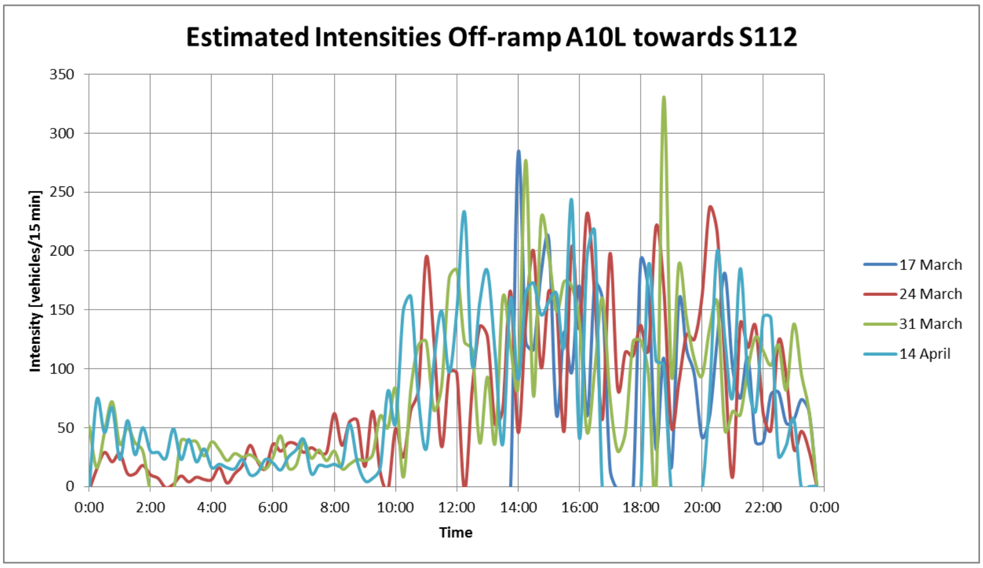

Intensities Off-ramp A9R Hm 8.657 to S112
Intensity [vehicles/15 min]
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
17 March
24 March
31 March
14 April


Intensities Off-ramp A9L Hm 9.17 to S112
Intensity [vehicles/15 min]
140
120
100
80
60
40
20
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
17 March
24 March
31 March
14 April

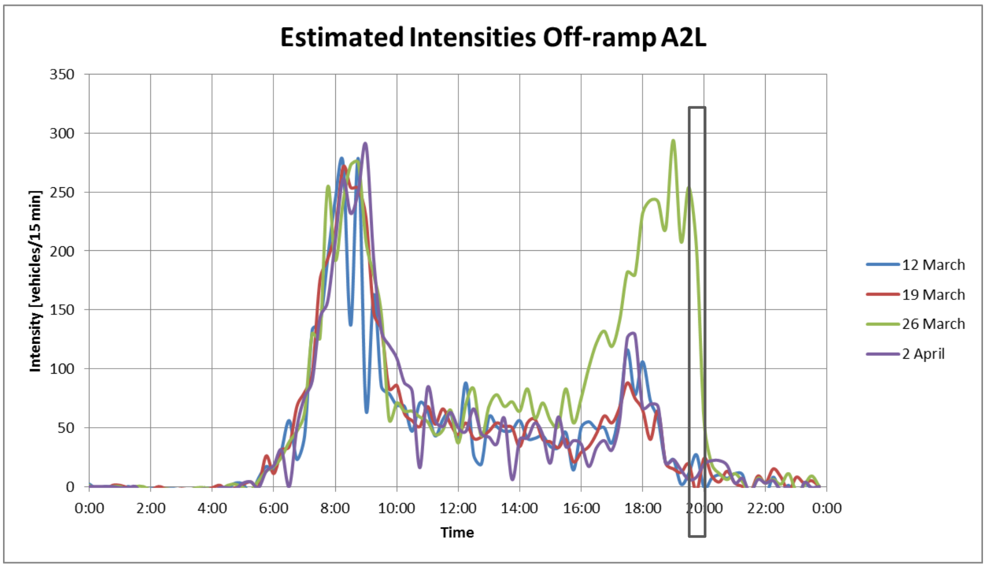

Intensities Off-ramp A10L Hm 14.775 to S111
Intensity [vehicles/15 min]
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
24 March
31 March

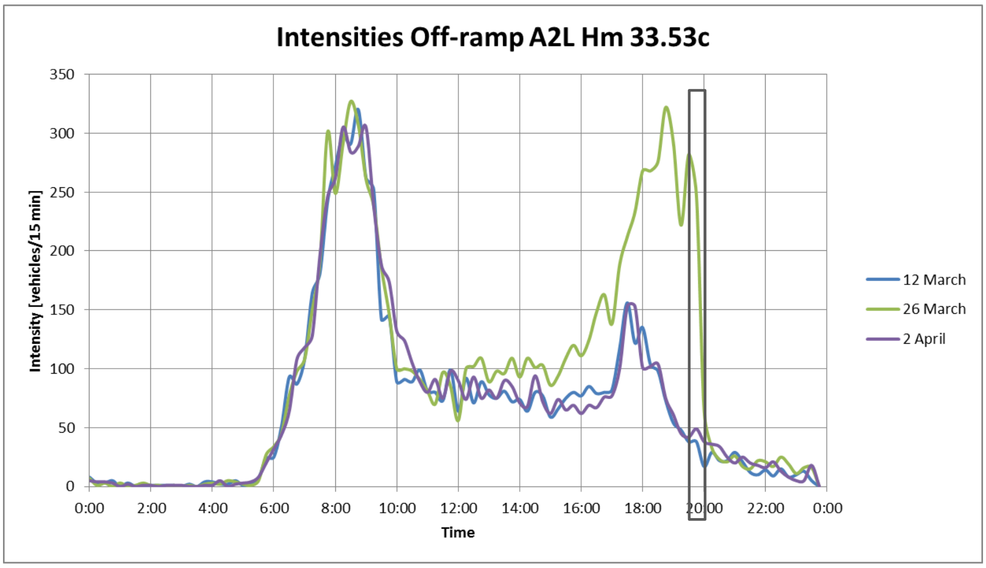

Intensities Off-ramp A10R Hm 14.665 to S111
Intensity [vehicles/15 min]
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
24 March
31 March

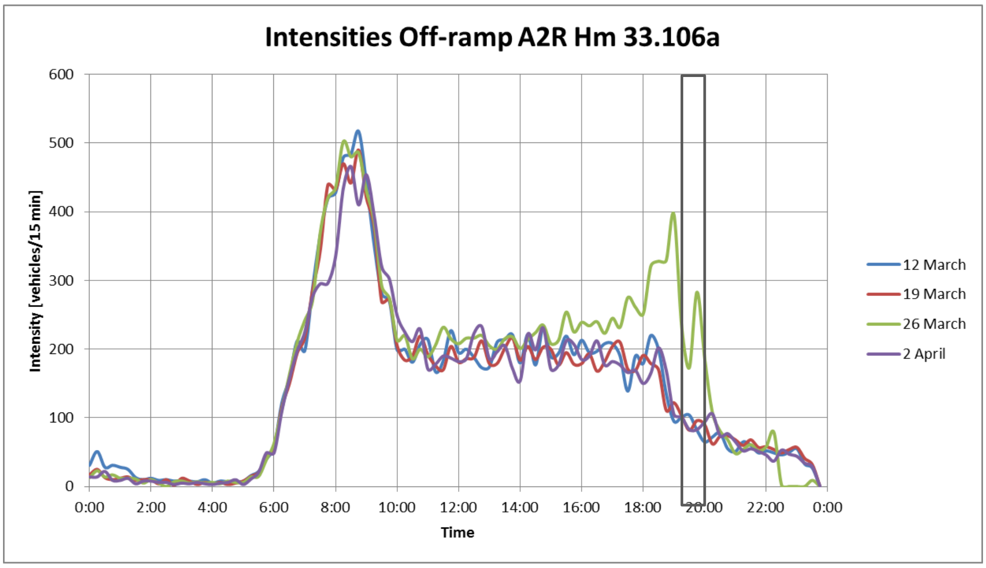

Estimated Intensities Off-ramp A10R towards S112
Intensity [vehicles/15 min]
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
24 March
31 March
14 April

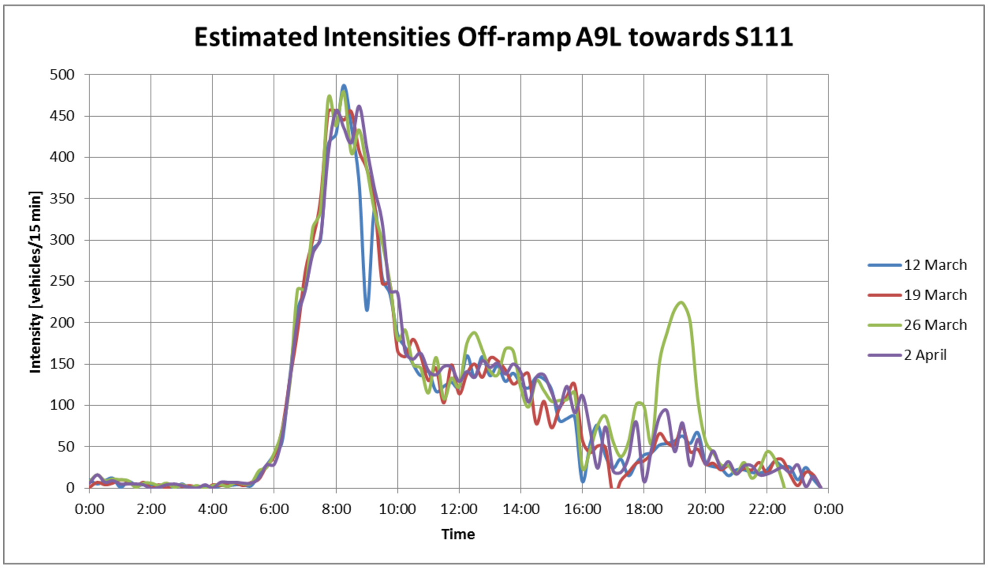

Estimated Intensities Off-ramp A10L towards S112
Intensity [vehicles/15 min]
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
17 March
24 March
31 March
14 April

