Design framework for network-wide traffic management strategies in urban traffic networks

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Master of Science Thesis

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The undersigned hereby certify that they have read and recommend to the Faculty of Civil Engineering and Geosciences (CEG) for acceptance a thesis entitled
Design framework for networkwide traffic management strategies in urban traffic networks
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Used terms

definitions

Traffic management	Collective term for all measures that can be taken in order to make optimal use of the available road infrastructure.
Traffic management instrument	Measures that can be taken temporarily in order to improve traffic conditions in a traffic network
Traffic management goal	The desired effects of traffic management
Indicator	Relevant traffic conditions indicating the effect of an instrument, at a specific location or set of locations
Networkwide traffic management strategy	A plan to coordinate instruments in a network for a specific traffic state
Traffic management design framework	Central in this thesis is the design of a methodology which structures the design of such a network-wide traffic management strategy. Such a methodology is called a *traffic management design framework*.
model area	complete set of modelled roads
control area	part of the model area where traffic management measures are considered
affected area	set of roads for which the traffic state is affected by traffic management measures
Ring	arterial ringroad around the city centre of Eindhoven. The ring consists of: Beukenlaan, Pastoriestraat, Onze Lieve Vrouwestraat, Insulindelaan, Kadeburg, Piuslaan, Loostraat, Boutenslaan and Limburglaan
Binnenring	Smallest ringroad, distributor road inside the ring accessing most important parking facilities in the city centre; the Binnenring consists of the Vestdijk and Wal
Travel time delay	difference between the speed limit and the average speed on a specific road

translation of terms

arterial	stroomweg
distributor road (collector road)	gebiedsontsluitingsweg
residential road	erftoegangsweg
excess traffic	sluipverkeer
residence attractiveness	verblijfsklimaat
PM10	fijnstof
high intensity pedestrian network	netwerk zeer drukke voetgangersstromen
primary cycle network	primair fietsroutenetwerk
motorway	autosnelweg
streaming space	opstelvak
congested road	kneltraject
Inbound arterial	inprikker
Sustainable traffic management approach	gebieds gericht benutten aanpak
Macroscopic fundamental diagram	Netwerk fundamenteel diagram
Traffic management design framework	verkeerskundige architectuur
BBZOB	Beter Bereikbaar Zuid Oost Brabant
GGB	Gebieds gericht benutten

Summary

The main goal of this research is to find an approach to assure both mobility- and policy goals in densely populated urban areas. Characteristics of these areas are a high amount of roads, a wide range of route choice possibilities and a large degree of entanglement with pedestrian- bicycle and public transport networks. Travel times are largely influenced by controlled intersections. The proposed traffic management design framework is applied in a case study in the city centre of Eindhoven. The objective in this thesis is:

Goal of this research is to develop a traffic management design framework for the development of traffic management strategies in urban traffic networks. The developed traffic management design framework is tested in the Eindhoven city centre network in a case study.

The research is divided into three parts. The first part discusses the proposed traffic management design framework. The second part presents the case study Eindhoven. In the third part the application of the framework to the case study is evaluated and conclusions are drawn. This structure is also maintained in this summary.

Theoretical framework

Traffic management design framework Traffic management problems in urban networks are complex. A traffic management design framework must be used to give structure to the process from noticing network problems to implementing traffic management strategies. A widely used traffic management scenario design framework in the Netherlands is the Sustainable traffic management approach (Gebiedsgericht benutten [6]). Several elements are added to make the GGB framework more suited for the design of traffic management strategies in urban networks. Application of the adapted framework framework results into a traffic management strategy for relevant traffic state in the tested traffic.

Traffic management strategy design Two elements are added to the GGB framework to improve the design process of network traffic management strategies which leads to more effective traffic management strategies. Traffic management instruments are designed separately at first. Leading in this design is the newly developed instrument design framework

(1). The newly developed instrument combination algorithm (2) must be used to combine the tested instruments into an effective traffic management strategy.

The assessment of separate instruments leads to expectations about the effects of combining effects of combining instruments. Also the separate instrument effects show the urgency to deploy new instruments. The instruments are simulated and optimized individually before they are combined into traffic management strategies. The problem analysis, traffic analysis and the instrument design framework form the tools to design the instruments. They are compared using the assessment framework.

There can be 3 goals for the combination of instruments. Effects on traffic conditions increase as instruments are combined (1), the affected area enlarges when separate instruments are combined (2) also negative effects can be mitigated by other instruments (3). The combined effect of instruments is assessed based on the separate analyses of instruments. For the focus area, a choice must be made. Combining instruments can either focus on a predetermined cordon, corridor or at a single location. Extra instruments can be implemented if it turns out that single instruments are not effective enough. When all conditions are met, it must be checked if there are no redundant instruments in the strategy.

Model selection and design When model predictions are used to design the actual traffic management strategies, it is important to use reliable simulation models. Therefore, model selection and design is added to the GGB-framework. Three important factors are indicated in selecting the model: model selection (1), model validation (2) and determination of the desired sample size (3).

The model objectives must be evaluated before the model suitability can be assessed. The type of model that is used must be suitable for the level of detail required in the model, for the collection of the desired data and for simulating the proposed instruments. A large number of simulation models is available. The chosen model characteristics must be evaluated to determine its suitability.

The model must be validated on the relevant characteristics for performance indication, for the validation of the traffic volumes in an urban network, the GEH statistic must be used.

If the model is valid, it can be used in the framework given that the right sample size is applied.

Theoretical contributions

The theoretical contributions in this research are:

- An adapted version of the GGB framework making it suitable for the structured search for traffic management strategies in urban networks.
- A method for the design of individual instruments in urban networks based on both traffic state as well as traffic management theory.
- An algorithm for the combination of individually designed traffic management instruments into a network-wide traffic management strategy.

Case study Eindhoven

The adapted design framework is applied to the Eindhoven city centre network in the case study. The city centre is considered the area inside the ring of Eindhoven.

Problem analysis There are five goals for the application of a traffic management strategy in the city centre of Eindhoven. The traffic flow on the roads in the city centre must be reduced as much as possible (Accessibility goal(1)). The amount of through traffic in the city centre must be as low as possible (Through traffic goal(2)). The travel speeds on the arterial roads around the city centre must not get below the accepted minimal speeds for these roads (Minimal policy speed goal(3)). Eight locations are selected where the one year average NO2 concentration can not get above 40 mg/m3 (Vehicle emissions goal(4)). Two intersections at the Binnenring must be monitored and the average waiting time for pedestrians cannot become below 20 seconds (Slow mode accessibility goal (5))

A control strategy on how to reach these traffic management goals is determined: the roads in the city centre must be made less attractive, while the Ring road around the city centre must be made more attractive.

Model selection and design A Paramics model of the city centre of Eindhoven is used in the research. Also some importantarterials in the greater Eindhoven area are included in the model. This model was already available and has been adapted for the specific demands of the case study. The most important change being that the size of the model has been reduced. The original model contained a detailed road network of the entire municipality and some roads outside the municipality. Public transport is also represented in the model. It is also possible to model pedestrians and vehicle emissions in Paramics. In this research however, pedestrian waiting times and vehicle emissions must be estimated using other parameters. The required sample size is three model runs per scenario.

assessment framework The assessment framework discusses how the policy goals can be applied to the model. Seven performance indicators are developed to assess the model results. The average traffic flow on city centre roads (1) and on ring roads (2) are measured to determine accessibility. Through traffic is measured on two important corridors in the city centre: north-south between the Boschdijk and the Leenderweg, and east-west between Kennedylaan/Eisenhowerlaan and the Karel de Grotelaan. Both traffic between these OD pairs over the Ring (3), as well as through the city centre (4) are measured. Roads are counted where the minimum policy speed is not matched (5). The minimal policy speeds in the reference situation is not met in almost half of all measured cases. Vehicle emissions are indicated by traffic flows at environmental locations (6). The average traffic flow should be below 2125 vehicles on average. This is 5% below the values in the reference situation. In short this means that these preconditions are not met in the reference situation. Local traffic flows at the indicated intersections are converted to average waiting times measuring slow mode accessibility (7). Average waiting time must be below 20 seconds, but already averages 22 seconds in the reference situation.

Traffic analysis A traffic analysis is performed resulting in an overview of problem locations in the city centre. Four different types of problems are found in the traffic analysis. There is a number of roads in the city centre where the traffic flow is too high (over 1000 veh/hr) (1). These locations are the Kennedylaan, the Fellenoord and the Binnenring. There are four clear bottlenecks (2) in the city centre, where average queues are long. There are also 3 Bottlenecks on the Ring, and 2 on the Eisenhowerlaan towards the ring. There are two roads in the city centre where the average speed is low: the Boschdijk and the Karel de Grotelaan (3) There are 2 important through traffic routes (4). North south between the Boschdijk and the Leenderweg, and East West between the Kennedylaan/Eisenhowerlaan and the Karel de Grotelaan.

Instrument design and -testing The problem locations are used to design a total of seven different instruments. The four instrument types that are considered are gating, speed reduction, blocking roads and adding lanes. There are two options for the implementation of gating. Both options aim at improving the average traffic speed and flow on the Fellenoord axis which goes through the city centre from east to west. In the first gating option the buffers are located at the intersections Leenderweg-Binnenring, Kennedylaan-Fellenoord and Boschdijk-Fellenoord. In the second gating option the buffers are located at the intersections Karel de Grotelaan-Limburglaan, Fellenoord-Kennedylaan and Boschdijk-Ring. Speed reduction is used to reduce the average traffic speed and the avarage traffic flow (indirectly) on the affected roads. There are three options for speed reduction. In the first option, the speed on the entire Binnenring is reduced from 50 to 30 kilometres per hour. In the second option both the Binnenring as well as the Mauritsstraat and Fellenoord are reduced from 50 to 30km/h. In the third speed reduction option, the average traffic speed is reduced on the Boschdijk inside the city centre. For blocking roads only one is tested. The Binnenring is cut into an eastern part and a western part which are both made accessible in both directions. The cut makes it impossible for traffic to use the popular through traffic route between the Leenderweg in the South and the Boschdijk in the North. The last instrument that is tested is the adding of an extra lane on the Karel de Grotelaan and on the Boschdijk.

Only two of the four tested instruments show overall positive results: speed reduction and blocking roads. The traffic flow through the city centre decreases on average 8% when speed reduction is applied and 6% when blocking roads is applied. Also the amount of through traffic on these routes decreases significantly. There is no instrument where all preconditions for minimal trajectory speeds, vehicle emissions and slow mode accessibility are met. Precondition values for the instruments do improve compared to the values in the reference model. Only speed reduction leads to an average waiting time for pedestrians at intersections below 20 seconds.

Combination of instruments The instrument combination algorithm is used for the combination of instruments. Only the two effective instruments speed reduction and blocking roads are combined into two different strategies. This is done in order to further decrease the traffic flow in the city centre. Both strategies include a 30k/h zone on the Binnenring, the Fellenoord and the Mauritsstraat, and the suggested cut in the Binnenring (this is called strategy 2). In one strategy the 30 km/h speed limit is also set on the Boschdijk (in strategy 1).

A decrease in average city centre traffic flow is measured as speed reduction and blocking roads are combined. When the Boschdijk is included, a total traffic flow decrease of 12% is predicted. If the Boschdijk remains a 50 km/h road, a 9% decrease in through traffic is predicted. More interesting than the average is to consider the morning- and afternoon rush separately. During the morning rush the traffic volumes are less than during the afternoon rush. The average traffic flow in the morning rush decreases by 5% in strategy 1 and 6% in strategy 2. In the afternoon rush the average traffic flow in the city centre decreases 18% in strategy 1 and 13% in strategy to. similar trends are also predicted for the change in through traffic. The slow mode accessibility criterion is met in both alternatives during the morning rush, but not during the afternoon rush. Whereas the vehicle emission target is only met during the afternoon rush for both alternatives. Based on the preconditions, the initial advice of including the speed limit reduction on the Boschdijk only during the afternoon rush remains unchanged.

Based on these results, separate recommendations are done for the morning and the afternoon rush. During the morning rush it is best to implement a 30km/h speed limit on the Binnenring, Fellenoord and Mauritsstraat, combined with a cut in the Binnenring. During the afternoon rush it is best to implement the same instruments as in the morning rush plus a 30km/h speed limit on the Boschdijk.

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Part I

Design framework

Chapter 1

Introduction

Urban traffic networks can be characterized by a high density of roads, a wide range of route choice possibilities and a large interdependence with pedestrian- bicycle and public transport networks. Travel times in traffic networks in densely populated areas are highly dependant on signal timings at intersections. Also the problems that occur in urban traffic networks deviate from problems in for instance regional traffic networks. Short travel times are only one of the goals, equally important is the attractiveness for pedestrians and people living, working and visiting in the area. One of the factors influencing these goals is a high accessibility of the city centre. Not only car accessibility, but also accessibility by bike, on foot and by public transport should be considered. Also the environment in terms of emissions and noise are important factors in urban networks. Stop and go traffic at high traffic volumes for instance, leads to high emission levels polluting the city. These characteristics demand for a specific traffic management design framework. The basis of this traffic management design framework is formed by the Sustainable traffic management framework (Gebiedsgericht benutten [6]) which is adapted for urban networks. This framework is adapted in this research to become more suited for urban networks. In order to test this new approach a case study is performed for the city centre of Eindhoven. This case study is presented in part II of this research. In this introduction to the master thesis, an introduction into traffic management is presented in section 1.1, the research goal and research questions are stated in section 1.2. In section 1.3 the research scope and research area are presented. The research approach can be found in section 1.5, and finally the contributions of this research are stated in section 1.4.