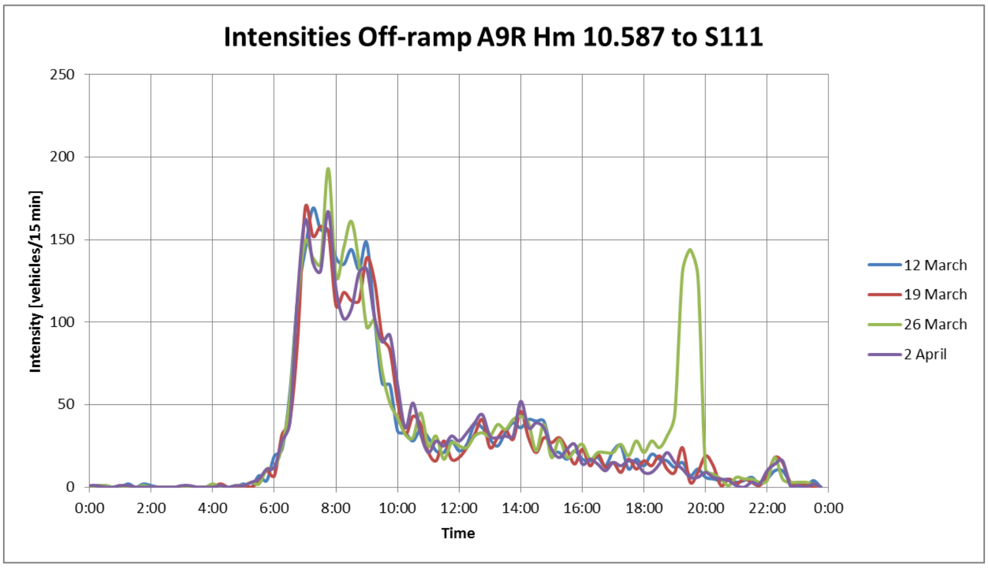
B.5.3. Netherlands-Romania – on Tuesday 26 March 2013

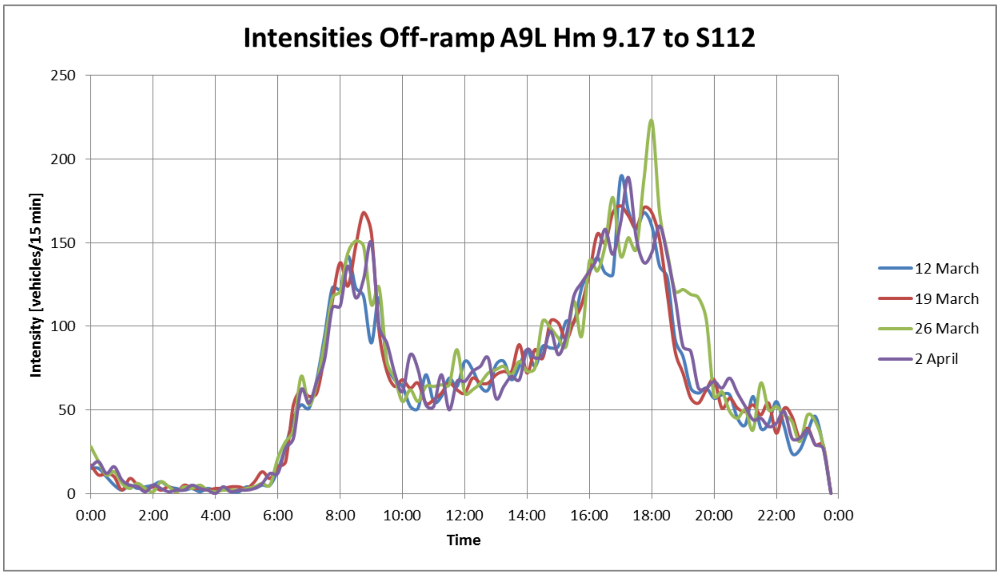


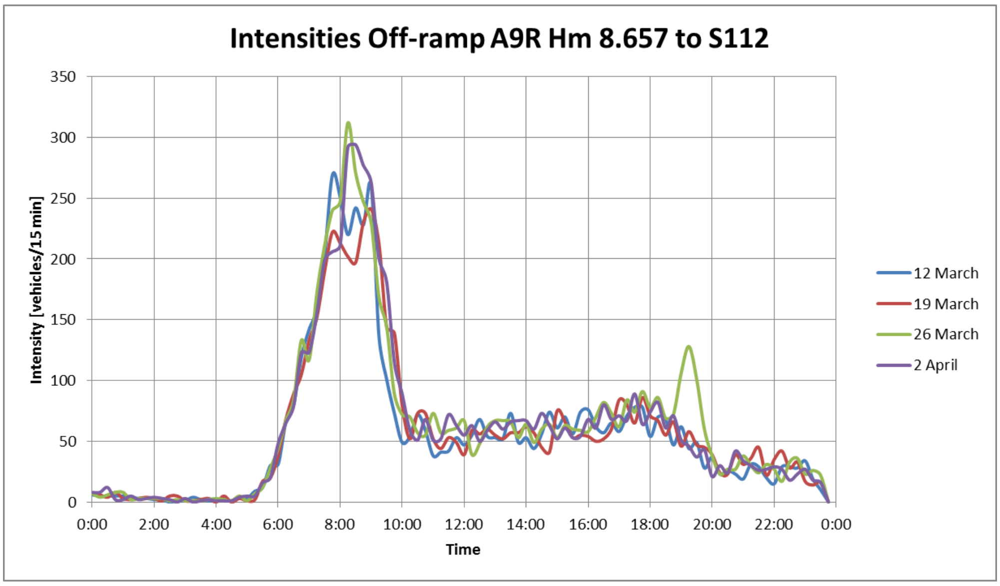


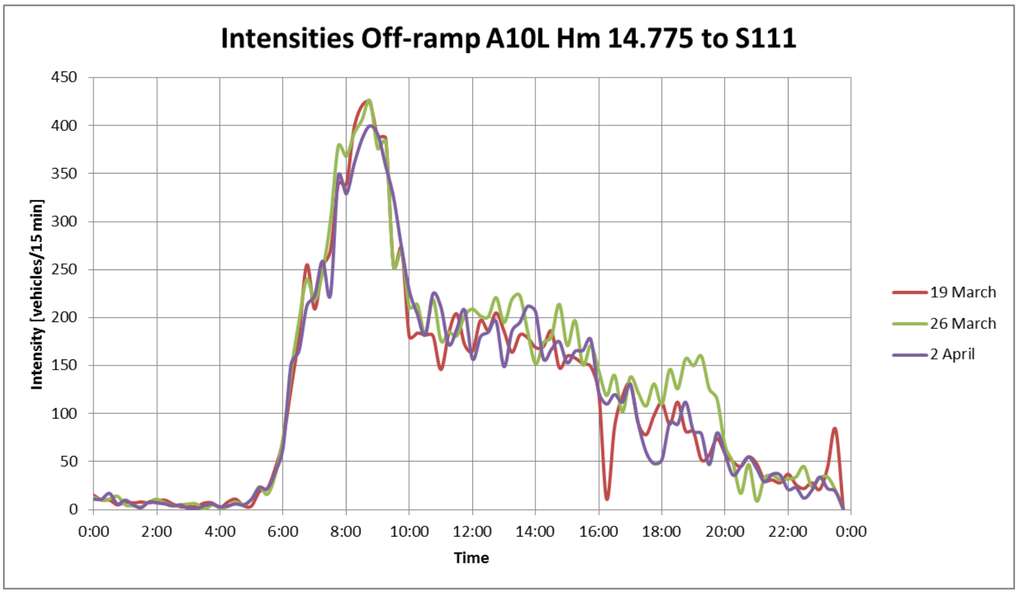


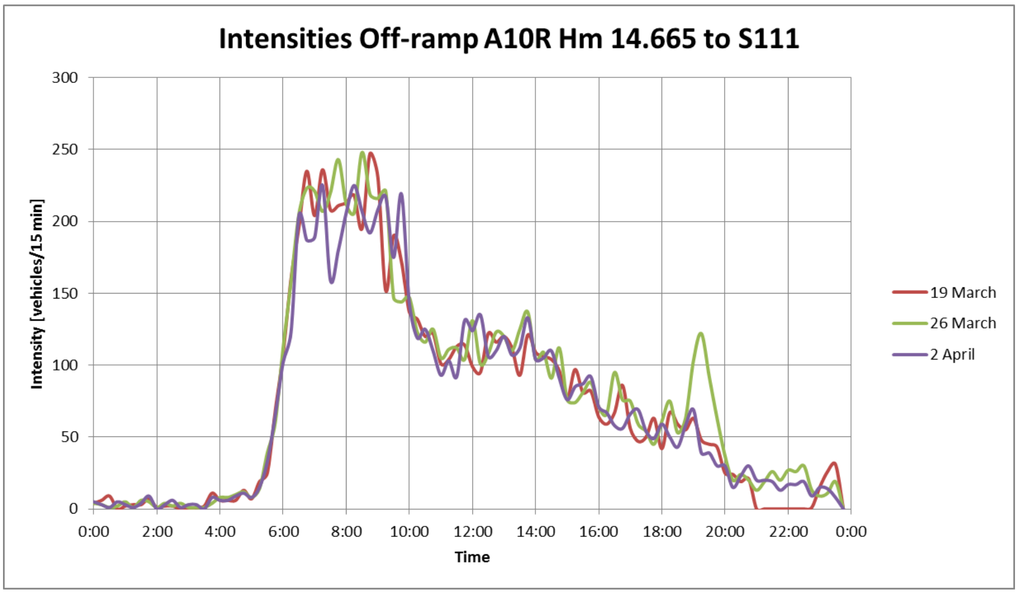

Estimated Intensities Off-ramp A9L towards S111
Intensity [vehicles/15 min]
0
50
100
150
200
250
300
350
400
450
500
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
12 March
19 March
26 March
2 April

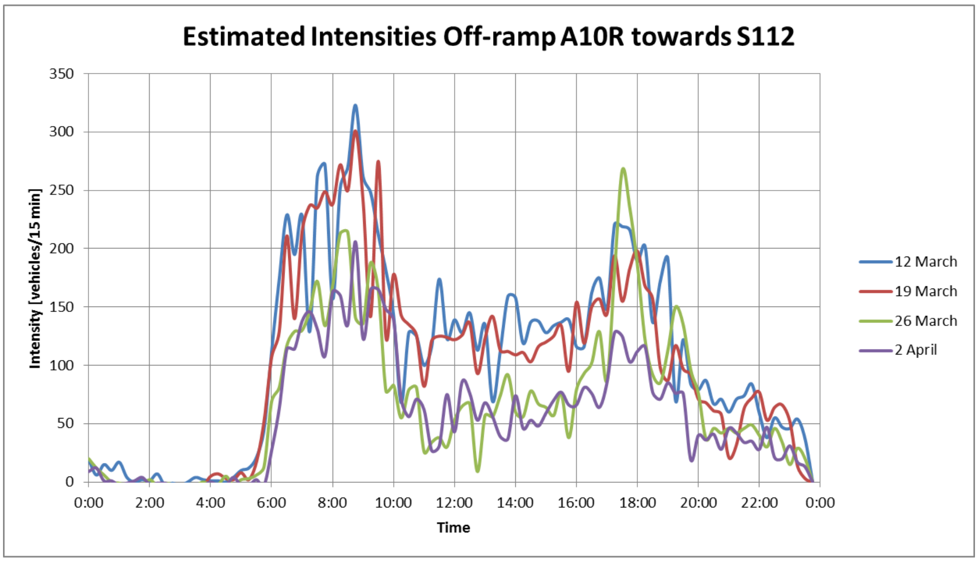

Intensities Off-ramp A9R Hm 10.587 to S111
Intensity [vehicles/15 min]
0
50
100
150
200
250
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
12 March
19 March
26 March
2 April

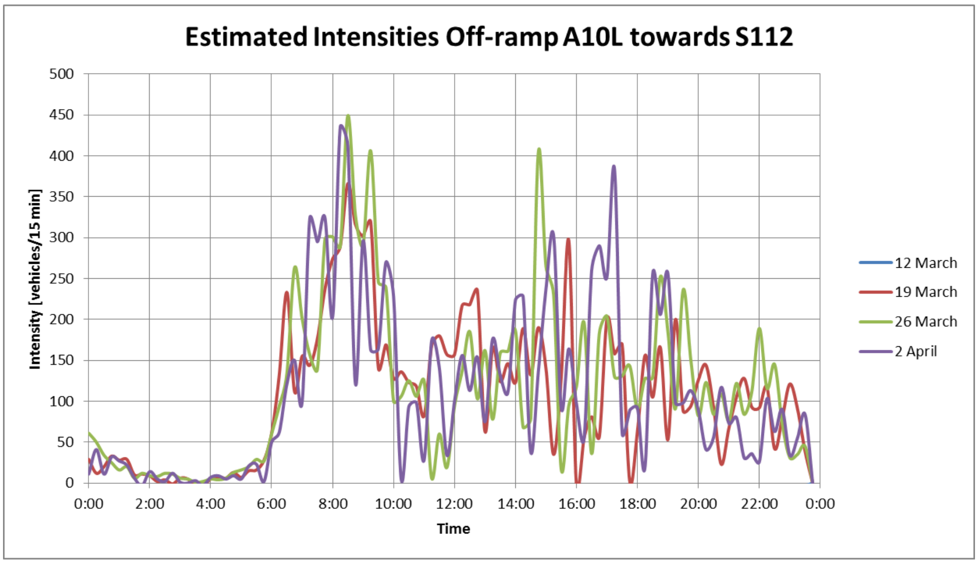

Intensities Off-ramp A9L Hm 9.17 to S112
Intensity [vehicles/15 min]
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
12 March
19 March
26 March
2 April


Intensities Off-ramp A9R Hm 8.657 to S112
Intensity [vehicles/15 min]
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
12 March
19 March
26 March
2 April


Intensities Off-ramp A10L Hm 14.775 to S111
Intensity [vehicles/15 min]
Time
19 March
26 March
2 April


Intensities Off-ramp A10R Hm 14.665 to S111
Intensity [vehicles/15 min]
Time
19 March
26 March
2 April

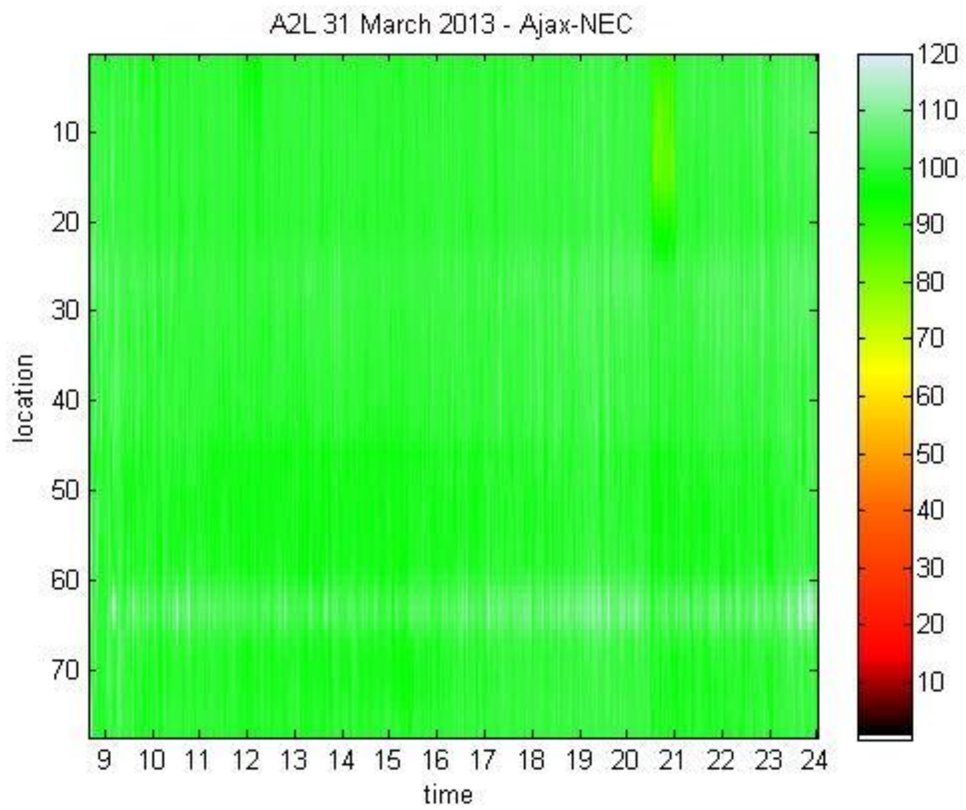

Estimated Intensities Off-ramp A10R towards S112
Intensity [vehicles/15 min]
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
12 March
19 March
26 March
2 April

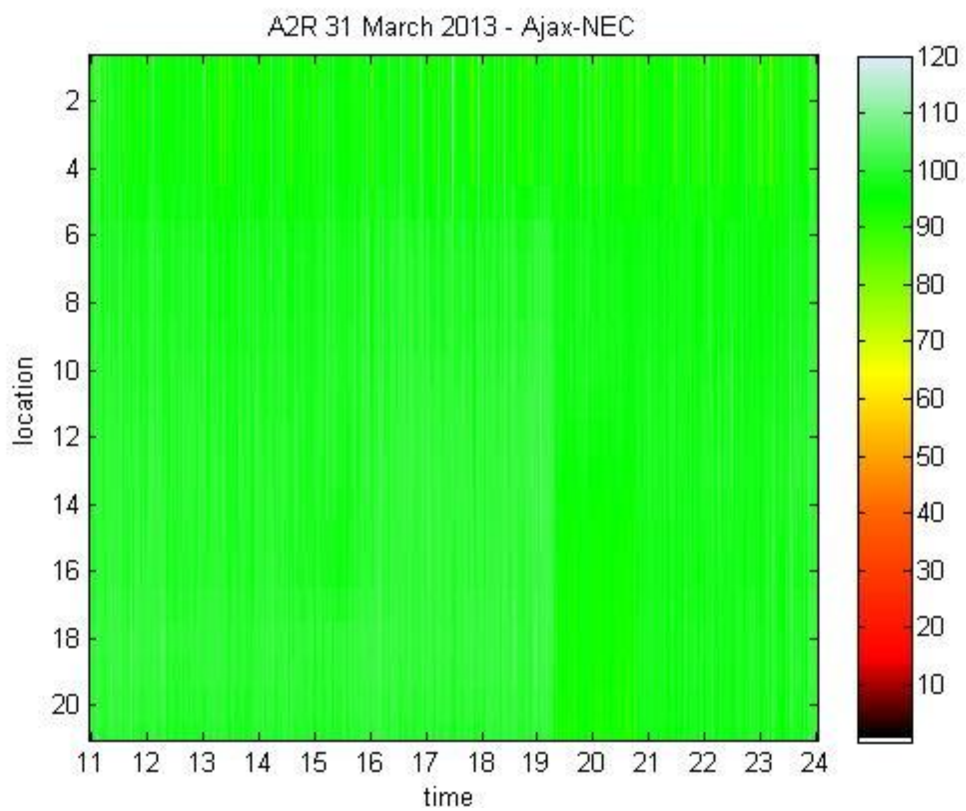

Estimated Intensities Off-ramp A10L towards S112
Intensity [vehicles/15 min]
500
450
400
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
12 March
19 March
26 March
2 April

B.7. Speed-contour plots of three scenarios

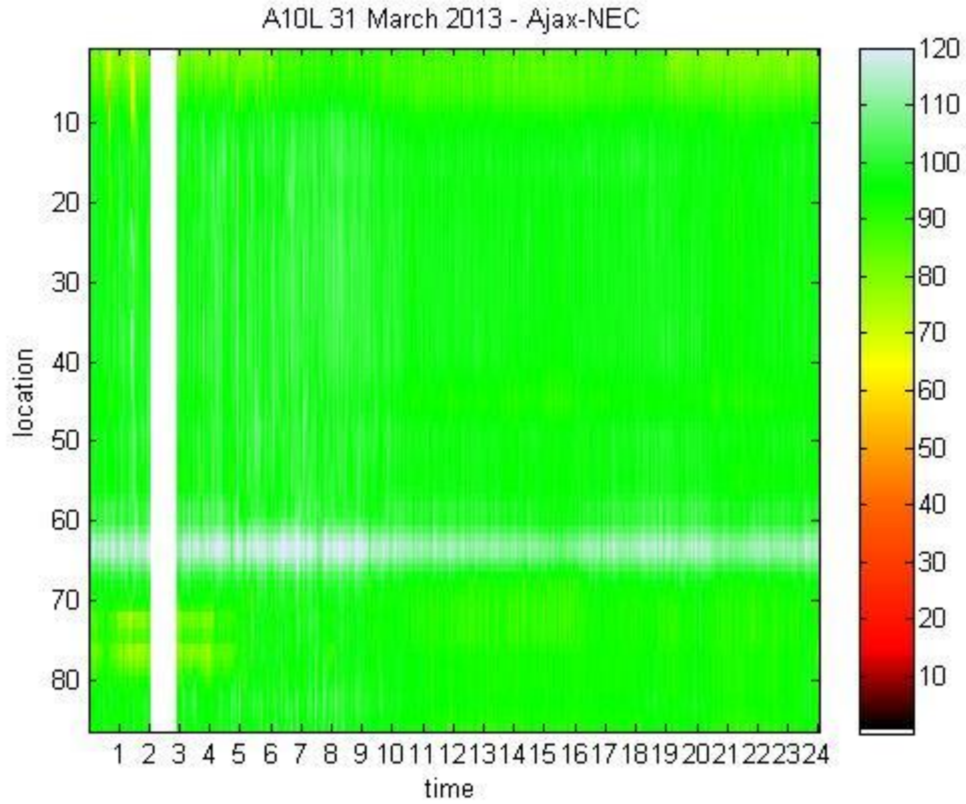
The speed-contour plots are given of highway A2 and highway A10 for the three scenarios. Data of highway A9 was not available for this research. Discussion about the speed-contour plots is given at the end of this section in B.7.7.