1.1 Introduction into traffic management

Traffic management is a collective term for all measures that can be taken in order to make optimal use of the available road infrastructure. During rush hours, road networks often reach their capacity and additional traffic management is necessary to avoid a system collapse resulting into reduced network capacity. Measures that can be taken in a network are called *traffic management instruments*, or in short: instruments. These instruments can be deployed temporarily, examples are traffic control at intersections, speed limit adaptations and dynamic route information panels. Instruments are deployed in order to reach a certain desired effect at a specific point, link, corridor or cordon in the network. The desired effects of traffic management are called *traffic management goals*. In order to decide whether traffic management goals are met, and when to deploy specific instruments, an insight must be gained in the traffic conditions. Relevant traffic conditions indicating the effect of an instrument, are called *indicators*. An indicator has a unit in which it is measured, and a specific value, and can also be bound to a specific location or set of locations. Often, traffic management goals will relate to parts of a traffic network or even entire networks. This means multiple traffic management instruments need to be deployed in a coordinated fashion. A plan to coordinate instruments in a network for a specific traffic state is called a *network-wide traffic management strategy*. Central in this thesis is the design of a methodology which structures the design of such a network-wide traffic management strategy. Such a methodology is called a *traffic management design framework*.

1.2 research goal

Goal of this research is to develop a traffic management design framework for the development of traffic management strategies in urban traffic networks. The developed traffic management design framework is tested in the Eindhoven city centre network in a case study.

research questions

Given the research goal, the following research question is formulated:

Which traffic management design framework can be used for the development of a coordinated traffic management strategy in urban networks in general and for the Eindhoven city centre in particular?

The main-question is be split up into the following sub-questions:

1. Which traffic management design framework can be used in order to design network wide traffic management strategies in urban networks?
2. Which method can be used to select effective traffic management instruments in urban networks?
3. How can separate traffic management instruments be implemented in a coordinated way; resulting into a network wide traffic management strategy in the defined problem area in order to realize the traffic management goals?
4. How can the instrument design framework be implemented in order to reach the traffic management goals for the city centre of Eindhoven?

1.3 Research scope

This research focuses specifically on urban traffic networks with a high concentration of activities and transport modalities on a relatively small area. The instruments used in this research are limited to the off-line application of traffic measures. This means that the shifting between control scenarios does not happen real-time/on-line; but is only done in between model runs.

An important part of the research is also testing the proposed instruments in the Eindhoven case study. In order to test the proposed instruments, microsimulation is used. The model that is used is derived from the model that Grontmij has used in the past for solutions for the municipality of Eindhoven, which is built in the microsimulation environment Paramics. Traffic demand over the network is considered to be fixed, meaning effects on exogenous variables influencing the traffic demand such as modal shift towards public transport or slow modes cannot be assessed. Also additional policies; for instance encouraging road users to avoid rush hours, road pricing, and also the possibilities of the high quality public transport in Eindhoven, are not further considered. They could however be used for the same goals as traffic management. Policy focus on public transport for instance could release pressure of the road network by decreasing traffic demand. These types of policies also need to be developed and encouraged besides this research.

1.4 Research contributions

The most important contributions resulting from this research can be divided into two categories: specific contributions to the Eindhoven case, and generic traffic engineering knowledge. Both categories are present in this report. Generic contributions that are made in the report are:

- An adapted version of the GGB framework making it suitable for the structured search for traffic management strategies in urban networks.
- A method for the design of individual instruments in urban networks based on both traffic state as well as traffic management theory.
- An algorithm for the combination of individually designed traffic management instruments into a network-wide traffic management strategy.

Contributions to the Eindhoven case are:

- An overview of estimated traffic situation in the network for the year 2020, including the problem locations and the severity of these problems.
- Specific network-wide traffic management strategies for the city centre of Eindhoven.

1.5 Report structure

As stated in the previous section; this research consists of a theoretical part, which is illustrated with the application of the proposed theory to the city centre of Eindhoven. In chapter 2, a traffic management scenario design architecture is developed and a theoretical framework for designing specific measures is presented. The basis for this framework is formed by the sustainable traffic management approach (GGB [10]) which is commonly used in the Netherlands, in addition to this, a traffic measure development framework is proposed, also a method for combining several measures into a complete traffic management scenario is proposed. In the second part, from chapter 3 until chapter 8 the developed framework is applied to the Eindhoven case study following the proposed steps in the framework. In the third part, the research approach and the case study are evaluated. In chapter 9 the implications of the case study results to the proposed traffic management design framework are elaborated. The conclusions and recommendations of the research are presented in chapter 10.

Chapter 2

Design approach

In this research, the development of traffic management strategies in urban networks is considered. This chapter presents a framework for the development of traffic management strategies in city centres. The development of such a framework is done in 3 steps; first, a traffic management design framework is developed, within this framework, instruments need to be developed and these instruments have to be combined in the final stage. The 3 subquestions which are subsequently discussed with these steps are:

- *Which traffic management design framework can be used in order to design network wide traffic management strategies in urban networks?*
- *Which method can be used to design traffic management instruments in urban networks?*
- *How can separate traffic management instruments be implemented in a coordinated way; resulting into a network wide traffic management strategy in the defined problem area in order to realize the traffic management goals?*

An existing approach for the design of traffic management strategies is the sustainable traffic management approach (GGB approach [6]). In section 2.1 this method is described and adapted for application in urban networks. How the use of simulation models can be positioned in the chosen traffic management design framework is discussed in section 2.2. Section 2.3 summarizes the available traffic management instruments for urban networks. How the instrument effects can be used for the design specific of traffic instruments is described in section 2.4. Section 2.5 describes how the separate measures can be tested separately. Finally, the Chapter conclusions are summarized in section 2.6.

2.1 Traffic management design framework

In this section, the traffic management development framework is presented. The research question that is answered in this section is:

Which traffic management design framework can be used in order to design network wide traffic management strategies in urban networks?

The GGB approach is an excellent starting point to design a traffic management design framework which is specifically suited for application in densely populated urban areas. This framework is common practise in the Netherlands for complete traffic management strategies in which accessibility, safety and quality of live are anchored. Several specifications are added to the GGB-framework giving more structure to the actual design of traffic management instruments in urban networks. These additions result into a different focus in the framework. The GGB approach itself is still used, but the focus in the urban network adaptation is shifted from the organisational focus towards the design and assessment of instruments. This section starts with a description of the sustainable traffic management framework. Then, the differences between a typical sustainable traffic management problem and traffic management problems in urban networks are pointed out. Based on these differences, an adapted framework is constructed which is described step by step in the final part of this section.

Sustainable traffic management framework The GGB framework consists of 9 steps in which the complete process from policy goals towards applied traffic management measures is carried out. Multiple parties are already involved in the project start-up, in this first step, the general goals for the study are determined. Specific widely supported traffic management goals are determined in the second step (policy starting points), resulting in the project outlines. In the third step, the control strategy is determined. The general policy goals are translated into specific traffic management goals. These qualitative goals are made operational in the reference framework in step 4, where measurable variables are used to determine performance indicators. The reference situation can be evaluated based on this framework in step 5, both the locations of bottlenecks as well as possible buffer locations are important in this step. These locations are specified and prioritized in step 6 (bottlenecks) resulting in the *description actual situation and bottlenecks* (dutch: Nota feitelijke situatie en knelpunten). The solution approach to these bottlenecks is determined in step 7, services. In this step a complete set of services is determined. There is a separate step in the framework in which the services are translated into actual measures. Also the prioritization of the measures is developed in this step, as not all measures will be implemented immediately. In the project finishing, all step results are put together into one document. Also the future continuation of the policy is explicitly described in this step [10].

Urban network additions The GGB approach offers an effective tool for the design of traffic management strategies. This is also applicable for the type of urban networks considered in this research. Therefore, the GGB approach is used for the design of traffic management strategies in urban networks. However, there is no method specified in the GGB to coordinate multiple instruments in a network in a way that they supplement each other. By adding several specifications to the framework, this coordinated combination of instruments and the quality of the resulting traffic management strategy in urban networks can be assured. Additions are a new design methods for traffic management instruments and -strategies in this framework, the framework becomes more valuable for application in urban networks. Also a method is offered to select a simulation model to assess the traffic management strategy results. The new additions offer a handle to come up with solid network-wide traffic management strategies.

Both the standard GGB framework and the framework with focus for urban networks are shown in figure 2.1. The most important additions to the GGB framework are indicated with a dark-green colour.

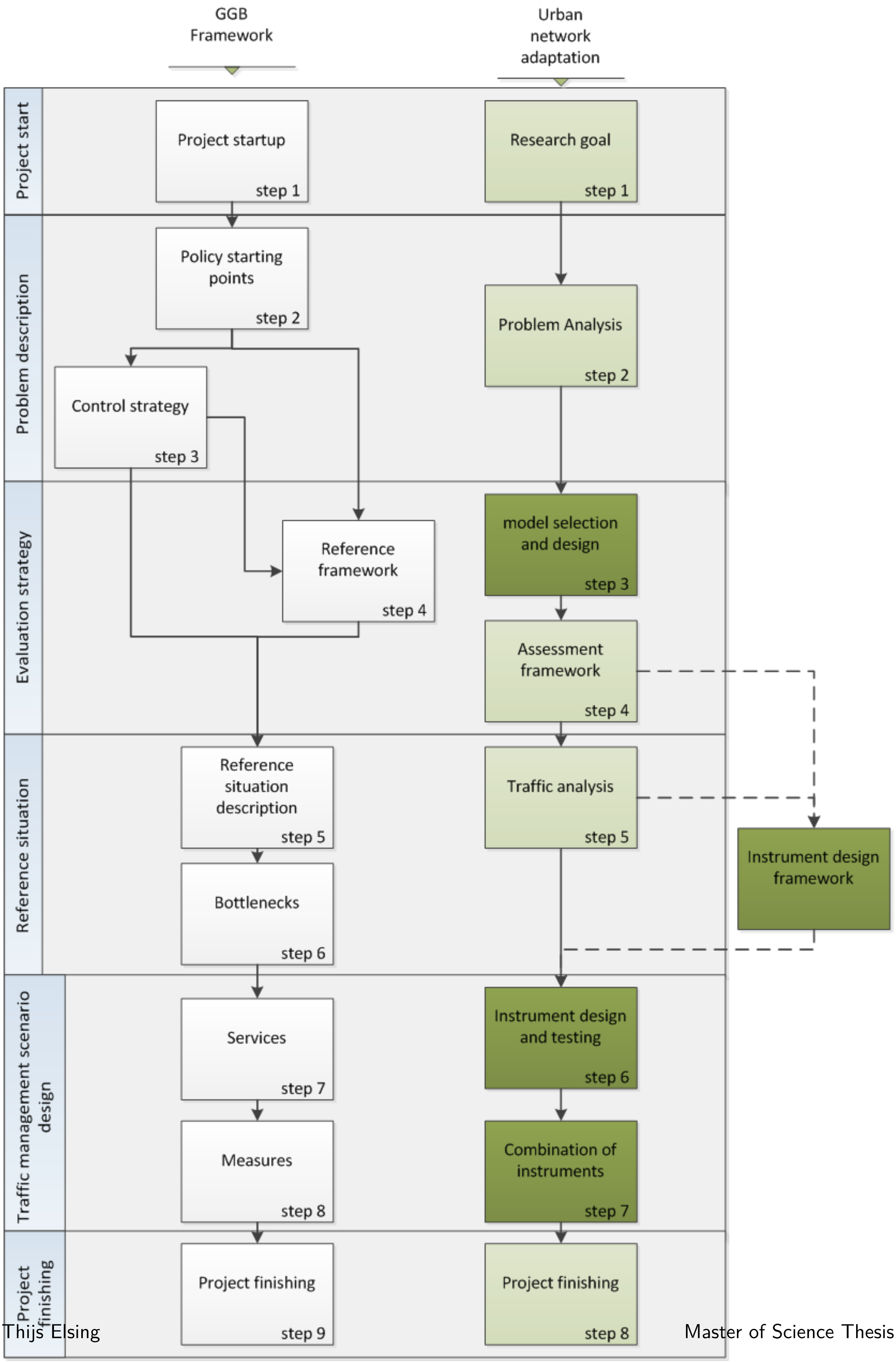

Figure 2.1: Adaptation of the GGB framework aimed at urban networks, steps marked dark green are discussed in detail in this chapter.

In urban networks, the number of involved parties is smaller than in regional networks. The only road authority is typically the municipality. If the number of involved parties is smaller, the focus can be more towards the actual design of instruments and strategies given the fact that the perception of the problems and control strategy can be more clearly determined as opposed to problems at a regional scale where there can be conflicting interests between different road authorities. The GGB approach is typically used in larger scale projects with more of a regional character. Therefore, the process of determining policy starting points can be less time consuming. The public interest is an important factor in urban network and should be clearly anchored in the policy goals and translated into a control strategy. These steps can both be executed by the same road authority. To balance the step sizes, they can be seen as one step. In the adapted framework.

Another adaptation to the GGB framework is the addition of a model selection step, models that are suitable for evaluating instrument effects on a regional scale are not necessarily suited for urban networks. It is important to be aware of the model requirements when selecting a simulation model.

The reference situation description and bottlenecks are joined in the traffic analysis, this traffic analysis should result in a aggregated bottleneck overview of the network.

The final important difference between the two approaches is that in the urban network approach, instruments are first tested and designed separately before they can be combined. The hypothesis is that this leads to better insights in the effects of separate instruments, making it more easy to come to a well-grounded combination of different instruments. For the design of instruments a design method is proposed. Based on the separate instrument results, an algorithm can be used to come to a network-wide traffic management strategy.

Additions to the GGB framework are:

- Model selection is internalized in the framework.
- An instrument framework is designed which can be used for the selection of traffic management instruments in urban networks.
- A method is specified for the design of traffic management instruments.
- An algorithm is specified which can be used to combine traffic management instruments into networkwide traffic management strategies.

Below, all steps in the adapted framework are discussed in short, the model selection and design, instrument design framework, and combination of instruments step are later discussed more extensively in section 2.2 until 2.5.