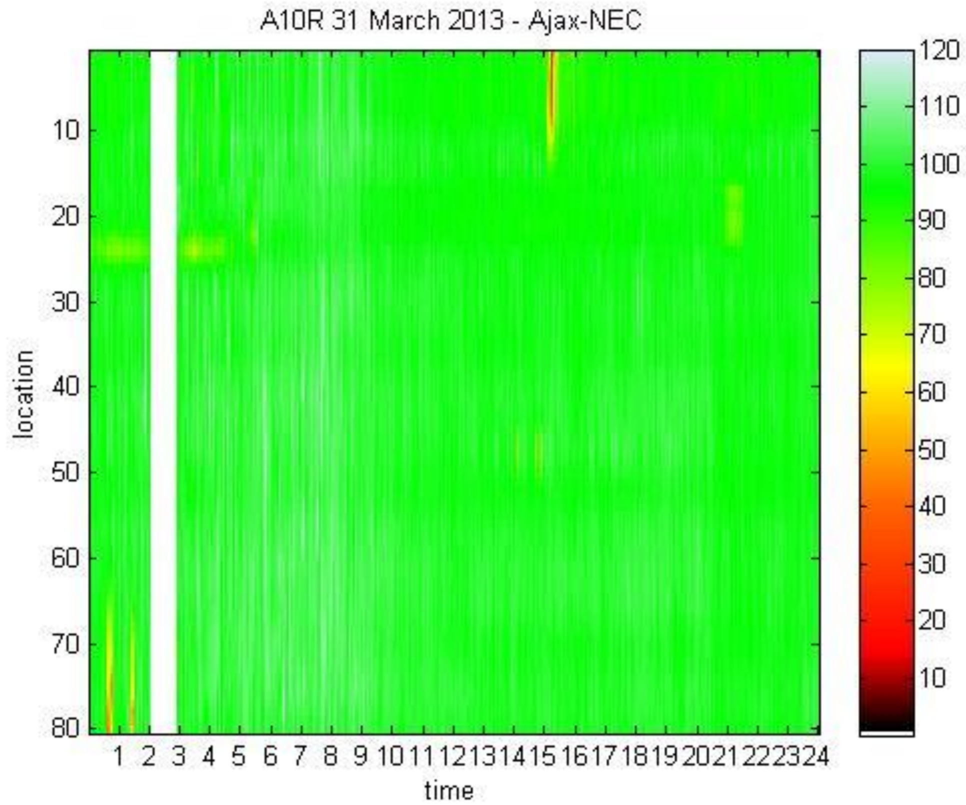
B.7.1. Ajax-NEC – highway A2



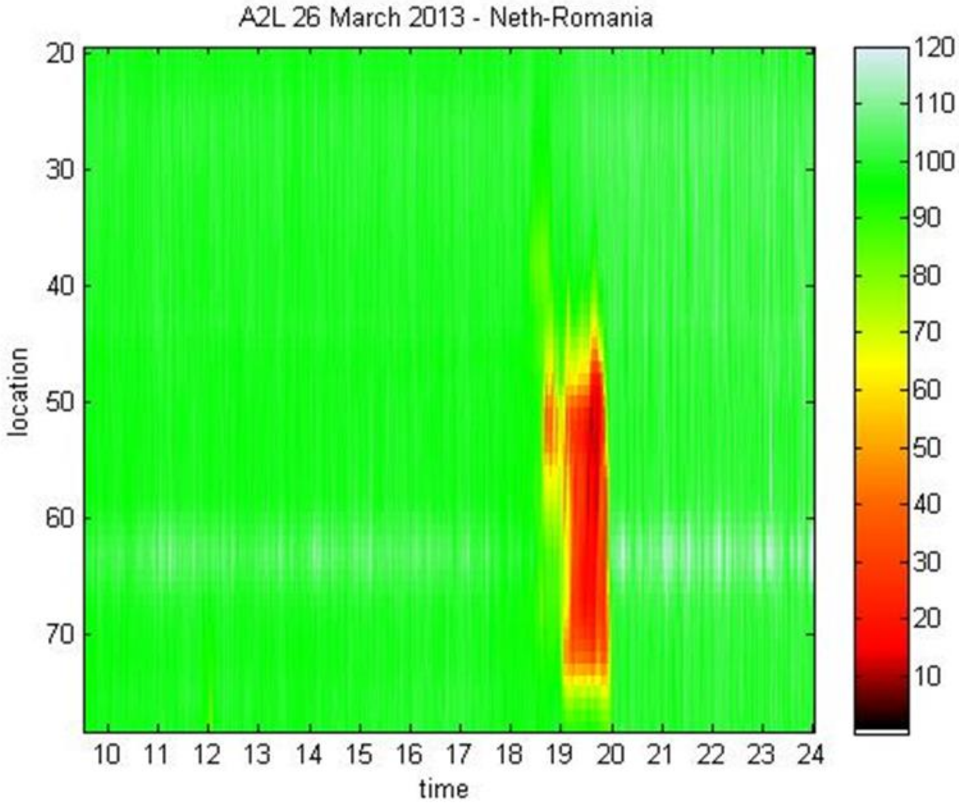


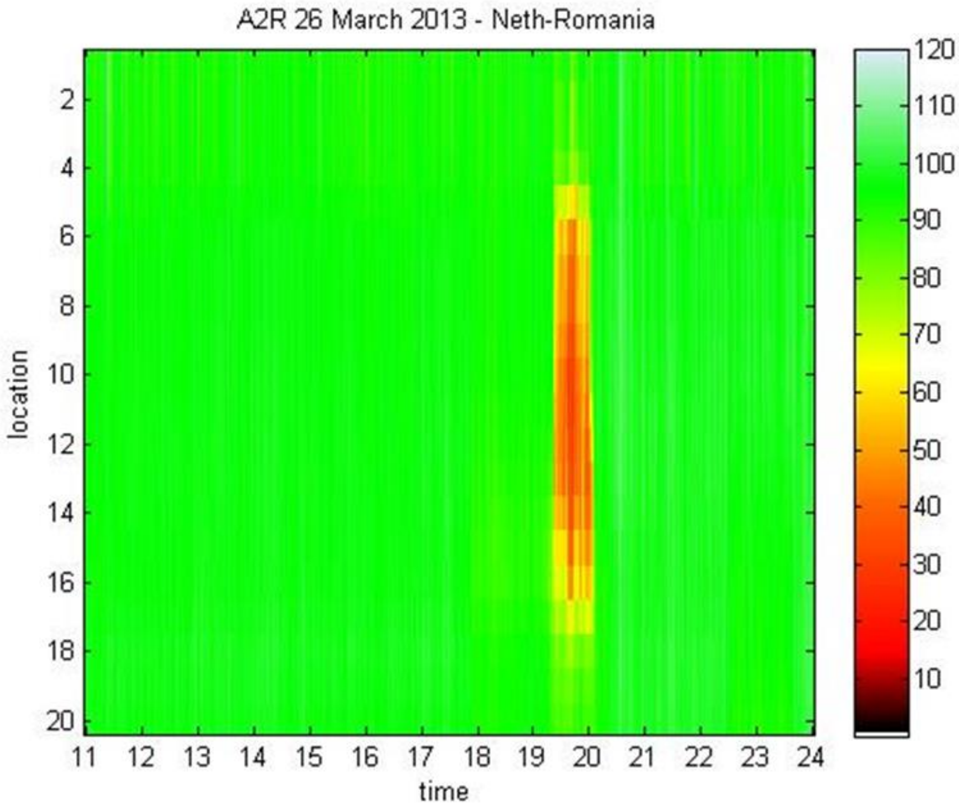
B.7.2. Ajax-NEC – highway A10



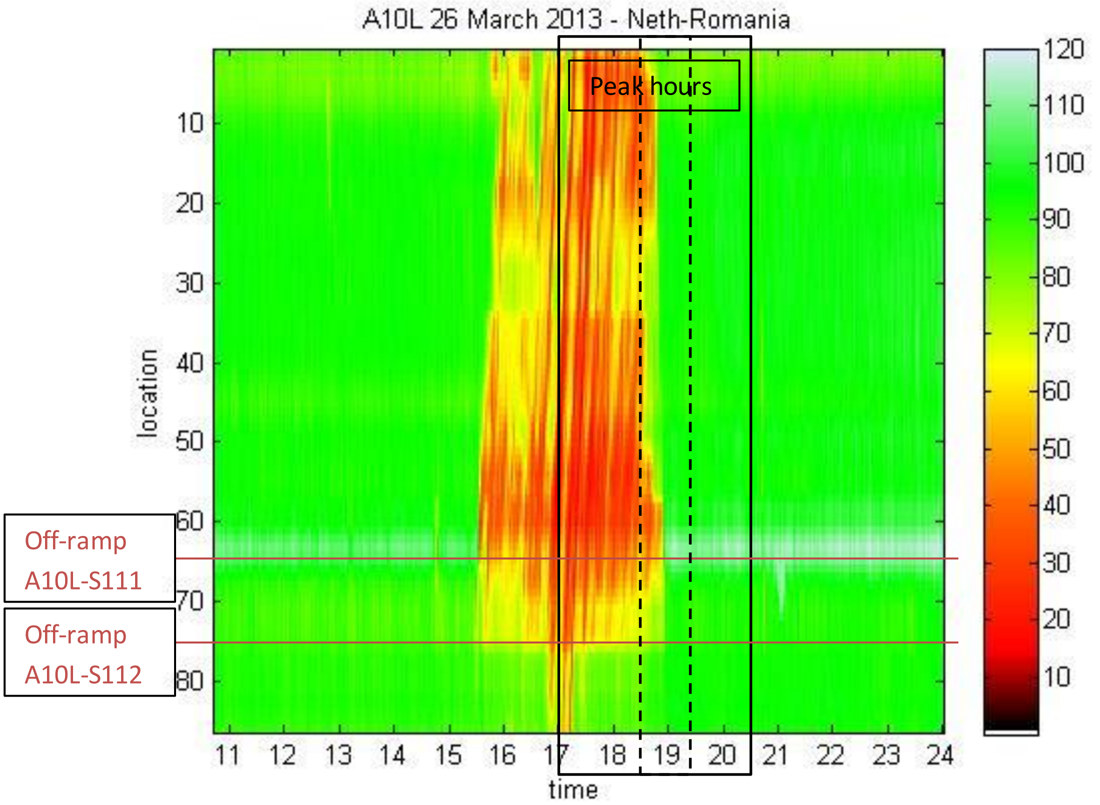