1 - Research goal The first step towards the design of a traffic management strategy in urban networks is the understanding of a traffic management problem and a problem description. This can be seen as the first step of the framework. The first step differs between both frameworks, as in the GGB framework, multiple parties are being involved in the first step. In the adapted framework, the research is most likely being initiated by the road authority.

2 - Problem analysis In the problem analysis, the complete set of policy goals related to the network is determined. This step elaborates on the goals which are indicated as being important in the problem statement. An overview is presented where the problems are likely to occur. Accessibility, vehicle emissions and slow mode accessibility are important factors. Also noise, modal split and traffic safety can be relevant in urban networks. The location and size of these problems is investigated, this can be done by summarizing available research and policies for the area. The main result of this research step is to identify traffic management goals. These goals consist of two parts: an overview of the current status of the goals as set for the network, and an area specific control strategy. In the control strategy, it is determined what the traffic management goals should be given the specific traffic state in the network. This step corresponds with the policy starting points and control strategy in the GGB framework.

3 - Model selection and design In order to test the proposed measures, a simulation model is needed. Based on the goals in the problem analysis, model requirements can be obtained. The model should be able to adequately measure all goals in the reference situation. Also the model should be able to calculate the effects of the proposed measures. Not only the focus area itself should be modelled, but also main arterials around this area. In this step, the model is also calibrated and validated. More about model selection is discussed in section 2.2. In the original GGB framework, the simulation model is not explicitly included as a step. Building a model can best be seen as the first step towards building a reference framework (GGB step 4).

4 - Assessment framework In order to be able to successfully assess the performance of the proposed instruments *and* alternatives, key performance indicators have to be determined in order to do this. The policy goals are translated into traffic variables which can be obtained from the simulation model. The reference values of the performance indicators are determined based on model results. The reference values form the basis of a multi criteria analysis in which all instruments and alternatives can be compared. The activities in this step correspond to the reference framework in the GGB approach.

5 - Traffic analysis In this step a detailed analysis of the traffic state in the reference situation is done; bottlenecks and possible buffer locations are analyzed. The result of this step is an overview of the different actual bottlenecks and problem locations for the different traffic phenomena. By linking these to the problem locations, desired services can be determined. The traffic analysis corresponds with steps 5 and 6 in the GGB framework: reference situation description and bottleneck analysis.

Instrument design framework This is not a step in the actual process, but as instrument design framework, the framework presented in section 2.3 can be used as input to develop and test the instruments in the instrument design. Instruments can be designed on basis of the established goals in the traffic analysis, these can form the primary intended effects. Any other effects of the instruments are secondary effects. The design variable values determine the instrument effects and location of the effects.

6 - Instrument design and testing In this step, specific individual measures are developed. The bottleneck overview of the traffic analysis, and the performance indicators in the assessment framework form input. The design framework can be used to select available measures. These measures can be selected and tested, based on the test results, the instruments need to be further improved. The result of this step is a collection of several individual measures which contribute to the improvement of the traffic network goals. The multi-criteria analysis scheme which is developed in step 4 can be used to compare the measures with each other.

7 - Combination of instruments In this step, a combination of instruments is made in order to further improve the measure results. There are multiple possible strategies conceivable for combining the instruments. The end product of this step is a number of traffic management strategies which can be used to effectively improve the traffic state in the network. The traffic management strategies can be compared using a multi criteria analysis.

8 - Project finishing In the project finishing, a complete strategy can be determined, policy recommendations are done and future research possibilities can be identified.

2.2 Model selection and design

The applied simulation model determines the quality of the research results. If the model is not suitable an effective traffic management strategy cannot be designed. This means that the selection and design of the simulation model must be thorough. The RBV (Regionale Benuttings Verkenner, [21]) model was developed specifically for the GGB approach. The RVB is basically a plug-in for the OmniTRANS software. The RVB software is one of the models that can be used for application in urban networks. It is however possible that other simulation models are more suited. This depends on the goals and instruments applied in the research. This section elaborates on how to assess if other simulation models can also be used for the design of traffic management strategies using the adapted GGB framework.

This step can be subdivided into 3 parts in order to come to a model which is ready to use and analyse traffic data, the model selection, the model validation and the determination of the required sample size.

2.2.1 Model selection

A simulation must be selected using simulation study objectives. Two aspects are relevant for the selection of a suitable model: the model objectives which are determined in the problem analysis (1) and the classifications of the simulation model itself (2).

Model objectives

The model that is selected must be suited for the assessment of possible traffic management instruments and -strategies that are proposed in the relevant traffic network. Three relevant aspects can be identified that describe to the model objectives of the simulation study. [26]

Detail level and model area For any urban network different user types will be relevant and different types of infrastructure facilities (for instance dedicated bus lanes and bycicle lanes.). Also the simulation area is important to determine, this must be big enough to model realistic behaviour in the study area, and should often be bigger than the study area.

Needed data The effects must be measured follow from the problem analysis. These indicators can be flow and speed, but also queue-length and individual travel times and route choice. Also other effects can be measured in some models such as vehicle emissions etcetera.

Instrument simulation The traffic management instruments must be known and must be applicable in the model that is to be used. Traffic management instrument can be categorized as static or dynamic. Also model predictive control is possible. In urban networks, many instruments are applied at intersections, and require the model to cope with for instance roundabouts and traffic responsive intersection control.

Model classifications

There is a large amount of simulation software available. A traffic network can often be modelled with whatever software is available. It is important to assess the suitability of the proposed model. In order to do this, the model can be classified based on its functionality, but also the model principles can be relevant for the validity of the model. The model classifications and the model objectives must be compatible.

Macroscopic versus microscopic Microscopic models describe individual behaviour of vehicles whereas macroscopic work with the macroscopic variables traffic flow, traffic speed and traffic density. Both macroscopic and microscopic models can be applied for urban networks. The description of traffic responsive behaviour at controlled intersections is not possible in macroscopic models. This is not problematic in itself but when a macroscopic simulation model is considered. It must be possible to apply all desired instruments in such a model. The model must be suited to apply accurate performance indicators. If this is not possible in a macroscopic model, a microscopic model must be used.

Route choice behaviour Route choice must be modelled in urban networks. Route choice depends on the utility of the different routes. Several aspects can be considered in utility function. Travel time is most important, but also aspects such as familiarity and road function must be considered. Route choice can be assigned pre trip in both a user optimum or a system optimum. In order to come to a realistic route choice if it is assigned pre trip, multiple iterations are needed. A more dynamic option is to adapt the route choice en-route as traffic conditions in the network change. Advantage is that only one model run is needed to come to a reliable route choice distribution. If variable message signs are deployed as an instrument. The route choice in the model must also be VMS-responsive.

Traffic assignment The assignment of traffic to the network can be statically, but with dynamic network loading, departure time choice and -location can be varied depending on the traffic conditions. The traffic network needs to be bigger if the traffic assignment is static.

Intersection control Intersection control is important in urban networks, travel times are largely dependant on queueing at intersections and also queue-lengts are often a relevant indicator. Most intersections in urban networks are traffic responsive. For dynamic traffic management application control schemes must be changed during the model run.

2.2.2 Model validation

Once the model is chosen, it needs to be validated. Model results are only predictions and real world results could deviate from these results. In order to make sure the model results approach the real situation, the model needs to be validated. According to van Lint et al. [12], 3 types of validity can be distinguished: face validity, content validity and predictive validity (see figure 2.2). Face validity means that the equations, parameters and characteristics are suited in order to tackle the research problem. This can be tested by checking if the model fits the model requirements. Content validity means that model results are consistent with observations in reality. This is tested in this report using several methods such as GEH values and travel time comparisons. Content validity needs to be proved after the model is selected Predictive validity means that the predictions that are made by the model are consistent with the actual evolution of the system. This can only be tested if the model predictions are compared to actual the autonomous development of the actual system.

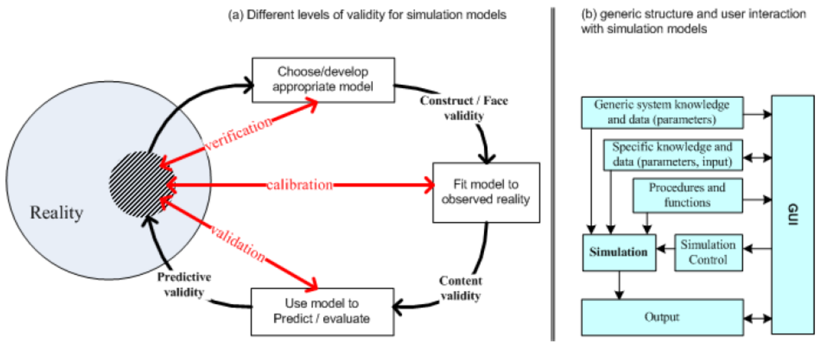

Figure 2.2: Validity of a simulation model [12].

The fact that there is always a certain uncertainty in model predictions should be considered in the evaluation of model results and the implications of these results. Although simulation studies are a powerful tool, they should always be viewed as a tool, not as the decision maker itself. Model outcomes should always be reviewed in the context of the available knowledge and insights.

Validation using the GEH statistic

In order to determine the construct validity of the simulated traffic volumes in the model, choosing a single accepted percentage of deviation in the traffic volume would not be fair. Links with low traffic volumes would have an overestimated impact on the validity of the model. To overcome this problem, the GEH statistic can be used which is shown in equation 2.1.

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}} \tag{2.1}$$

Where:

- GEH = GEH statistic, used to compare 2 sets of traffic volumes, name derived from Geoffrey E Havers.

- M = Average traffic flow on a specific link during 1 hour in the subarea cordon model
- C = Average traffic flow on a specific link during 1 hour in the original model

This is an emperical formula which is only reliable if traffic volumes are converted to traffic flows. The Wisconsin microsimulation modelling guidelines [18] give an indication of when a model is valid based on this GEH statistic; when this value is below 5 for a specific link, the traffic flow for that link is considered valid. This statistic is used for checking if the new OD matrix is correctly built and for comparing link counts.

2.2.3 Sample size determination

The predictive power of the model increases as the sample size (number of times the model is ran per alternative) increases. The desired amount of model runs depends on the desired confidence interval for the relevant variables in the model. Based on the desired confidence interval, the standard error of the sample consisting of the results on one variable in multiple model runs, the desired sample size can be calculated using equation 2.2 [7].

$$n > \frac{Z^2}{d^2}\sigma^2 \tag{2.2}$$

Where:

n : desired sample size.
Z : value depending on desired confidence interval.
d : size of the confidence interval.
σ : the standard error of the sample.

The confidence interval is different for each variable in the model. It is impossible to base the sample size on all variables. Therefore it is wise to select a limited number of variables which are relevant for the research goals and need to be measured to assess the model results. These must be used to determine te desired sample size.

2.3 Instrument design framework

A key difference between the original sustainable traffic management framework, and the urban network adaptation is the way traffic management instruments are designed based on the reference situation. For the design of instruments in this adapted framework, a specially designed framework can be used. This instrument design framework is presented in this section. With this instrument design framework, the following sub-question is answered:

Which method can be used to design traffic management instruments in urban networks?

In order to get a fundamental understanding of urban networks, the theory of macroscopic fundamental diagrams can be used, this diagram is discussed in section 2.3.1. In the traffic measure framework in section 2.3.2, traffic engineering phenomena, goals and available measures are structured. A top down logic is presented in order to categorize traffic management instruments. How this framework can be used for the design of specific instruments based on a traffic analysis is described in section 2.4.

2.3.1 The generic macroscopic fundamental diagram

A useful approach in order to describe traffic conditions in urban networks, is to consider the network at an aggregate level. Generic rules at network level can be used to define a strategy to improve traffic flow in the network. In order to predict the traffic behaviour in urban networks at an aggregate level, the *generic macroscopic fundamental diagram* (g-MFD) was developed at the TU Delft [23] from the original MFD which was already proposed by Godfrey in 1969 [24]. In the g-MFD the key traffic variables can be correlated for a network section or an entire network, just as is done for individual roads in the standard fundamental diagram. The number of vehicles in the network, the density, and the spatial variance of the density in the network, or spreading, can be used in order to predict the exit rates in the network. The visualization of this relation is shown in figure 2.3, where the g-MFD for the A10 around Amsterdam is shown. The highest network flow for this particular network (indicated by colour red in the figure) can be realized with a traffic density of about 60 vehicles per kilometre where the spatial variance of the density is as low as possible. Based on the g-MFD two approaches of increasing the exit rates of an urban network can be considered; optimizing traffic density in the network, and decreasing the spatial variance in the network. Another reason for the decrease of spatial variance in the network is that bottlenecks have the tendency to cluster together in a network. This approach of urban traffic networks, can be used in the next subsection when traffic phenomena and traffic measures are linked. Specific Macroscopic fundamental diagrams can be used for macroscopic modelling urban networks in which very few of the variables are used. Based on real time traffic densities, specific control strategies can be used applied to the situation. How specific instruments can be deployed based on traffic density information and a network specific g-MFD is discussed later in this section.

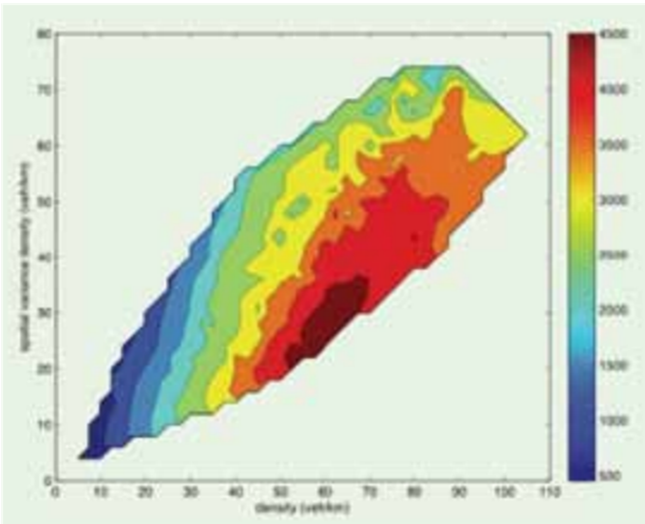

Figure 2.3: Average flow in urban network predicted by the Spatial variance in density(km/) on the vertical axis and the density (veh/hr) on the horizontal axis [23].