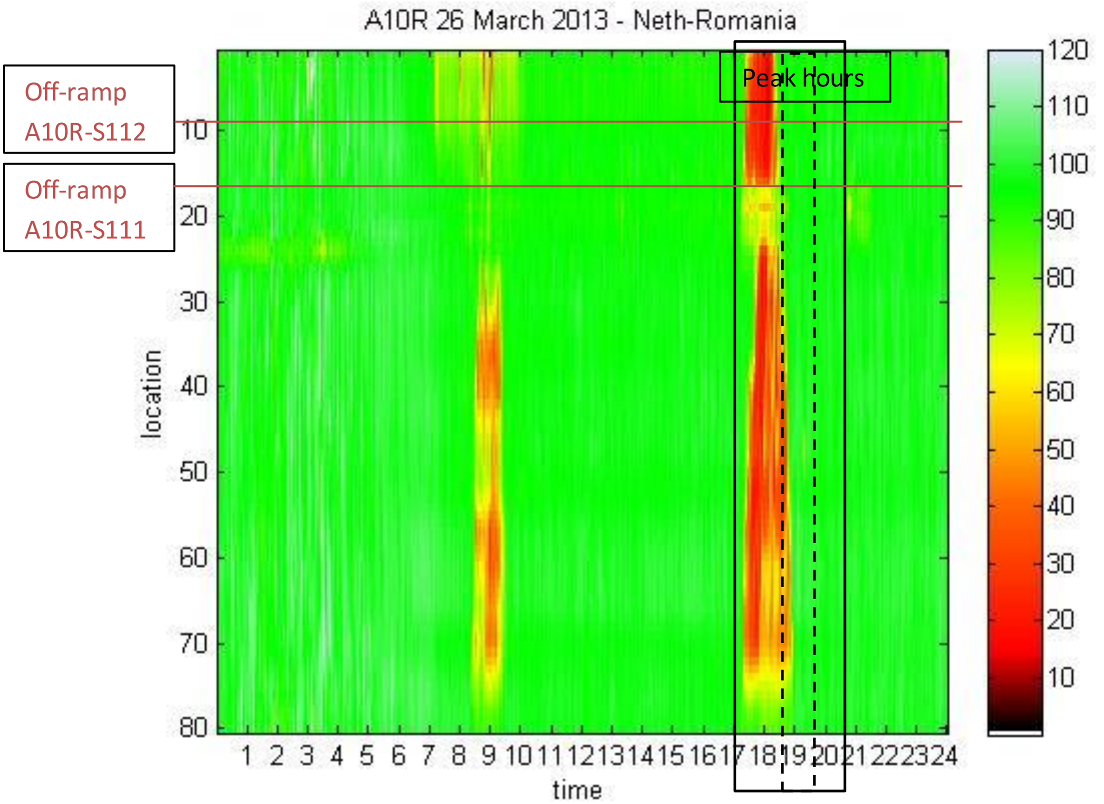
B.7.3. Netherlands- Romania – highway A2



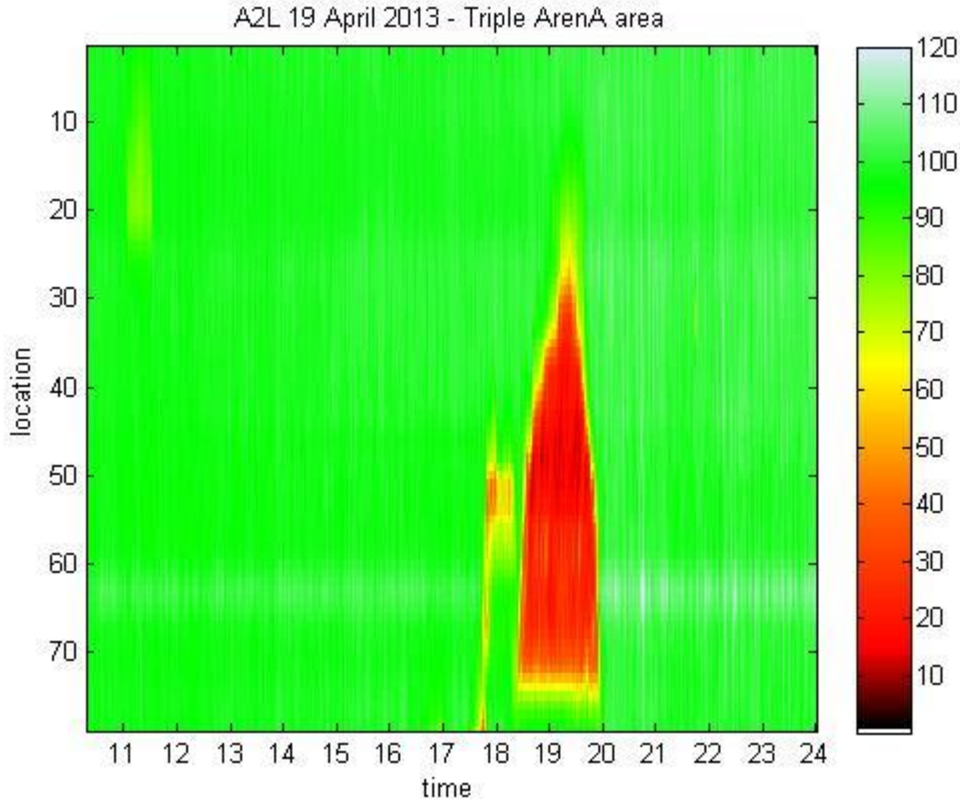


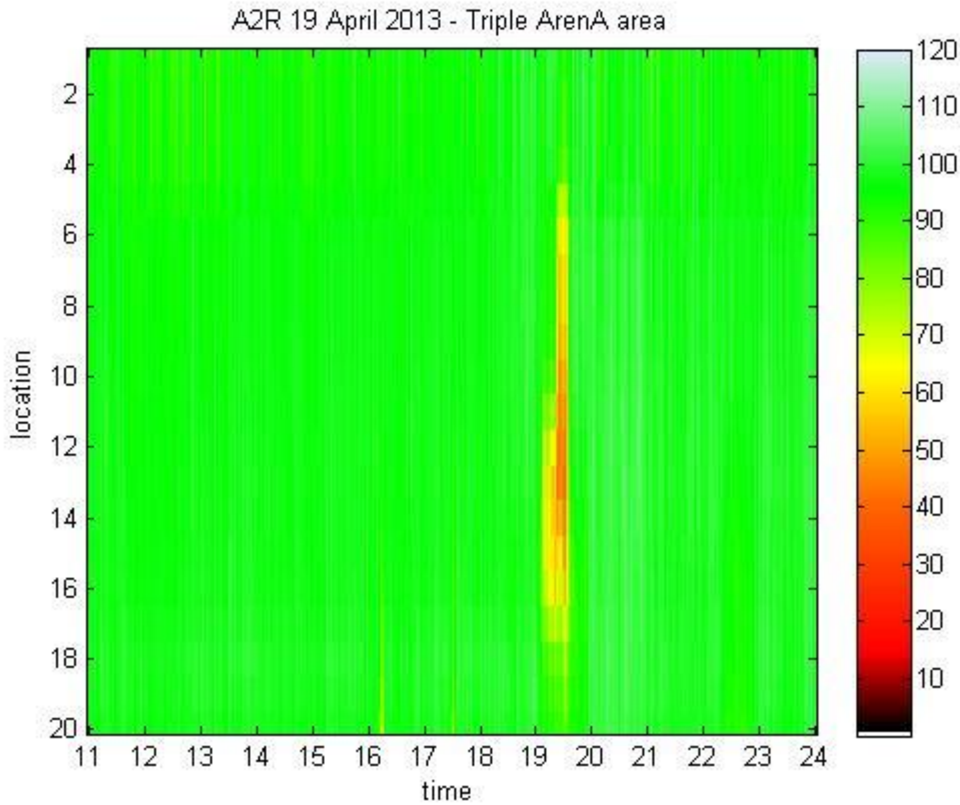
B.7.4. Netherlands- Romania – highway A10