2.3.2 Traffic management instrument overview

The traffic management instruments can be structured in a *traffic management measure framework* as shown in figure 2.4. The layers in this framework each correspond with a step in the adapted urban network design framework which has to be done before instruments can be developed. The goals are determined in the problem analysis where both the problem locations and the control strategy are relevant. Desired services can be determined with the traffic analysis. And performance indicators are determined in the assessment framework. The final step of designing the actual instruments is described in section 2.4.

In the traffic management measure framework , the identification of possible instruments starts with the identification of the major traffic phenomena that can influence the traffic situation in an urban network.

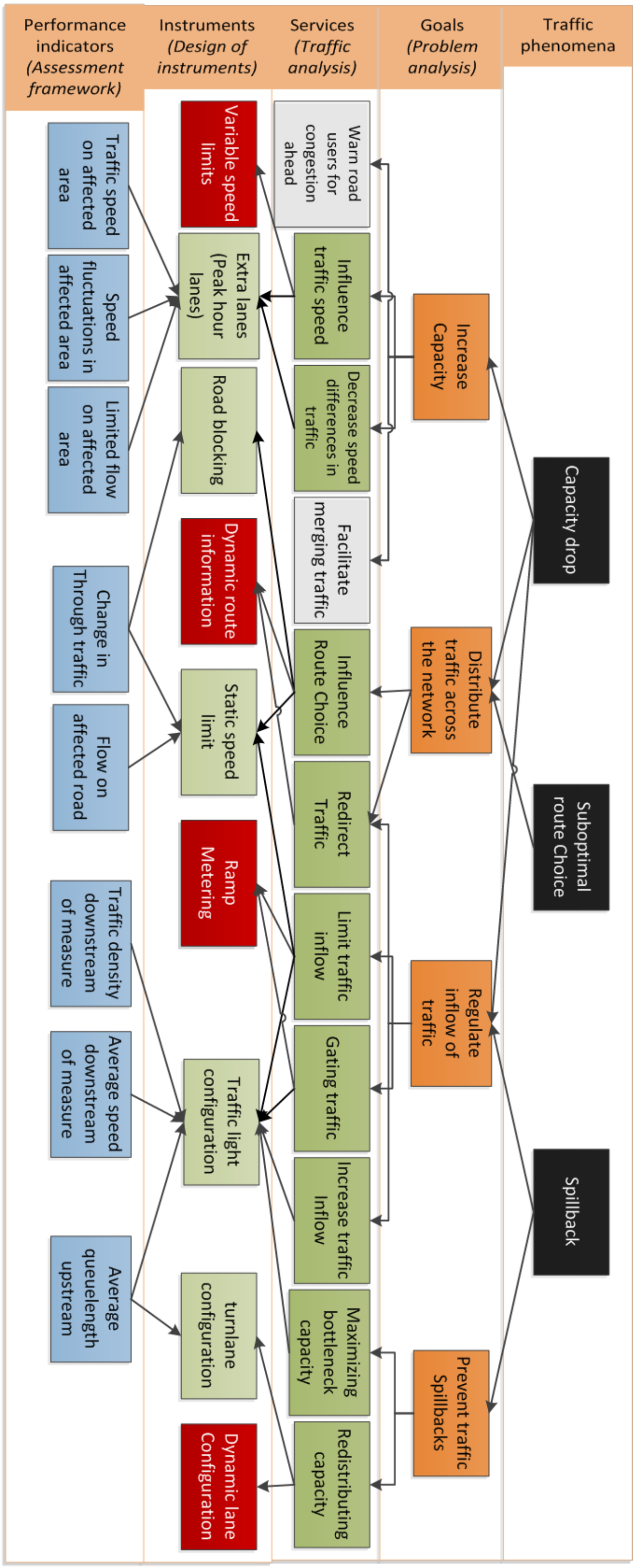

Figure 2.4: Overview of traffic management goals, services and instruments, red boxes indicate instruments that are only applicable for on-line traffic control.

Traffic phenomena

There are a few different phenomena which can cause congestion in a network. For urban networks, the main phenomena in urban networks are stated:

- *Spillback* - Spillback occurs when a queue emanating from a bottleneck obstructs the traffic flow at an upstream location. In an urban network this can also lead to a network wide capacity drop resulting in dramatic increase of travel times.
- *Suboptimal route choice* – What optimal route choice is, depends on the goals set for the traffic network. For high exit rates, traffic should be divided over the network homogeneously. This can increase the total traffic output of the network. However the system optimum is not always equal to the user optimum. Also road users are not always fully informed about the optimal route choice according to their utility functions.
- *Capacity drop* – A road attracts too much traffic which causes the actual capacity of that road to drop. In an urban network, not the capacity of the road, but the network capacity will drop.

Goals

The second level in the overview can be seen as a translation of the traffic phenomena into more operational traffic management goals, the general goals that can be identified for the phenomena are:

- *Increase capacity* – One of the solutions for limited capacity in a network is to simply increase the capacity. In the context of the network it should always be considered that the capacity increase at one location could cause bottlenecks elsewhere in the network. Capacity in urban networks is mainly determined by controlled intersections.
- *Distribute traffic across the network* – The theory emanating from the g-MFD is that the capacity in a network can be increased by increasing the spreading of traffic over the network. This goal is thus two sided, capacity problems can be solved either locally or on the network as a whole. This supports the idea that choice of individual vehicles is not always conform the traffic management goals. Providing information and route advice can help distributing traffic over the network, but also indirect measures can be used to redirect traffic.
- *Regulate the inflow of traffic* – If capacity is limited, and increasing capacity is not an option, inflow in the network could also be regulated. Regulating the traffic inflow can also be effective to prevent capacity drops on roads. An indicator when to regulate inflow could be the density of downstream roads, if an MFD of the considered network is available, a target density can be determined on the basis of this diagram. Possible instruments to influence the inflow of traffic over the network are speed limits on access roads or adaptation of the traffic signalling.
- *Prevent spill-backs* – Other than regulating inflow traffic, where spill-backs can be reduced by measures upstream of the spill-back location, preventing spill-backs focuses on the intersection causing the spill-back, downstream of the actual queues. The main strategy that can be used in order to reduce spill-backs on urban roads is intersection control.

Services and Instruments

The general goals can be linked to problem locations in the network where the traffic phenomena actually occur. This location specific goal is called a *service*, for each goal, multiple services are conceivable. The services can translated into an *instrument*, which is applicable in practice. Only instruments and services that are suited for urban networks are included in the overview. Only roadside traffic management measures are considered. In car instruments could also be used in traffic management scenario, with the increasing use of navigation systems this could be a valid option in the future, however this is outside the focus in this research. A distinction can be made between on-line, and off-line instruments. For on-line instruments, real time indicators are used to adapt the control of the instrument. Most instruments are both suitable for on-line as well as off-line application or only suitable for on-line application.

Instruments:

- *Variable speed limit* – Variable speed limits can best be used on major, arterial roads. Influencing traffic speed can be used to increase traffic over a road, but also to limit inflow of traffic on a road downstream. Matrix signs above the road are needed and might need to be placed above the road. This measure is specifically suited for on-line application.
- *Extra lanes* - adding lanes can increase capacity of the affected area, given that the capacity downstream is sufficient to handle the extra inflow as a result as the extra upstream capacity.
- *Road blocking* – This is a static measure which can be used in order to redistribute traffic across the network. This can be a radical solution for roads which are not meant for through traffic.
- *Dynamic route information* – This is the only dynamic measure that has been identified in order to better divide traffic across the network. A dynamic route information panel can show alternatives. It could become more effective when route advice is based on traffic predictions instead of real time traffic information.
- *Static speed limit* – This is a static measure which can be used to either increase throughput or decrease inflow. This is more suited for minor roads than variable speed limits because infrastructural investments are less. This measure can be implemented off-line, but there are also scenario's possible where the speed limits are variable, just as what is done on motorways.
- *ramp metering* - Ramp metering is used to prevent cars from merging on a motor in order to prevent or reduce congestion on that freeway, it could be used for the purpose of gating traffic.
- *Traffic light configurationTr* – Both decreasing as well as increasing maximum green times at an intersection can be useful in traffic management. Limiting greentimes can be used to limit traffic inflow into an area or road. This can be used in order to prevent capacity drops in the network. When decreasing green times is done as a coordinated measure to reduce inflow into an entire area, this is called gating. Increasing greentimes can be used to increase the traffic inflow in an area. When there is a bottleneck at

the location, also the bottleneck capacity will be increased. This can help preventing spillbacks. Also capacity drop in the network can be delayed.

- *Turn-lane configuration* – This is a form of capacity redistribution. This is very suited at controlled intersections, if one direction has a capacity that is too low, an extra lane can be dedicated to this direction in order to prevent traffic spillbacks.

- *Dynamic lane configuration* – This is mainly suited for larger roads. An example of this measure is for instance the A10 through the Coentunnel in Amsterdam, where there are two lanes open in a direction depending on the traffic flow. The effect is that capacity is effectively used during rush hours. This measure is only suited for high volume axes, there will probably a need for large investments.

The bottom layer of the framework contains the instrument performance indicators. The effect of each instrument should be measurable in the actual traffic state. With help of the targeted service, such an indicator can be formulated for each instrument that is designed.

2.4 Design of instruments

In the urban network adaptation of the sustainable traffic management, the problem analysis, the assessment framework and the traffic analysis results form the input for the design of instruments. In section 2.3 these steps are put into context of the traffic management measure framework. This framework forms the basis on which traffic management instruments can be designed. How this framework can be applied is illustrated in this section for several instruments.

A schematic overview of how to design instruments is shown in figure 2.5. Green boxes indicate research steps, and blue boxes indicate specific levels in the traffic management measure framework. The use of the steps and the instrument framework this way, ultimately leads to an evaluation of the measure results. For each instrument, a set of design variables can be identified to describe the instruments. The design variables can be subdivided in two categories: the instrument location and the impact and corresponding impact area. The location where to implement an instrument is dependant of the desired services and their locations. The impact is measured by the changes in traffic conditions, the bigger the impact of the measure, the more the traffic conditions will be affected. The effect of varying design variable values for an instrument in an urban network is different for every situation. How to influence the impact of an instrument can best be determined experimenting with the value of the design variables for this instrument. Such experiments can also be used to determine generic rules for the effects of instruments based on design variable values.

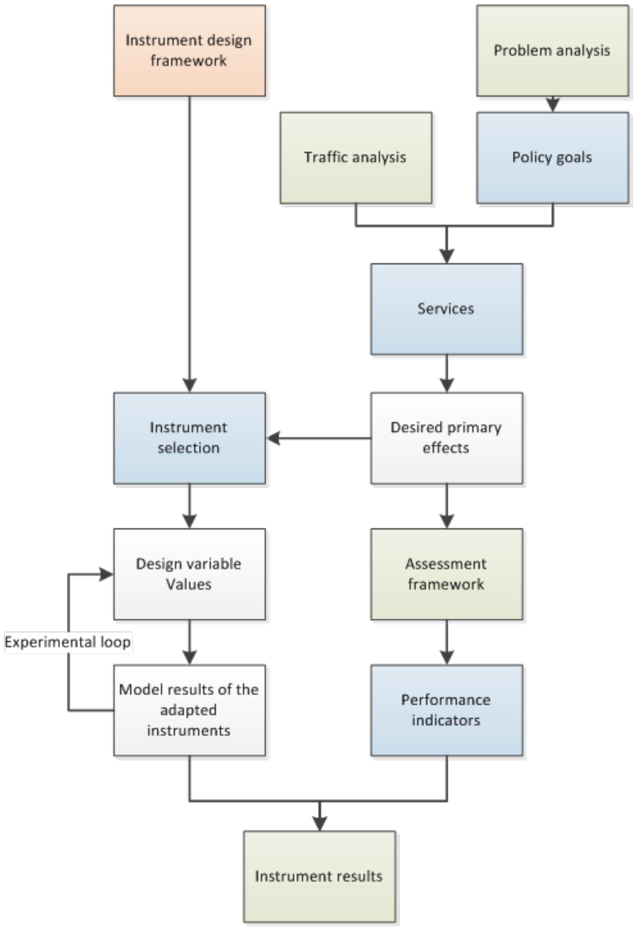

Figure 2.5: Algorithm for the design of instruments, green boxes represent research steps, blue boxes represent the levels in the instrument design framework, and the red box indicates the instrument design framework.

The interpretation of the design framework is in this case reduced to four instruments for which for which the design variables and the most important instrument effects are determined, the same principle can also be used for other instruments. The worked-out measures are gating as a coordinated approach of decreasing green-times; speed adaptations; blocking roads and adding extra lanes. First, the general approach to finding instrument effects and design variables is described.

Instrument effects General performance indicators which can indicate an instrument as a possible solution can be found at the bottom level of the instrument framework. These phenomena are also indicators for the design of services. The performance indicators deduced from specific services are called the primary effects of the measure. There are also the effects which occur, but are not the primary goal of deploying the instrument, these effects are secondary effects. Emissions for instance are also often an important secondary effect. Secondary effects can be either positive or negative.