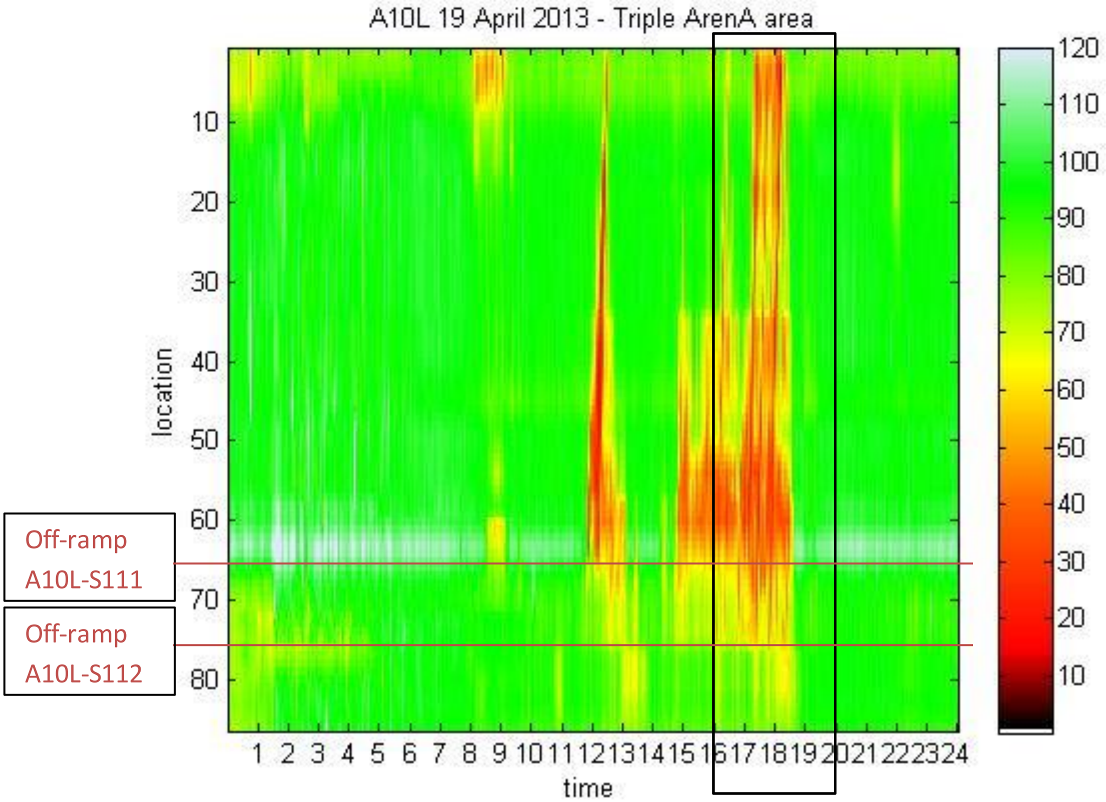


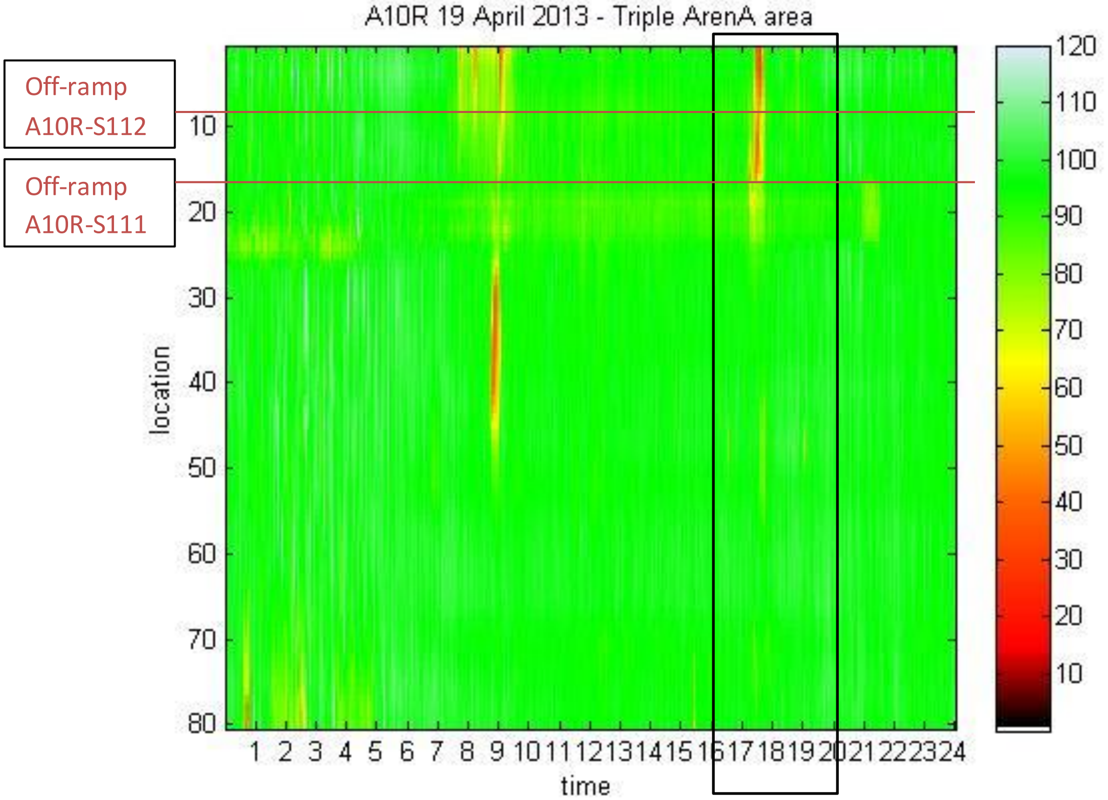
B.7.5. Triple – 19 April highway A2





B.7.6. Triple – 19 April highway A10





B.7.7. Speed-contour plots highway A10 25 & 27 March

The following speed-contour plots show the traffic situation on 25 March and 27 March 2013. This is one day before and one day after event Netherlands – Romania on Tuesday 26 March 2013.

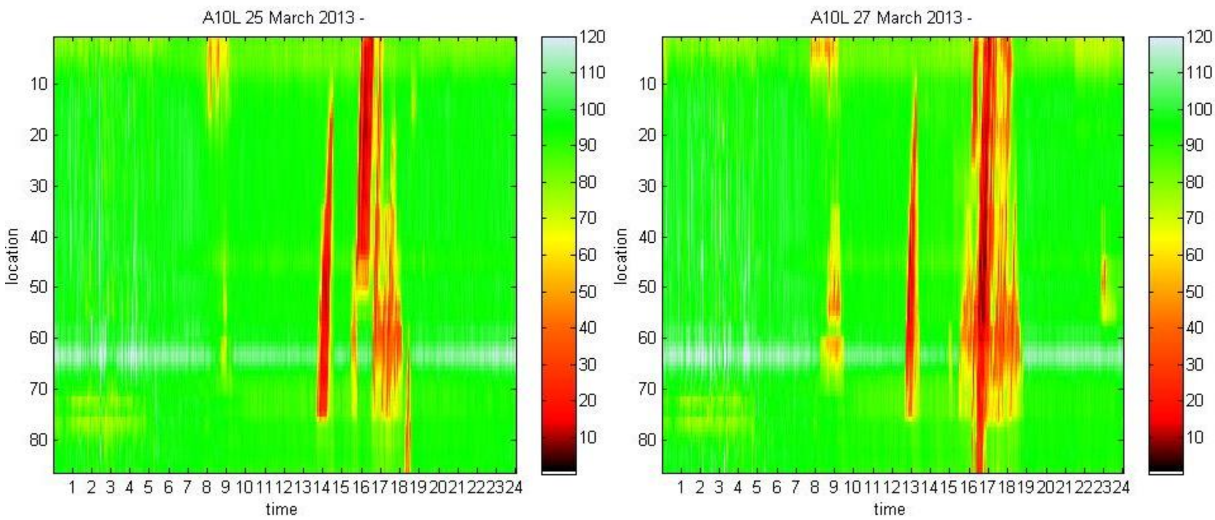


Figure 37: Speed-contour plot A10L 25 March (left) and 27 March (right)

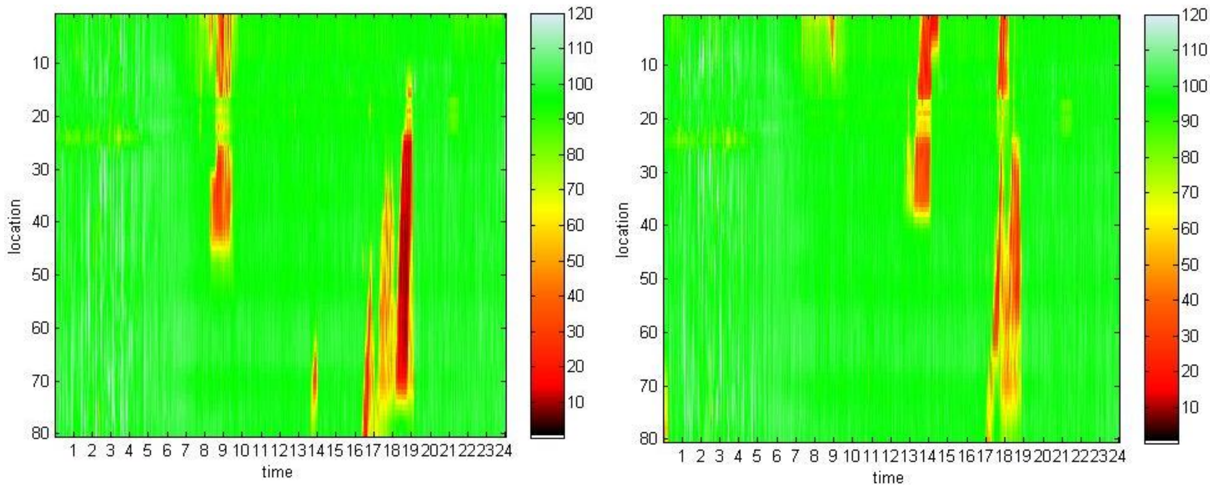


Figure 38: Speed-contour plot A10R 25 March (left) and 27 March (right)

B.7.8. Discussion speed-contour plots

First of all the speed-contour plots of scenario Ajax-NEC are discussed. The plots of highway A2 and A10 is no congestion visible. This means that event traffic travelling towards the ArenA area is not limited in their route choice because of congestion on the primary road network.

The speed-contour plots of scenario Netherlands-Romania and scenario Triple show congestion on highway A10 and A2 in both directions. Congestion on highway A2 is clearly caused by the inflow of event traffic. The congestion exists at the location of the off-ramp. Furthermore the time that congestion exists is right after a peak inflow at off-ramp A2. The cause of congestion at highway A10 is less obvious. Congestion is most of the time already there when the inflow of an event starts. The exception is congestion at A10R that looks to start at the location of the off-ramp. However, if we compare it to the inflow intensity at that time frame on the off-ramps we see that the inflow intensity is low. Furthermore the shape of congestion has no straight line horizontally. With other words; the congestion starts not at one specific point and therefore there can be deduced that congestion does not start at the off-ramp. The geometric design of the highway A10 exists of a lot of weaving sections and off-ramps and on-ramps. Besides that congestion occurs during the evening peak hours of regular traffic. Section B.7.7 shows the traffic situation the day before and after event Netherland –Romania. There was no event in the ArenA area during these two days but the traffic situation is comparable to Tuesday 26 March 2013. All together there can be concluded that congestion is caused by the high intensities of regular traffic.

B.8. Verification of "Analysis of the current situation in the ArenA area"

After the analysis of the current situation, described in chapter 4, the conclusion of the analysis are verified by the municipality of Amsterdam. Aafke den Hollander is traffic engineer at *Ingenieursbureau Amsterdam* and works partly at the municipality of Amsterdam to improve the inflow and outflow in the Amsterdam ArenA area. The verification conversation took place by e-mail.

Statements:

1. A concert in Ziggo Dome generally does not lead to congestion on the A2.
   Answer: True.

2. A football match of the Dutch national team always leads to congestion on the A2;
   Answer: True.

3. A football match of Ajax generally does not lead to congestion on the A2;
   Answer: True, and when congestion appears it is located on the off-ramps of the A2.