Design variables In order to manipulate the instrument impact, design variable values must be selected well-reasoned. For each instrument, there is a very specific set of design variables. Being able to recognize these variables and vary their values makes the design of instruments a more structured process. In order to quantify the effect of a design variable, an experimental set up can be used. By varying the value of design variables each test, the differences can indicate the impact of the changing variable value. This method of designing instruments is depicted in the schedule as the experimental loop. For the four instruments which are central in this analysis, the design variables are summarized in the following of this section.

gating

Figure 2.6 shows how the traffic management framework can be interpreted to find general performance indicators for the instrument. Locations from the Gating enhances the coordinated decrease of green-times at several locations around a predetermined area. For gating, specific performance indicators are downstream traffic density and average speed downstream of the decreased green times. Because less traffic is entering the area, spill-back might occur upstream of the gating area, this is the first secondary a secondary effect. The expected changes in traffic flow can also have an impact on location specific vehicle emissions.

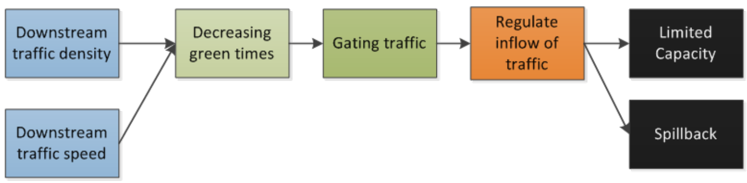

Figure 2.6: Gating goals and effects according to the instrument framework, the desired effects of the measure are the performance indicators on the leftside of the schedule, the traffic phenomena that can be treated with gating are a limited capacity and spill-back in the network.

The expected effects result into two locational variables: the gating locations are determined by locations of undesired travel time delays. Buffer locations must be created upstream of the gating locations. The buffer locations can be selected considering the function and space on these upstream roads. The impact of the instrument gets bigger as the green-time is further reduced. As an extra effect the phase structure at gating locations can also be adapted. Figure 2.7 gives an overview of the design variables and effects of gating. How the table can be filled out depends on the specific network properties and this can be done based on an experimental set-up. Input for the desired density within the gated area could be an area specific macroscopic fundamental diagram, as the density in the gated area gets higher than the optimum according to the g-MFD, gating can be applied.

Gating		Primary effects		Secondary effects	
		Downstream traffic density	Downstream traffic speed	Upstream bottlenecks	Vehicle emissions
Measure location	Gating locations Buffer locations				
Measure impact	Greentime adaptation				
	Phase structure adaptation				

Figure 2.7: Overview of design variables and expected effects for the gating instrument

Speed Adaptation

The two desired effects of speed limit adaptation can be a change in the amount of through traffic and a change in the traffic density on the affected road. If the affected road is, or becomes congested, average speed on upstream roads could also drop, this is one of the possible secondary effects. Also the accessibility (average speed and flow in the network) as well as the vehicle emissions at environmental locations might be affected and needs to be monitored. The overview of the possible effects and design variables for speed adaptation is shown in figure 2.8.

The location where the speed limit can effectively be reduced can be chosen by assessing the routes of unwanted traffic where the traffic has to be redirected to alternative routes. The impact of the measure can depend on the new speed limit.

Speed Adaptation		Primary Effects		Secondary effects		
		Change in through traffic	Traffic flow on affected roads	Vehicle emissions	Accessibility	Affected road average speed
Measure location	Affected roads					
Measure impact	Speed difference					

Figure 2.8: Overview of design variables and expected effects for the speed adaptation instrument

Blocking Roads

Blocking roads effectively changes the network structure and the route options available for road users. Figure 2.9 shows the expected effects and design variables for Road Blocking. The blocking of certain roads can be an effective tool in preventing through traffic, there are conceivable configurations where through traffic would become impossible, this could happen if the blocked roads divide the city into several sections. If less roads are blocked, through traffic might look for routes around the blockade resulting in cut-through traffic. Also as a result of shifting traffic patterns, the total accessibility could change as a result of implementing this measure.

The location where to implement the road block is the most important part of the instrument design; this location is less obvious than determining the location for the other instruments. Road blocking could be done coordinated over several locations splitting a network into several segregated sub-networks. A less heavy form is to only block a road on an important through traffic route. The impact of the measure could be determined by only blocking a road for certain vehicle types, for instance by using a bus-lane, still allowing buses, or a freight lane. Road blocking could also be a physical blockade. Another option is to block the road in only one direction, denying vehicles access to the other direction.

Blocking roads		Primary Effects	Secondary effects	
		Through traffic reduction	Accessibility	Cut-through traffic
Measure locaction	Roadblock location			
Measure impact	Affected vehicle types			
	Roadblock method			

Figure 2.9: Overview of design variables and expected effects for the blocking instrument

Adding Lanes

The overview of design variables and measure effects for adding lanes is presented in figure 2.10. Adding lanes can be used when capacity on certain roads is limited. The indicators when to use the adding lanes instrument are low travel speeds and low traffic flows. Another direct effect of adding lanes can be an increased flow on the affected roads. When the downstream traffic flow is limited however, congestion may occur downstream, also traffic is prone to taking the affected road as a result of the decreasing travel time. As a result of these effects,the emission rates at environmental locations can also be influenced.

The location of adding lanes can be chosen on locations where desired travel times or flows are higher than the desired travel times and flows. The impact can be influenced by the amount of lanes added. Also the configuration at intersections on the route might be a factor, although the amount of turn-lanes at intersections is most of the times higher than on the bulk of the road, resulting into a constant situation for the turn-lanes at intersections. Also, the lanes could be limited accessible, by for instance, only adding a bus-lane.

Adding lanes		Primary effects		Secondary effects		
		Affected road traffic speed	Affected road traffic flow	Vehicle emissions	Traffic spreading over network	Downstream congestion
Measure location	Location of added lanes					
Measure impact	Number of added lanes					
	Turnlane layout					
	Allowed vehicle types per lane					

Figure 2.10: Overview of design variables and expected effects for the adding lanes instrument

2.5 Combination of instruments

So far, only individual instruments have been discussed, in the context of an urban network, multiple measures are implemented simultaneously. In this section methods for combining area-wide traffic control are identified, the research question that relates to this part is:

How can separate traffic management instruments be implemented in a coordinated way; resulting into a network-wide traffic management strategy in the defined problem area in order to realize the traffic management goals?

The traffic management instruments in this research focus on static solutions, this also means that the possibilities for smart area wide traffic control are limited. Several elements that can be used are already presented: the control strategy, the g-MFD, the traffic state analysis for instrument results and the multi criteria analysis results are all elements which can be used for the combination of measures. Within this group of elements a distinction can be made between the spatial dimension, covered by the g-MFD and the control strategy, and the impact dimension, covered by the separate instrument analyses. Note that the multi criteria analysis only measures global impacts, and for the combination of traffic measures, more detailed analysis might be needed. This detailed analysis can be performed using the design variable and expected effects overview presented in section 2.4. Also the location of the measure effect can be considered with a more detailed analysis. Based on specific results of these elements Different approaches for the combination of measures based on the control strategy, g-MFD and MCA can be considered. Instrument combination methods could be implementing instruments, reinforcing instruments and the corridor approach. The overview of available elements and combination factors is shown in figure 2.11. The combination factors are discussed below.

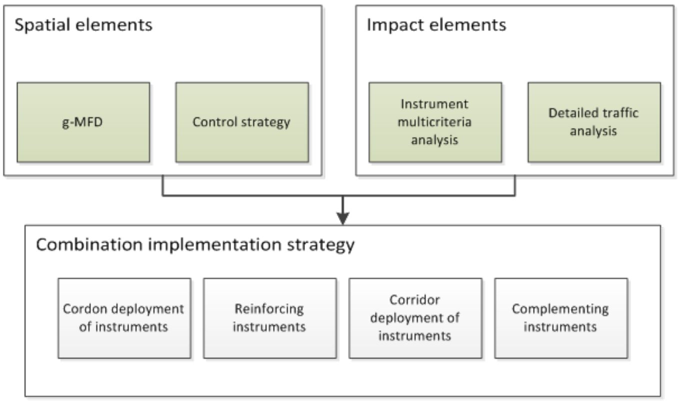

Figure 2.11: Overview of elements available to select an instrument combination method.

Complementing instruments Primary effects are leading in the initial selection of instruments, but may lead to negative effects considering the secondary effects. Instruments can be strategically used to complement each others strong and weak points; the weakness of one instrument can be a strength of another instrument.

Reinforcing instruments The focus of reinforcing instruments is specific problem locations. If severe problems occur on specific locations, or a single instrument does not lead to the desired result, multiple instruments focussing on a single location can be combined. All instruments together can contribute to an effective traffic management strategy. Reinforcing instruments can be used for both primary effects, to maximise the effect, but also for secondary effects,to reach the limit value.

Corridor approach Often specific routes are defined essential in the control strategy. Multiple bottlenecks could be related to a single route, especially in urban networks with multiple controlled intersections. Implementing multiple instruments along a single axis can be necessary to improve the traffic conditions corridor wide.

Cordon approach This approach does not only focus on a corridor, but on a small part of the network, a cordon. Instruments are implemented in the entire cordon in order to optimize traffic conditions in the cordon.

Traffic management strategy design approach

By combining the elements discussed in the above, the combination of measures can be optimized in several iterations. An algorithm which can be used to select instruments to combine with each other, is shown in figure 2.12. The combination of instruments can start from a number of instruments implemented in a corridor or cordon or even a single measure from the previous step when there are problems on the impact or secondary effects of this measure. How the locational scope is chosen depends on the problem description, and is not further specified in the framework. The algorithm can work for isolated deployment, corridor deployment and also for cordon deployment. First, the impact of the selected instruments must be tested. If the selected instruments do have a big enough impact, the locations of the effects must be considered. Is the effect of the measures big enough? If not, multiple instruments must be deployed at the same location which increases the effect of the measures. Is the traffic management strategy effective in the entire targeted area? If this is not the case, additional instruments might be needed at other location in order for the traffic management strategy to be effective in the entire area. The final check is for secondary effects. If there are secondary effects which are negative in a specific traffic management strategy, measures can be taken to counter these negative effects and additional instruments can be deployed. If the negative secondary effects are also removed, an effective traffic management strategy is found.

Note that the chosen strategy will not be an optimal solution, since more effective strategies cannot be excluded. An optimal strategy would mean that there is no better strategies conceivable out of all possible strategies. When this algorithm is used, not all possible strategies will be considered. The definition of optimal in traffic management strategies is also not clear, since multiple assessment criteria are considered equally, and the weight of these criteria is not exactly known.

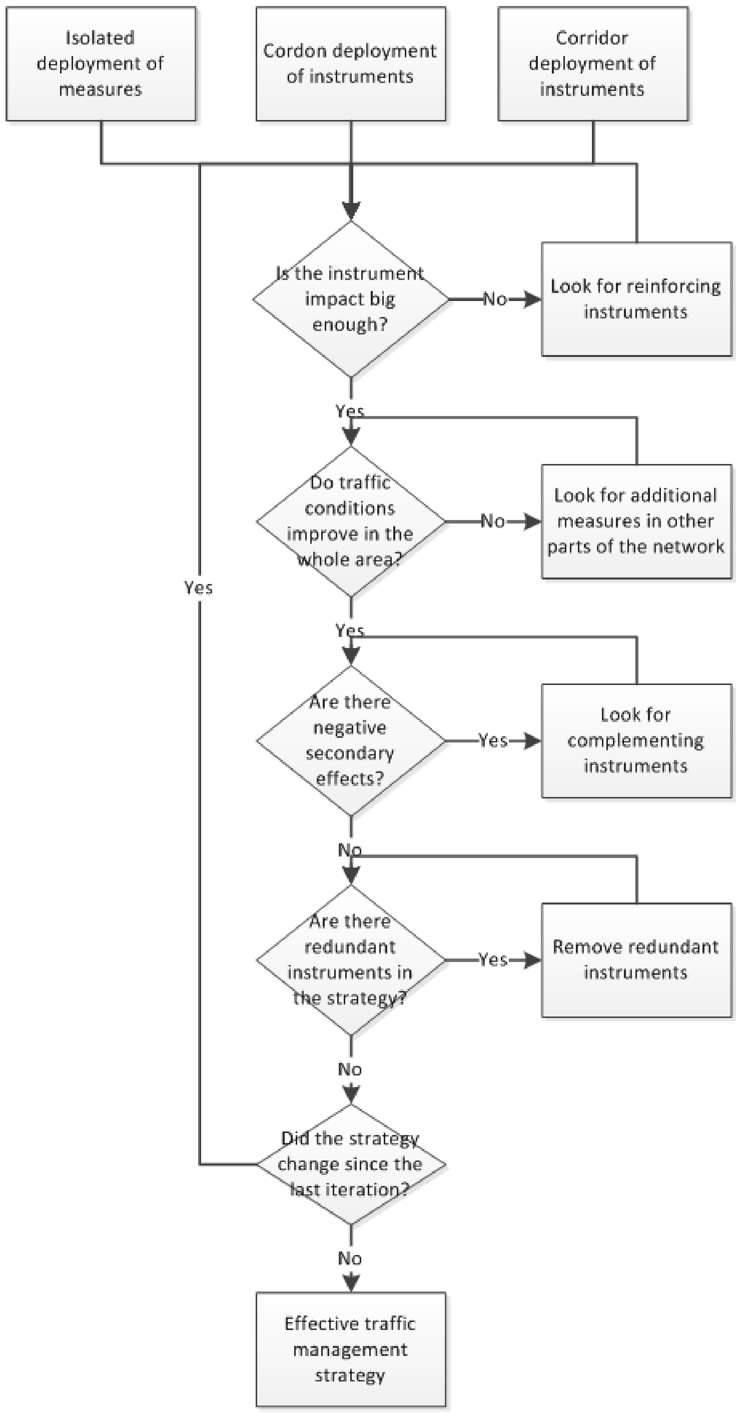

Figure 2.12: Algorithm for the combination of traffic management measures.

2.6 Design approach summary

In this chapter, adaptations to the GGB framework have been made in order to be able to come to effective traffic management strategies in urban situations where the instruments used are deployed network wide. In order to do this, some additions to the framework are proposed. The main additions to the framework, are the integration of model selection and -development in the framework, and the addition of a structured approach for designing individual instruments at first, later combining them into a network wide traffic management solution.

Four instruments are further analysed: gating, speed reduction, blocking roads and adding lanes. For each instrument primary- and secondary effects are interpreted. The primary effects can be used to identify the traffic conditions that indicate the need for that instrument. Secondary effects can be used to assess the effects of the instrument on the preconditions of in the project goals. Next to the measure effects, the design variables are assessed. Varying the values of these variables can be used to influence both the location and the impact of the effects.

The method that is proposed for combining individual instruments into a traffic management scenario, subsequently looks at 3 elements: size of the impact, impact area, and negative side effects. These factors can be dealt with in an iterative process, where instruments can be added or removed every step, resulting into an effective traffic management strategy.

The framework that is proposed in this chapter will be applied to the case study Eindhoven in chapters 3 to 8.

Part II

Case Study Eindhoven

Introduction to the case study Eindhoven

The framework that was introduced in 2 is in this part applied to the city centre of Eindhoven. The research question that relates to this part is:

How can the traffic management design framework be implemented in order to reach the traffic management goals for the city centre of Eindhoven?

This research question is subdivided into a number of sub-questions following from the traffic management design framework:

1. Which traffic management goals can be identified for the city centre of Eindhoven?
2. What method and which indicators can be used to assess the traffic performance for the city centre of Eindhoven?
3. Which problem locations in the city centre of Eindhoven can be identified for considering the traffic management goals?
4. How can the instrument framework be used to design traffic management instruments for the Eindhoven city centre?
5. How can the separate instruments tested for the Eindhoven case be combined into an effective networkwide traffic management strategy?

The municipality of Eindhoven

Eindhoven is the biggest city in the South of the Netherlands with 219 000 inhabitants in the municipality and 440 000 in the greater Eindhoven area. The city centre is an area where a lot of activities are combined, each requiring scarce space and have their own demands related to transportation and mobility. The mobility and traffic management for this dynamic area is a constant challenge for the local politicians. The current goals of the municipality are to keep the city centre an attractive area, and to get more visitors to this city centre. These people come to the city centre in order to live, work study, shop or spend their spare time. In order to enhance the attractiveness for visitors of the area, the municipality has anchored it's mobility goals in the city centre in several policy documents. These goals can be divided into several topics (table 2.1). An extensive overview of the research goals is presented in chapter 3. The case study in this research identifies the possibilities of network-wide traffic management for the city centre area of Eindhoven.

Table 2.1: The goals that are marked green are relevant in this research

Theme	Goal	Source
Environment	30% reduction of motorized vehicles within the ring road (2015)	Collegebesluit Actieprogramma Luchtkwaliteit en Mobiliteit
Accesibility	Reduction of bottlenecks	Brainportprogramma 2020 (2011)
Number of visitors	Enlargement of the number of visitors to the city center.	Structuurvisie 2004
Modal Split	+50 percent PT, +10percent bike usage, -9 percent car usage	HOV-Strategie (2009)
Traffic safety	10 percent reduction of heavy traffic victims each year	Actieprogramma Verkeersveiligheid

Case study research area

The city centre of Eindhoven is enclosed by a ring road, the speed limit on this ring is 70 km/h and its roads are to be used as arterial roads. Within the city centre, the most important roads have a distributor function.

Within the Eindhoven network, *traffic management measures* are to be taken only on a few roads, focused at the traffic driving towards the city, *effects* are measured networkwide. Figure 2.13 shows the roads where traffic management measures are to be implemented in the research. These are busy roads which are used by large amounts of vehicles. The traffic state predictions that are presented in this research apply to the traffic situation in Eindhoven in the year 2020. The results that are measured are also applicable to that year.

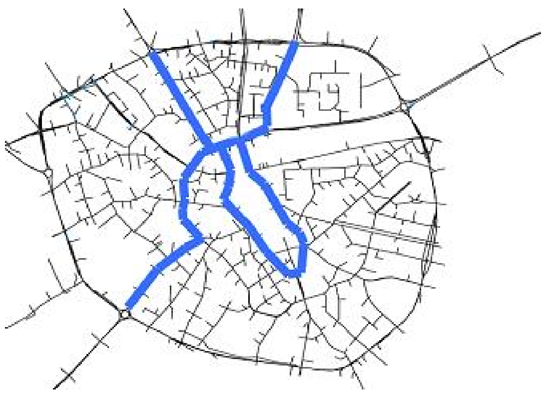

Figure 2.13: Implementation area for the measures, on the left side.

Chapter 3

Problem Analysis

In the problem analysis, the complete set of policy goals related to the network is determined. This step elaborates on the goals which are indicated as being important in the problem statement. An overview is presented where the problems are likely to occur. Accessibility, vehicle emissions and slow mode accessibility are important factors. Also noise, modal split and traffic safety can be relevant in urban networks, these are left out of the context of this research. The location and size of the problems is investigated, this is done by summarizing available research and policies for the area. The main goal for this research step is to identify traffic management goals. These goals consist of two parts: an overview of the current status of the goals as set for the network, and an area specific control strategy. In the control strategy, it is determined what the traffic management goals should be given the specific traffic state in the network. The problem analysis eventually leads to an answer to the following research question:

Which traffic management goals can be identified for the city centre of Eindhoven?

Policy goals and traffic engineering goals go side by side in the city centre of Eindhoven. Increasing traffic flows in the city centre lead to excessive vehicle emissions and inaccessibility for the slow modes. In order to reduce vehicle emissions and average crossing times for pedestrians, traffic flow should be decreased instead of increased. The goals for Accessibility, the environment in the city and slow mode accessibility are presented in sections 3.1, 3.2 and 3.3. Based on these goals, a vision is needed on how to deal with the different goals in the city centre. This vision for the centre of Eindhoven is presented in the control strategy in section 3.4.

3.1 Accessibility

Two factors that indicate accessibility are travel time, or speed and traffic flow. They are both important, but it is hard to combine them in one indicator. Higher total travel time could be positive in terms of traffic management, when it is caused by a higher flow, or negative when it is caused by a high route travel time. In this section, the goals for the city centre are described, and after that the goals for the arterial roads around the centre are described.

City centre

In the city centre, the ring road is the most important arterial road, it is part of the primary car network, inside the ring road, there is a couple of roads which is part of the secondary car network. This is shown in figure 3.1. This division of roads can be seen as the road prioritization for accessibility goals. For the roads which are not indicated as part of one of the two road networks, the objective is to reduce large traffic flows. For the ring road, the objective is to increase the traffic flow. Roads in the city centre which are part of the secondary car network, the Kennedylaan, Geldropseweg, Karel de Grotelaan, Leenderweg, Prof. doc. Dorgelolaan, Mauritsstraat, Fellenoord and the Eastern part of the Binnenring are the roads where large traffic flows are present. These roads should remain accessible, but they have a clear function to provide for locally bound traffic. Through traffic which is not bound to the city should be on the ring road and not in the city centre.

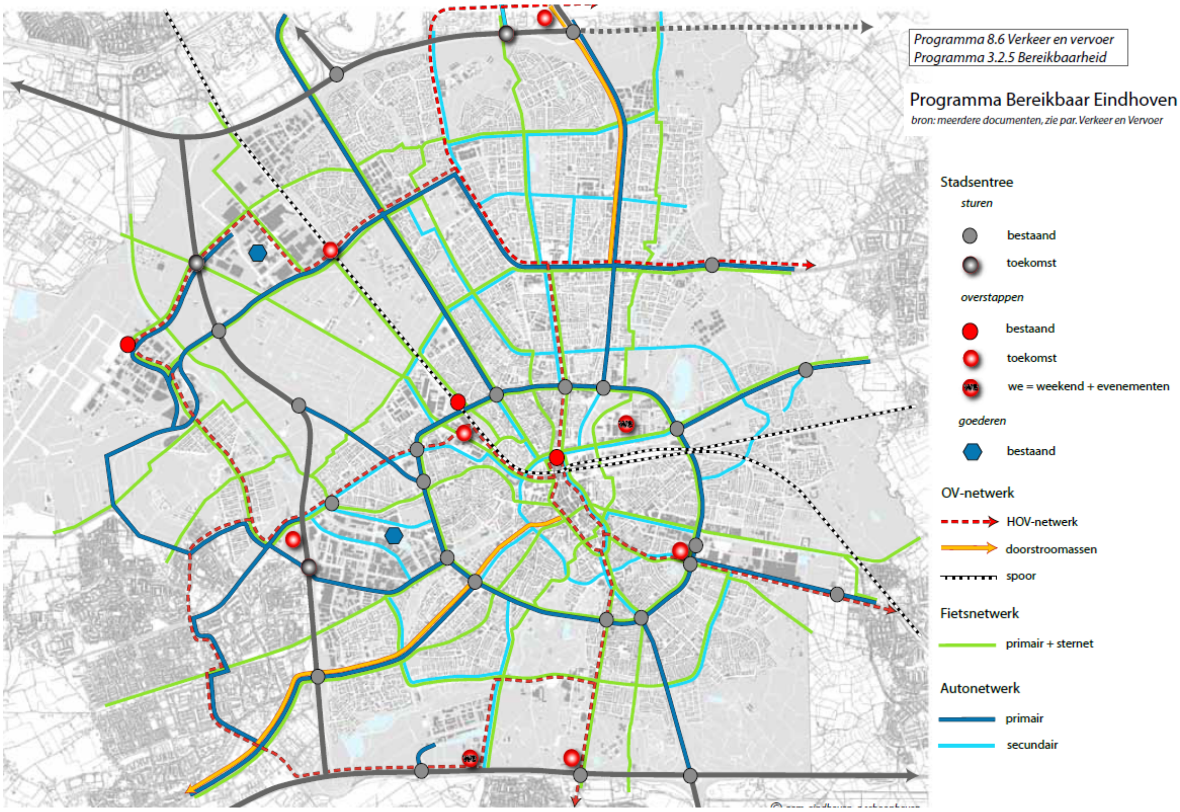

Figure 3.1: Road prioritization in Eindhoven, dark blue lines indicate roads part of the primary car network, light blue lines indicate roads part of the secondary car network [4].

Arterial roads

For the arterial roads outside the city centre, regional policy on accessibility of the road network has been developed where average speed is a leading indicator. Minimum accepted speeds are defined in the 'Beter Bereikbaar Zuid Oost Brabant' programme [6]. These minimum accepted speeds can be compared to the speeds that are being measured in the model. The road priority map is shown in figure 3.2. This categorization can be used to link the arterial roads to actual minimal speeds, the minimum speed per road section is shown in table ??. Since these roads are less important for the problem definition, average speed is the only factor that is concerned on these roads. Traffic flow is not further considered

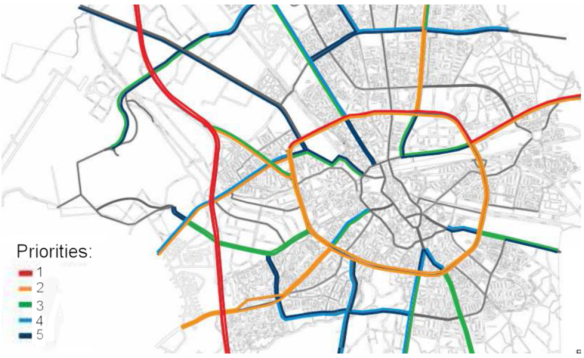

Figure 3.2: Road priorities as determined for the Eindhoven network in the context of BBOZB.

Table 3.1: Minimum trajectory speeds for the modelled roads

Road	Morning speed (km/h)	Afternoon speed (km/h)
Kennedylaan into City	45	45
Kennedylaan from City	45	45
Boschdijk into City	-	35
Boschdijk from City	35	-
Tilburgse Weg into City	45	35
Tilburgse Weg from City	35	45
Meerenakkerweg into City	35	35
Meerenakkerweg from City	35	35
Karel de Grotelaan into City	40	40
Karel de Grotelaan from City	40	40
Leenderweg into City	35	35
Leenderweg from City	35	35
Eisenhowerlaan into City	50	45
Eisenhowerlaan from City	45	50
Karel de Grotelaan	35	35
Ring	35	35

3.2 Environment

Two indicators for pollution are used in the policy documents for the situation in Eindhoven: PM10 and NO2. In the interimstructuurvisie of the municipality of Eindhoven[4], similar problem locations are found for both pollutants. PM10 problems however are more severe at locations where higher speeds are allowed, whereas NO2 concentrations are higher at locations with a lot of start and stop movements. This observation is in accordance with the data that is found by Cragg [13] (table 3.2). In the problem area start and stop movements are the most relevant factor, this is reason to consider NO2 as main polluter in this research. Next to being a more relevant indicator for movements in the city Centre; NO2 is also a more practical

Table 3.2: Comparison of NOx and PM10 emissions between fixed speed and stop-start average speed of 32 km/h [13]

Link	NO_x mg/m	PM_{10} µg/m
20mph constant speed	37.1	306.1
30mph stop start - mean speed 20mph	69.6	321.4
% increase	87.8%	5.0%

indicator to use for predictions than PM10 because the limit value is measured in yearly average instead of in number of days exceeding the limit. This can be seen in the Eindhoven programme for measurements of air quality [14]. Also it is a more common indicator for which outcomes can be predicted more effectively. In this section, the current problem locations of Eindhoven are determined first, followed by the severity of the problems at these locations. From this information, environmental goals can be deduced.