4. The cause of congestion on the A2 is spillback coming from parking facilities. This spillback reaches the Burgemeester Stramanweg and in the end highway A2.
   Answer: This is partly true. The cause of congestion is also 'zoekverkeer' in combination with the outflow of commuting traffic.

5. The bottleneck of the ArenA area is the inflow capacity [veh/time] of the parking garages or the capacity of the capacity of the parking garages.
   Answer: This is partly true. The bottleneck is also the capacity of intersections. Especially when there is outflow of commuting traffic and 'zoekverkeer'.

Questions:

6. Which parking facilities lead to spillback and so to congestion on the A2?
   Answer: P1 and P2

7. Which parking facilities do still use their barrier during the inflow of a parking facility?
   Answer: I think all parking facilities except for P12. But I am not really sure.

8. Do you know what the inflow capacity per parking facility is? It is assumed on 350 vehicles/hour/entrance based on NEN 2443. Do you think this is assumable?
   Answer: I don't know

9. Is the bottleneck during the inflow of an event sometimes the traffic lights at the end of off-ramp A2? Is that on off-ramp A2L (from the south)? On off-ramp A2R (from the north)? Or both?

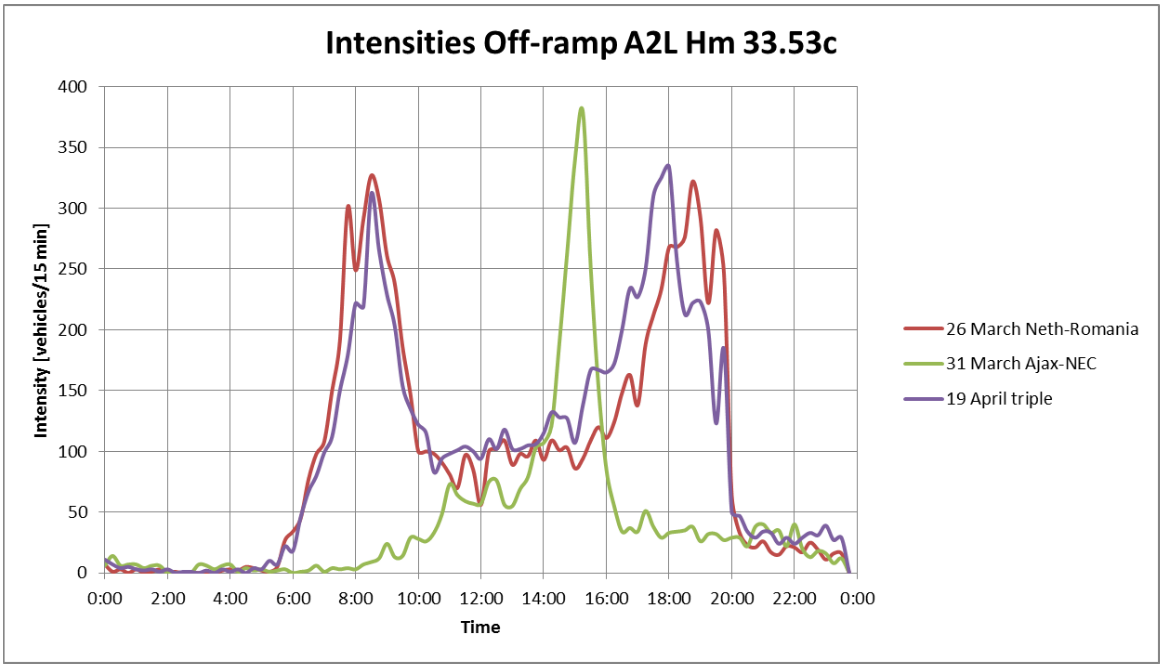
Answer: Mainly from the south A2L. The possible traffic throughput of the traffic light cannot handle the peak demand of event traffic.

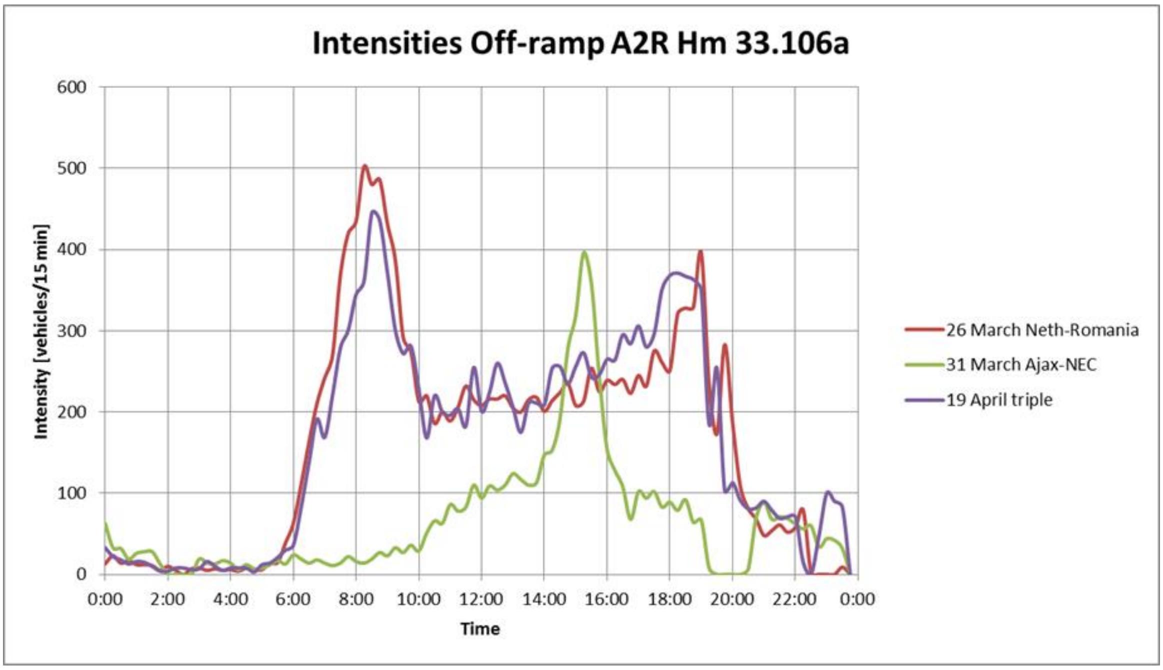
10. Is there sometimes congestion on the A9 or A10 caused by the inflow of event traffic?
    Answer: Congestion on A9 or A10 are caused by incidents or other extern effects, not by event traffic. The only weak point is the connection between A9-A2 (1 lane).

11. I suspect that Ajax supporters know how to spread themselves over the available parking facilities. The more unfamiliar drivers (e.g. concert visitors) will drive to the first best parking facility (P1-P5) and this will lead to spillback and so to congestion on highway A2. Do you think this is assumable?

    Answer: Yes. I would say parking facilities P1-P7.

B.9. Comparison of the inflow of three scenarios on off-ramp A2





C. Model approach

There are many possibilities to make a transport model. This section arguments the choice of the executed model software and executed model approach.

C.1. Executed model software

ITS modeller is designed to model the effect of road side and in-car systems. The disadvantage of this model is that currently not used in practice. A lot of errors in the model are not discovered or solved yet. Modelling the network and the strategy will cost a lot of time and in the end the question will rise if the output is sufficient to answer the main question; has the designed strategy a positive effect on traffic throughput? Another argument is the fact that the strategy is designed on a rather abstract level. In this research the algorithms for the real-time traffic situation to generate the route- and parking advice are not developed yet. Therefore the in-car system cannot be modelled into detail.

The model Indy, developed by TNO and TU Delft is a macroscopic dynamic transport model. It can identify bottlenecks, effects of spillback and it can give an estimation of travel time delay. However, the model is not able to incorporate the fact that a part of the travellers uses different information than others. This means that Indy is not able to test the effect of the designed strategy.

OmniTRANS is a sufficient model to show the current distribution over the network and to show the available capacity on the links. Here the modeling part of the strategy will be a challenge as well. Since Excel is a much more easy and clear software to work with, OmniTRANS is not chosen.

C.2. Executed model approach

One of the most common output of transport models is travel time. Such an approach can compare the output of the different scenarios and compliances rates of the strategy based on average and/or total travel times in the area. The travel time can be construct by in-car travel times on the primary road network, in-car travel times on the secondary road network and walking times to the ArenA. Besides that the delay - if travel time is bigger than free flow travel times – can be calculated. However, it is decided not to work with this approach and that has several reasons.

First of all, the bottleneck and capacity analysis in chapter 4 showed that the ArenA area has enough capacity to handle a peak hour of the majority of events. However, since visitors are not spread effectively over the network and parking facilities congestion occurs. The goal therefore is not to reduce vehicle lost hours (the goal of Amsterdam Practical Trial) but the goal should be to improve throughput. That is why it is interesting to have ‘throughput’ as indicator instead of ‘vehicle lost hours’. If delay is not an indicator, it does not have to be calculated as well.

Secondly, the model cannot be validated on travel times driven in the secondary road network. The only information that is available for this research about the secondary road network are the distances and free flow travel times given in Google Maps and many assumptions. An important question that needs to be answered when a complex model is used, is the accuracy of the output. As mentioned before, the input is limited.

In the end the effect of the strategy can be shown much more easier than a complex model of travel times, waiting queues and the effect of spillback on the network expressed in travel times. The effect of the strategy is in the chosen approach demonstrated with the indicator: the shortage of capacity per route per hour. The main report explains this approach.

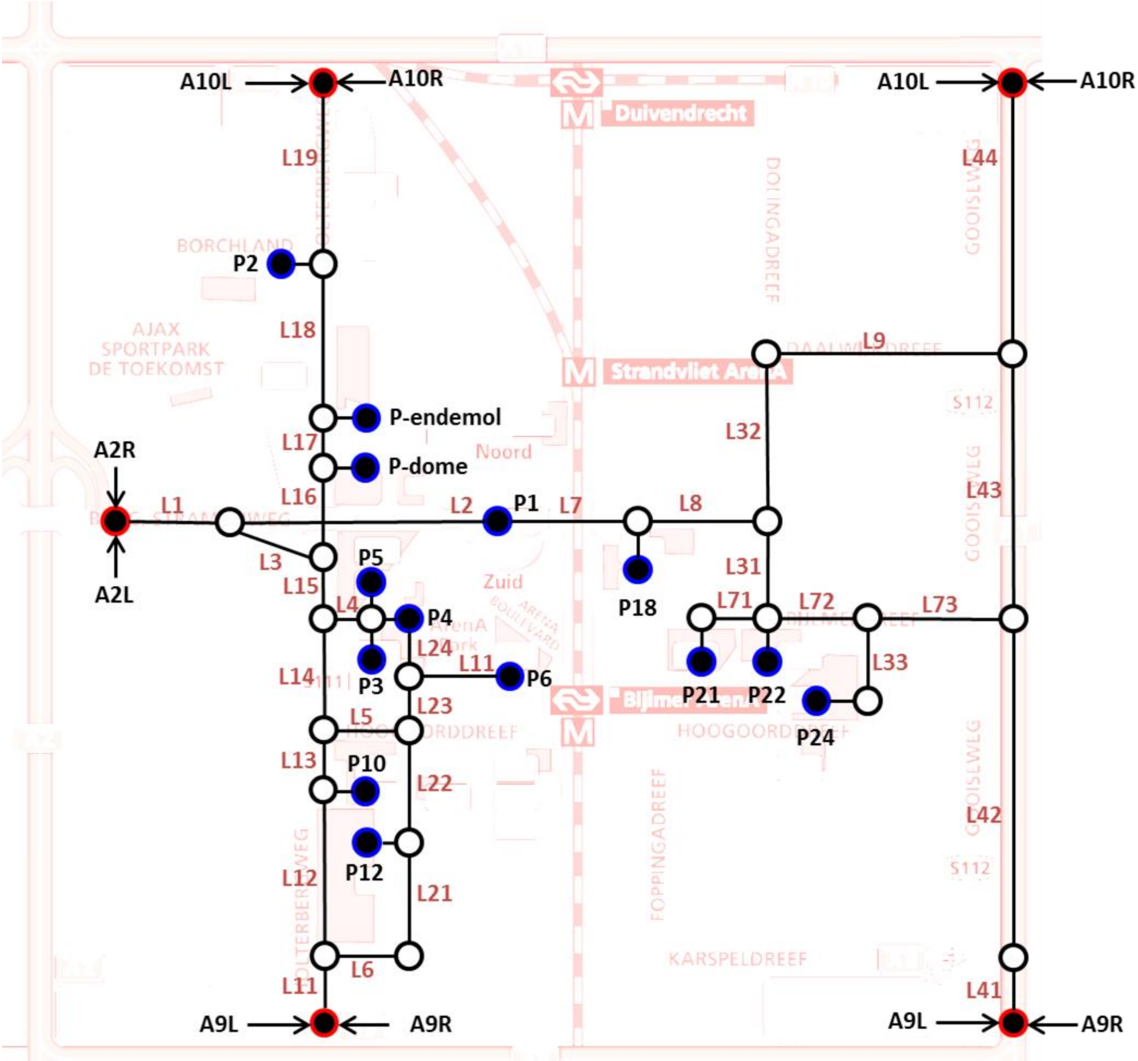
C.3. Logit method for parking choice model

There is looked into detail to use a Logit model for the parking choice model. It turned out that this model was not suitable for its purpose and so it is rejected. The logit model estimates the probability that a visitor coming from off-ramp O chooses parking facility P to park its car. It is based on the utility per O-P. A disadvantage is that a logit assignment cannot deal properly with overlapping routes/parking choices. It sees every combination O-P as a new route and a new parking facility. The utility function consist of betas and multiple variables. Only variables which are known could be taken into account. This means travel distance, number of turning movements, parking capacity and inflow capacity of parking facilities, parking cost and walking time from parking facility to the ArenA. The distribution of vehicles turned out to be unrealistic. The first reason is that the limitation of parking capacity could not be taken into account. This means that the model shows more vehicles choosing a certain parking facility than the capacity allows. Especially since overlapping choices – different origin (O) choosing same P - cannot be taken into account in a Logit model. Furthermore this method is that the value of the different betas should be theoretically founded. There is carried out many research about these values. However, this research is specified on a small area with typical variables. The values of the different values could not be found within the time of this research or are not determined in scientific research yet. The last reason to reject this method is that the characteristics of the infrastructure cannot be taken into account so far. An example is the utility of parking facilities P3-P5. All variables ensures that these three P's have a high utility. However, the infrastructure towards these parking facilities provides a limited capacity. Because all limitations the Logit model could not be incorporated in the model, it was not suitable.

D. Model input

This section contains the input of the model.

D.1. Secondary road network:



D.2. Capacity per links:

Link:	Coming from:	Capacity/ hour	Number of lanes	LT RT Cont	Factor	Green time	Sat. flow per lane	Capacity/ 15 min
off A2L	A2L	1656	2,5	LT	0,92	0,4	1800	414
off A2R	A2R	1325	2	LT	0,92	0,4	1800	331
off A9L	A9L	1490	1,5	RT	0,92	0,6	1800	373
off A9R	A9R	994	1,5	LT	0,92	0,4	1800	248
off A9L	A9L	684	1	LT	0,95	0,4	1800	171
off A9R	A9R	918	1	RT	0,85	0,6	1800	230
off A10L	A10L	1368	1	LT	0,95	0,8	1800	342
off A10R	A10R	855	1	LT	0,95	0,5	1800	214

off A10L	A10L	1836	2	RT	0,85	0,6	1800	459
off A10R	A10R	1325	2	LT	0,92	0,4	1800	331
L1	A2	5400	3	-	1	1	1800	1350
L2	L1	1800	1	-	1	1	1800	450
L3	L1	3600	2	-	1	1	1800	900
L4	L15	662	1	LT	0,92	0,4	1800	166
L5	L14	684	1	LT	0,95	0,4	1800	171
L6	L11	918	1	RT	0,85	0,6	1800	230
L7	L8	2160	2	-	1	0,6	1800	540
L8	L32	1836	2	RT	0,85	0,6	1800	459
L8	L31	684	1	LT	0,95	0,4	1800	171
L8-total		3600	2	-	1	1	1800	900
L9	L44	1530	1	RT	0,85	1	1800	383
L10	L24	1710	1	LT	0,95	1	1800	428
L10	L23	1530	1	RT	0,85	1	1800	383
L10-total		1800	1	-	1	1	1800	450
L11	A9	5400	3	-	1	1	1800	1350
L12	L11	2160	2	-	1	0,6	1800	540
L13	L12	2160	2	-	1	0,6	1800	540
L14	L13	2160	2	-	1	0,6	1800	540
L14	L15	2160	2	-	1	0,6	1800	540
L15	L3	1836	2	RT	0,85	0,6	1800	459
L16	L3	1325	2	LT	0,92	0,4	1800	331
L17	L16	2160	2	-	1	0,6	1800	540
L17	L18	2160	2	-	1	0,6	1800	540
L18	L17	2160	2	-	1	0,6	1800	540
L18	L19	2160	2	-	1	0,6	1800	540
L19	A10	1325	2	LT	0,92	0,4	1800	331
L21	L6	684	1	LT	0,95	0,4	1800	171
L22	L21	1080	1	-	1	0,6	1800	270
L23	L22	581	1	LT&RT	0,81	0,4	1800	145
L24	L23	684	1	LT	0,95	0,4	1800	171
L31	L72	1530	1	RT	0,85	1	1800	383
L31	L32	900	1	-	1	0,5	1800	225
L32	L9	1440	1	-	1	0,8	1800	360
L33	L73	684	1	LT	0,95	0,4	1800	171
L41	A9	3600	2	-	1	1	1800	900
L42	L41	3600	2	-	1	1	1800	900
L43	L44	3600	2	-	1	1	1800	900
L44	A10	3600	2	-	1	1	1800	900
L71	L31	1836	2	RT	0,85	0,6	1800	459
L71	L72	1080	1	-	1	0,6	1800	270

L71-total		3600	2	-	1	1	1800	900
L72	L73	0	1	-	1		1800	0
L73	L43	918	1	RT	0,85	0,6	1800	230
L73	L42	684	1	LT	0,95	0,4	1800	171
L73-total		1800	1	-	1	1	1800	450

D.3. Characteristics of parking facilities

Parking facilities	Total cap.	Inflow cap.	Walking time [min]	Costs/ event	Walking distance [m]
P1-west	2400	700	2	20	100
P1-east		700	2	20	100
P2	2010	780	9	12	600
P3	399	350	8	12	500
P4	1300	700	8	12	500
P5	1200	700	8	12	500
P6	399	350	5	12	300
P10	814	700	12	12	800
P12	296	350	12	12	800
P18	291	350	9	12	600
P21	450	540	9	13,5	600
P22	228	540	12	13,5	800
P24	487	540	15	13,5	1000
P-dome	550	350	3	20	200
P-Endemol	350	350	8	12	500
P-Amstelborgh	700	350	17	12	1100

D.4. Sequence of in-car route and parking advice

A10-west	destination:	off-ramp:	Sequence:
Preferences	P1-west	A2	1
	P-dome	A10-S111	2
	P6	A2	3
	P1-east	A10-S112	4
	destination:	off-ramp:	Sequence:
Preferences	P2	A10-S111	1
	P-Endemol	A10-S111	2
	P3-P5	A2	3
	P18	A2	4
	P18	A10-S112	5
	P21	A10-S112	6
	destination:	off-ramp:	Sequence:
Preferences	P10	A2	1
	P12	A2	2
	P-Amstelbor	A10-S111	3
	P22	A10-S112	4
	P24	A10-S112	5

A10-east	destination:	off-ramp:	Sequence:
Preferences	P1-east	A10-S112	1
	P-dome	A10-S111	2
	destination:	off-ramp:	Sequence:
Preferences	P18	A10-S112	1
	P21	A10-S112	2
	P2	A10-S111	3
	P-Endemol	A10-S111	4
	destination:	off-ramp:	Sequence:
Preferences	P22	A10-S112	1
	P24	A10-S112	2
	P-Amstelbor	A10-S111	3

A2-south	destination:	off-ramp:	Sequence:
Preferences	P1-west	A2	1
	P6	A9-S111	2
	P6	A2	3
	P1-east	A9-S112	4
	destination:	off-ramp:	Sequence:
Preferences	P3-P5	A9-S111	1
	P18	A2	2
	P18	A9-S112	3
	P21	A9-S112	4
	destination:	off-ramp:	Sequence:
Preferences	P10	A9-S111	1
	P12	A9-S111	2
	P10	A2	3
	P12	A2	4
	P22	A9-S112	5
	P24	A9-S112	6

A9-east	destination:	off-ramp:	Sequence:
Preferences	P6	A9-S111	1
	P1-east	A9-S112	2
	destination:	off-ramp:	Sequence:
Preferences	P3-P5	A9-S111	1
	P18	A9-S112	2
	P21	A9-S112	3
	destination:	off-ramp:	Sequence:
Preferences	P10	A9-S111	1
	P12	A9-S111	2
	P22	A9-S112	3
	P24	A9-S112	4