Locations of Air pollution

There are two different sources which can be used in order to locate current environmental problems in the municipality of Eindhoven: in the Interimstructuurvisie [4] , predictions for the 2020 environmental situation are presented and several problem locations are indicated. Furthermore there are actual measurements in the municipality of Eindhoven [15], this is exact data for the 2012 situation. Data from these measurements is shown in figure 3.3. The problem that occurs is that both sources don't always signalize the same problem areas. The most important problem location resulting from the Interimstructuurvisie is the Mauritsstraat whereas the actual measurements don't detect unacceptable NO2 (average concentration of 34Mg/m3 in 2012). Locations where actual problems are signalized are both at the Kennedy-laan and Montgommerylaan, and in the city Centre at the Keizersgracht. In this research, mainly the effects within the ring area are important, outside the ring only emissions at the Kennedylaan and Eisenhowerlaan are measured.

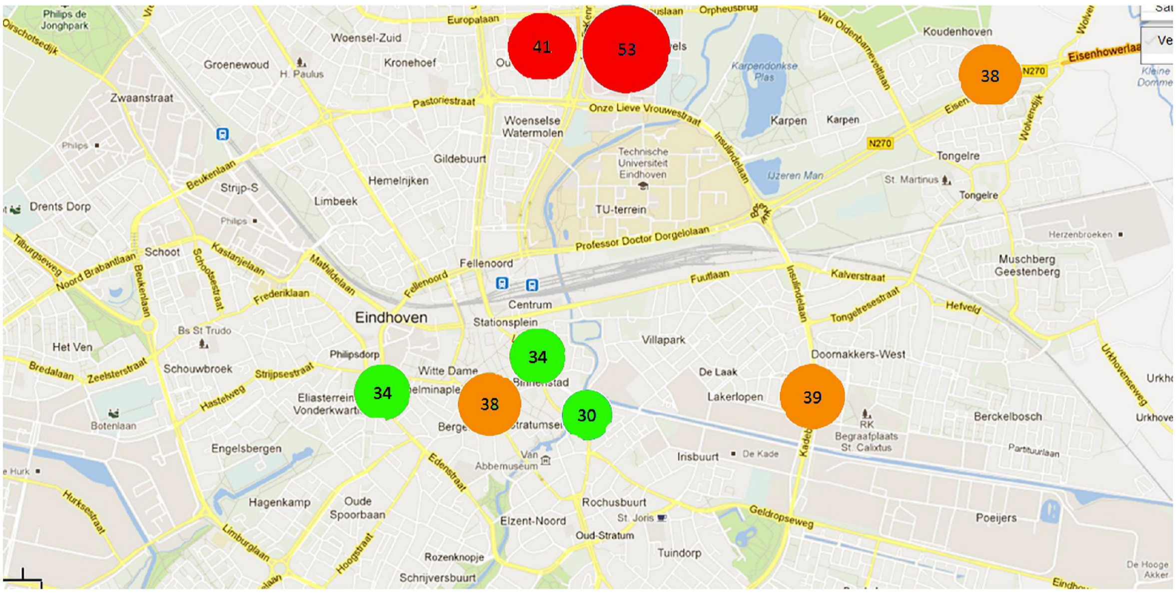

Figure 3.3: Measured concentration of NO2 in mg/m^3 in 2012 at the important pollution locations throughout the city.

Severity of air pollution problems

The NO2 concentrations at the indicated problem locations in Eindhoven are listed in table 3.3. For NO2, the maximum permitted yearly average after 2015 is 40 micrograms [14]. According to the measurements, this goal is met at every potential problem location within the city centre. Note also that over the last 3 years there is actually a downward trend in air pollution at these locations.

Table 3.3: Average NO2concentrations on the most important problem locations in Eindhoven, based on numbers (based on data obtained from geogids.info[10.2]). Green locations are in the city Centre.

Location	Year Average NO2 concentration (mg/m3) 2010	Year Average NO2 concentration (mg/m3) 2011	Year Average NO2 concentration (mg/m3) 2012
Mauritsstraat (westtangent)	38	32	30
MauritsstraatB	-	35	34
Wal/Keizersgracht (Binnenring)	42	40	38
Vestdijk (Binnenring)	32	36	34
Kennedylaan	50	53	53
Kennedylaan B	0	40	41
Eisenhowerlaan	37	38	38
Jeroen Boschlaan (Ring)	45	41	39

Environmental goals

The three traffic related factors that can influence traffic emissions are fleet composition, amount of vehicles and traffic flow factors such as average speed, acceleration deceleration and idling of these vehicles. Next to traffic related factors, other conditions also play a part in levels of emission gas in the near environment, such as weather conditions, buildings in the environment, and background levels of contaminants. This leads to two possible ways in which traffic management could reduce pollution: reducing traffic flow, or increasing the average speed. The latter one however, will result in a higher flow, and thus results into a conflict with the strategic traffic management goals. The major method to reduce emissions is to reduce the local flows at the environmental problem locations.

With the situation as described, there is no instant need for reducing traffic in Eindhoven for the sake of environmental goals in Eindhoven. There is however almost no more room for extra traffic, because the limits are almost reached. It can be useful to assess the influence of traffic variables on the amount of pollution in the city. In order to reduce emissions, traffic flow would have to drop; in order to stay within the emission bounds, the amount of vehicles at the environmental problem locations should not increase.

3.3 Slow mode accessibility

The municipality has prioritized all controlled intersections [3]. For most intersections at the Binnenring. Public transport has the highest priority, and after that cyclists and pedestrians. The intersections where slow traffic is prioritized are indicated in figure 3.4. In order to indicate this prioritization of traffic on the intersections; two important intersections on the Binnenring are considered for this research (table 3.4.): Vestdijk - 18 Septemberplein and Mathildelaan - Boschdijktunnel. Cars have absolute lowest priority at these intersections. At these intersections the Public transport is part of the HOV network; pedestrian flows are part of the high intensity pedestrian network and the cycle lanes at these intersections are part of the primary cycle network [10.2]. This categorization of intersections is also linked to desired waiting times for the different modes at these intersections.

Figure 3.4: Overview of the intersections prioritized for pedestrians in Eindhoven [10.2].

Whether the desired waiting time is met in the actual situation is dependant on the realisation of the intersection control scheme which is vehicle dependant. This information cannot be filtered from simulation. From observations at the intersections themselves, it seems that the cycle times during rush hour are about 75 seconds, where the average green time is on average 16.5 seconds. During off peak hours and the average waiting time is 60 seconds. When this data is compared with flow data from the model during the corresponding periods, an estimation of actual waiting times could be made based on the measured flow in the alternatives.

Table 3.4: Desired average waiting times in seconds of the different traffic categories at the two observed intersections during rush hours, obtained from Beleidsnota verkeerslichten [10.2].

Intersection	PT	Car	Bike	Pedestrian
Mathildelaan - Boschdijktunnel	5s	-	20s	20s
Vestdijk – 18 Septemberplein	5s	-	20s	20s

3.4 Control strategy for the Eindhoven Network

The urban network for the city of Eindhoven consists of a ring of arterial roads where 70km/h is allowed around the city centre. From all directions there are inbound-arterials that lead towards the Ring, but also into the city centre. On the Ring and also in the centre, traffic from all directions comes together. Not only the Ring, which is meant as an arterial road, can get very busy during rush hours; also the roads in the city centre are over-flooding with traffic. The high traffic flows in the city centre conflict with other goals for the area. The environment is being pressurized and slow traffic such as bikes and pedestrians experience long waiting times at level intersections. The traffic management philosophy that is applied in this research focusses on keeping cars as much on the arterial ring roads and roads outside the city centre as possible. The roads that are concerned are shown in figure 3.5. Redistributing traffic of traffic over the city centre can be done by making the city centre roads less attractive for through traffic and also for destination traffic. The city centre however, should stay accessible for this destination traffic and roads should stay available. The most important route choice factor that car users use; is travel time. If the travel time on the most important corridors in the City Centre becomes higher than the corresponding travel times on the route alternatives over the ring road; the city centre is likely to be avoided as much as possible, and the city centre roads will be primarily used by city centre traffic.

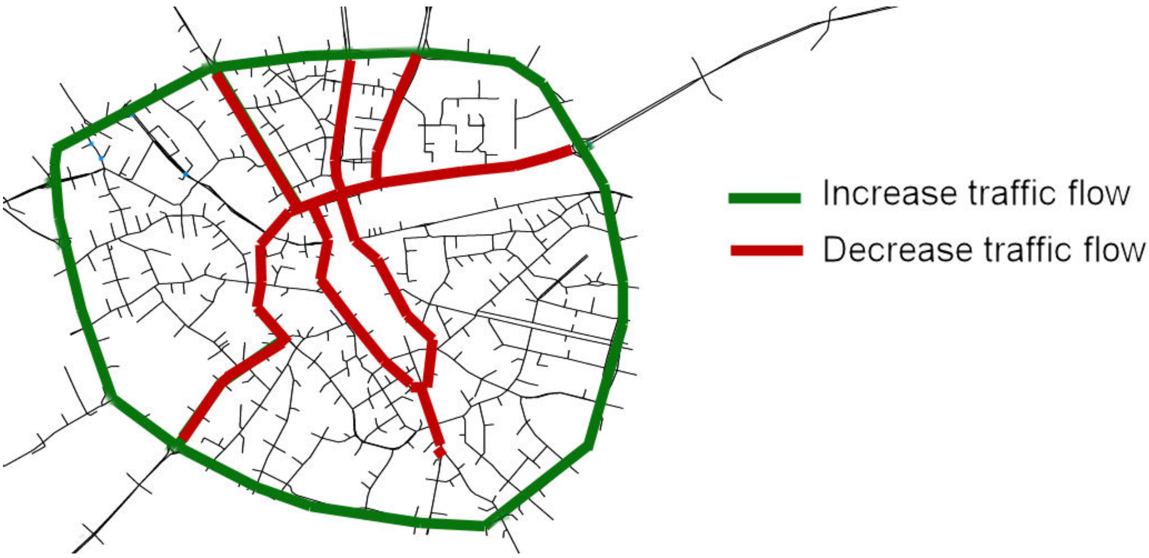

Figure 3.5: Traffic management strategy for the City Centre: the goal is to decrease traffic in the City, and move this towards the ring.

3.5 Problem analysis summary

In this chapter the traffic management goals for the city centre of Eindhoven are determined and a control strategy is formulated. The control strategy implies that the traffic flow on the roads in the city centre is to be decreased, whereas the traffic flow on the ring is to be increased. On the roads arterial roads around the centre, minimal policy speeds can be used to indicate the traffic performance on these roads. This optimization has to be executed with 2 preconditions. Emission levels for NOx should be monitored at 8 different locations around the city. Also, 2 intersections are monitored in order to indicate the accessibility in the city centre. The average pedestrian waiting times at these intersections should not be above 20 seconds. In chapter 5 these goals are made operational so they can be measured in the simulation model. Model results can indicate the initial values for the performance indicators, and can be used to assess the model performance. In the assessment framework, the results of this problem analysis are used to link the research goals presented here to the actual model results.

Chapter 4

Model selection and design

In order to test the proposed measures, a simulation model is needed. Based on the goals in the problem analysis, model requirements can be obtained. The model should be able to adequately measure all goals in the reference situation. Also the model should be able to calculate the effects of the proposed measures. Not only the focus area itself should be modelled, but also main arterials around this area. In this step, the model is also calibrated and validated. With this model and the assessment framework presented in chapter 5, the fifth research question can be answered:

What method and which indicators can be used to assess the traffic performance for the city centre of Eindhoven?

First a simulation model is selected, the selection and development of the reference model are discussed in section 4.1. The validation of the selected model is discussed in section 4.2. In this section the validity of the original model is discussed first, after that the validity of the reference model for the simulation study is tested. To determine the amount of model runs needed in order to acquire an acceptable accuracy, confidence intervals for several important variables are calculated in section 4.3.

4.1 Model selection

This section starts with the assessment of the software tool that is to be used to model the city centre network for the Eindhoven region, after that, the development of the reference model is discussed.

4.1.1 Simulation tool selection

A lot of simulation models are available for the simulation of urban traffic networks. Based on the model objectives requirements for this project a model can be selected, functionalities that the model should have are:

- Traffic responsive intersection can be simulated.
- Effects of instruments on traffic flow and speed have to be observed at intersections and road sections.
- Buses can be simulated as separate vehicle types according to a schedule.
- Route choice behaviour can be modelled.
- The modelled area is big enough to result into realistic traffic behaviour in the problem area.

A lot of models submit to these conditions. For the city of Eindhoven, a model built in Paramics is already available, if this model meets the demands as stated, it can be used for the case study. Another option would be to use the RVB tool which is often used as the GGB framework is applied. In table 4.1, the properties of both models are listed. Arguments to choose the Paramics software over the RBV are that the Paramics software is better in modelling detailed, urban networks. The need for accurate modelling of controlled intersections is also high in this type of models. Another reason is that the step size of the microsimulation model is significantly smaller. Given the type of network that is to be modelled in the city centre of Eindhoven and the model tool characteristics, the Paramics model is best suited for modelling the network in Eindhoven.

Regionale benuttings verkenner	s-Paramics
+ Dynamic route choice	+ Dynamic route choice
+ short simulation time	- Long simulation time
- Low level of detail	+ High level of detail
+ Quantitative recommendations	+ Quantitative recommendations
- Developed for application in regional networks	+ Suited for urban networks
- Step-size is measured in minutes	+ Step-size is measured in seconds
- Controlled intersections are modelled stochastically	+ Controlled intersections are modelled more realistically

Table 4.1: Properties of two available simulation tools, the applicable benefits regarding the choice of the Paramics model are highlighted green.

4.1.2 Reference model development

In order to do calculations for the 'strategische mobiliteitsagenda' for the municipality, Grontmij has used a Paramics model of the entire city of Eindhoven in the reference year of 2020. This model forms the basis for the model that is used in this research. In this research however, a subarea cordon version of this model is used. Losing the parts of the model which are outside of the research area, outside the city centre thus, can lead to significantly lower calculation times. the model is not yet suited for the application of dynamic traffic instruments. The traffic control schemes that are implemented in the model can not be adapted during model runs and traffic conditions cannot be evaluated during a model run. This makes it impossible to change for instance control schemes real-time.

The subarea cordon that is chosen is shown in figure 4.1. Traffic management measures are focused in one central area. Traffic behaviour outside this area however, can also influence traffic conditions in the focus area, and also roads outside this area have to be considered. These effects should stay visible in a smaller version of the model. This can be done either by manually adapting the OD matrix, or by leaving important roads outside the Centre in the subarea cordon. In order to define a functional subarea cordon, it is important to know which are the most important roads. This is done by looking at link intensities, and road priorities as set by the municipality of Eindhoven. Roads with high amounts of vehicles, and roads which are included in strategic plans such as Beter Bereikbaar Zuid Oost Brabant [6], should be included. Road users often have multiple routes available to approach the city, when the travel time on one route changes, this has an effect on the travel speeds on the other route. This effect will be lost if too much of the network is removed, therefore it is important to keep the main arterials in the network.

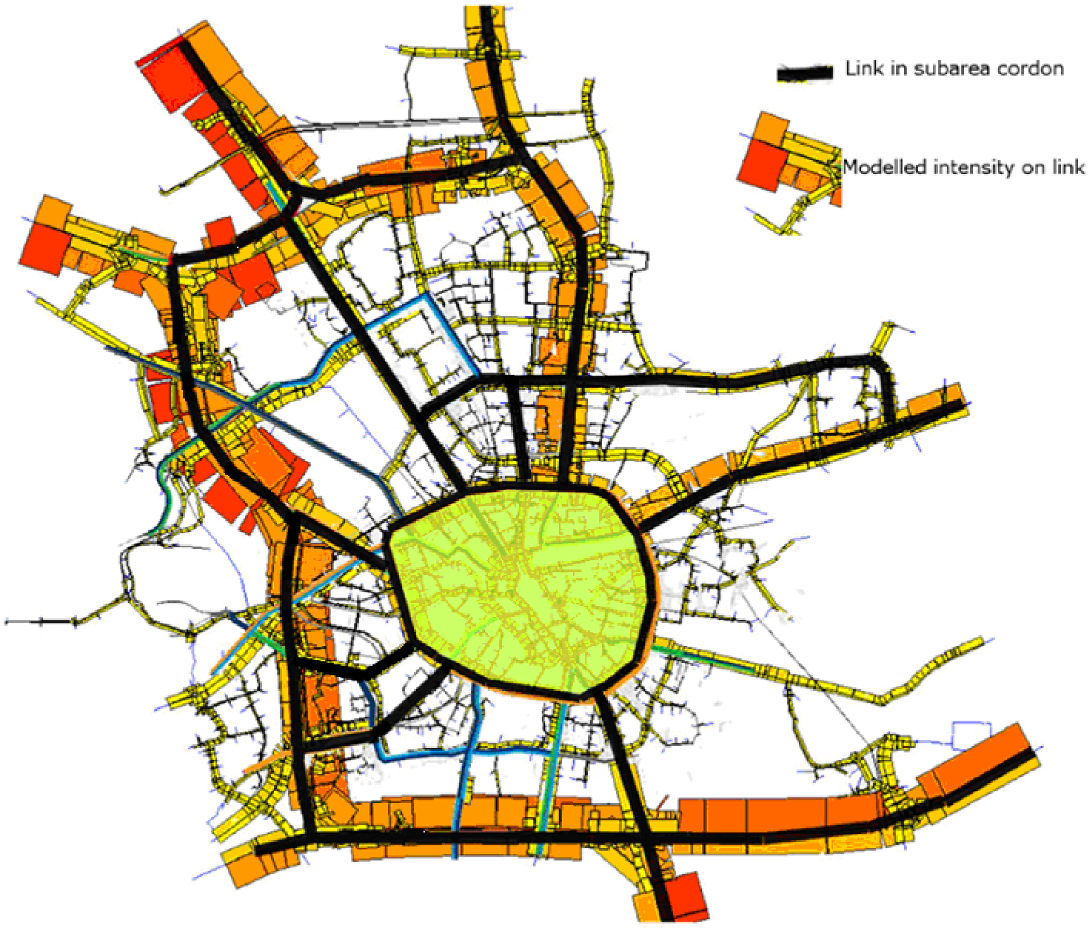

Figure 4.1: Seleced subarea cordon, against the road intensities and network priorities, Orange and yellow background-colours represent the intensities that are modelled, all black coloured roads and the green centre area are included in the final version of the model.

4.2 Model validitation

In this section construct validity of the developed model is tested. Since the model is constructed from an existing model, the validity of the original model should first be proven, this is discussed in section 4.2.1. For the developed reference model, four aspects are considered in this validation: validity of the OD-Matrix, validity of the link intensity, validity of travel times, and validity of route choice. These aspects are all relevant since they all need to be measured in order to determine the model performance on the policy goals. If the model is valid on these points, the model results can also be considered valid, hence, the model results are reliable. The reference model validation is discussed in section 4.2.2.

4.2.1 Original model validity

The validity of the original model for 2020, has already been proven in the modelbouwrapportage [17], results of this validation are briefly summarized in this section. The base-year model, representing the 2007 situation, is calibrated based on survey data which stems from 2006. In order to make a prediction for the traffic demand in 2020, every year a 0,5 percent traffic growth is applied. Additional to this, extra local vehicle productions and attractions are added based on development of housing and businesses. Network changes which have been planned to be finished by 2020 are also incorporated in the model. These changes have led to adapted VRI regimes at over 40 intersections [17].

In order to get reliable model results, the traffic density should be realistic from the start to the end of the data collection period. In order to do this, a warming up- and a warming cooldown period are included in the model runs. During these periods traffic is sent into the model at 70% of rush hour volumes, both periods last 1 hour. In between there is a two hour period which represents the rush hour. During these two hours 100% of rush hour traffic volume is sent over the network. Measurements that are reported all stem from this period. The total simulated time of each run thus, is 4 hours. Both morning- and evening peak can be simulated. Morning peak is simulated between 6 and 10 AM, the evening peak is simulated between 4 and 8 PM [17]. The difference between these peak hours is that there is more traffic in the afternoon rush hour, and the traffic flows are directed opposite to the flows during the morning, representing the trip from work-place to living place.

Four different OD matrices are present in the model which make a distinction between normal- and freight traffic, and also between rush hour and warm up/cooldown time.

- 1 - Normal traffic at rush hour volume
- 2 - Freight traffic at rush hour volume
- 3 - Normal traffic at 70% of rush hour volume
- 4 - Freight traffic at 70% of rush hour volume

By removing parts of the modelled network, the original bus routes cannot be modelled any more. The way paramics works is that buses cannot drive through the network when links on their route are missing. In order to still be able to observe bus traffic, the bus routes are only simulated inside the ring area with the original frequencies.

4.2.2 Reference model validation

The reference model is validated for factors subsequently in this section: validity of the OD-Matrix, validity of the link intensity, validity of travel times, and validity of route choice. For OD matrix validation and link intensity validation, the GEH statistic was used. The travel time validity is not done quantitatively, but travel time developments over time are compared quantitatively. For route choice validation, the results of a license plate survey carried out in 2007 in the city centre of Eindhoven was used.

OD matrix validation

In the process, a new OD matrix has been created using a special delivered tool. Where links have been cut, the OD amounts of the created zones should be the same as the intensities on the corresponding links in the original model. Because it would be too extensive to check validity for all created zones, a sample of 6 zones has been analysed for both Origin as well as destination traffic, these zones are shown in figure 4.2. Table 4.2 shows the results. A third important check is looking at route times compared between the subarea model and the original model. Travel times have been registered for vehicles on various routes and can be compared between both models.

Table 4.2: The new OD matrix is a good representation of the original model, deviations are small. (e) stands for extern, a new created zone, (i) for intern a zone, which exists also in the original model. The Morning rush OD matrix was used for this analysis.

	Origins			Destinations		
zone	Original	Subarea Model	GEH Value	Original	Subarea Model	GEH Value
38 (e)	3728	3731	0.05	1259	1264	0.14
167 (e)	519	479	1.79	2009	2022	0.29
293 (i)	10657	10323	3.26	7156	7143	0.15
72 (e)	777	827	1.77	755	727	1.03
297 (i)	14665	14166	4.16	10775	10792	0.16
186 (e)	2481	2414	1.35	1834	1773	1.44

Figure 4.2: Test locations for testing if external zones generate the correct amount of traffic, for this check, the GEH statistic is used

Differences can be explained by stochasticity and route choices which can differ from the original model.

Link intensity validation

Same as the validation of the original model, link intensities in both models can be compared. Difference is that in this model, all link loadings of both models are known. For the comparison of the models, the GEH statistic is used.

In the Wisconsin Microsimulation modeling guideline[18] it is stated that when 85% of the links in the model has a GeH below 5, further calibration efforts will only lead to small improvements in the results. In this situation, the GEH value can be calculated for all links in the subarea model. The average hourly vehicle count of 3 morning runs in the morning in the original model has been compared with the same count averaged over 3 runs in the subarea model. The average GEH value over all links was calculated to be 1.81. The percentage of links with a GEH statistic of lower than 5 is shown in table 4.3.

Table 4.3: GeH statistic of the comparison between the original model and the subarea model for the morning rush situation

	# links	GEH < 5	% GEH<5
7:00-8:00	3873	3556	91.8%
8:00-9:00	3878	3699	95.4%
Total	11589	10877	93.9%

The overall GeH values give little reason to doubt the validity of the subarea model. On specific locations in the model big differences are still possible. However the average GEe value is pretty low, there are still 28 links with a GeH statistic higher than 10. After checking the network it can be stated that these locations are not at critical points in the network. These points occur on the edges of the network where minor changes in the network layout were applied in order to make the subarea cordon. They can cause different counts on local levels, but don't affect the bigger network. On the main roads, as well as all routes relevant for this research, these high values do not occur.

Route travel time validation

The above has proven that the amount of vehicles in the subarea model is representative for the original model. Another important factor, are travel times and average speeds. These can be compared by looking at route times in both the original and the subarea model. This is not a scientific analysis, but it can be used to indicate validity of traffic behaviour in the model. The averaged route travel time over 3 runs has been compared between both models. Travel times were obtained by averaging the travel times over 5 minute intervals. This procedure has been done for 23 different routes across the City Centre. An overview of these routes is shown in figure 4.3.

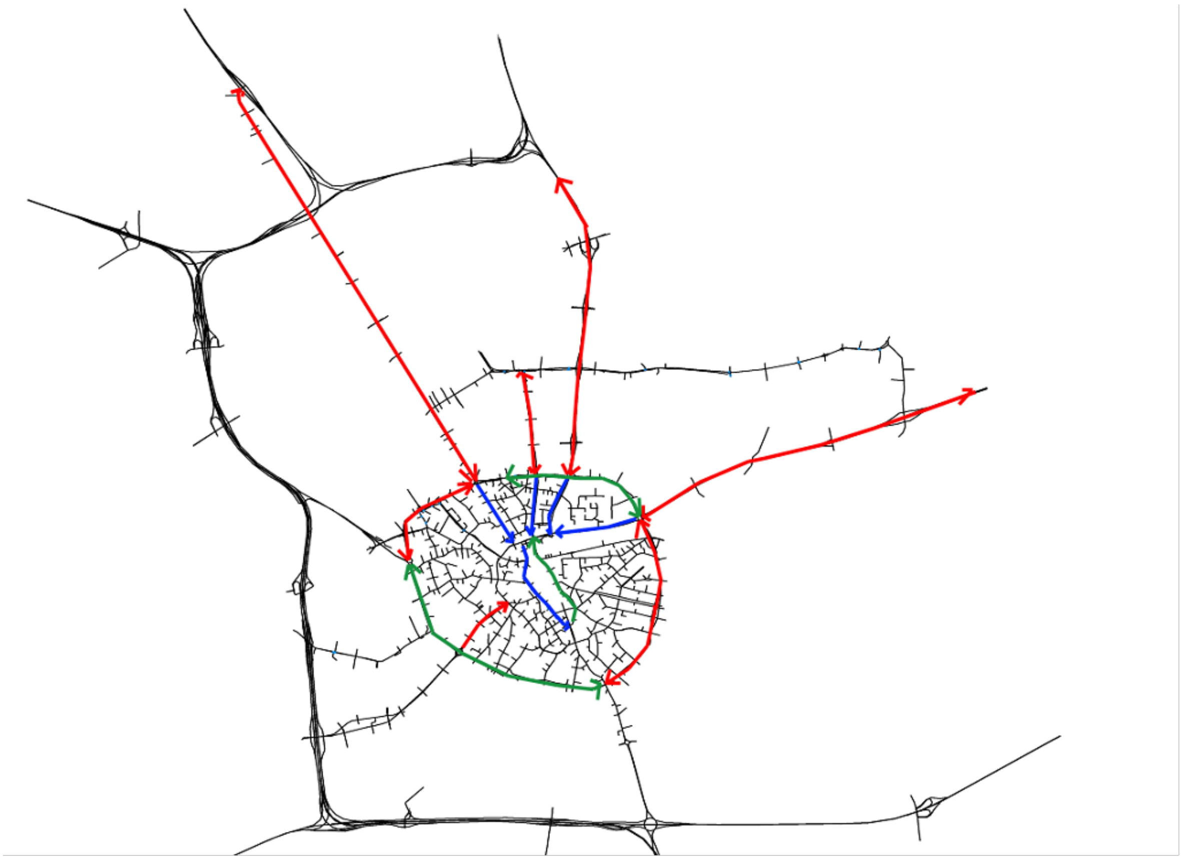

Figure 4.3: Paths used to analyze route travel times for this analysis.

In figure 4.4, route times at the Montgommerylaan and Eisenhowerlaan are shown. The travel time pattern in both models is similar, and, with the previous parts in mind, there is no reason to suspect differences between the models. Also the other 21 paths there are no anomalies, route times are very similar and both models.

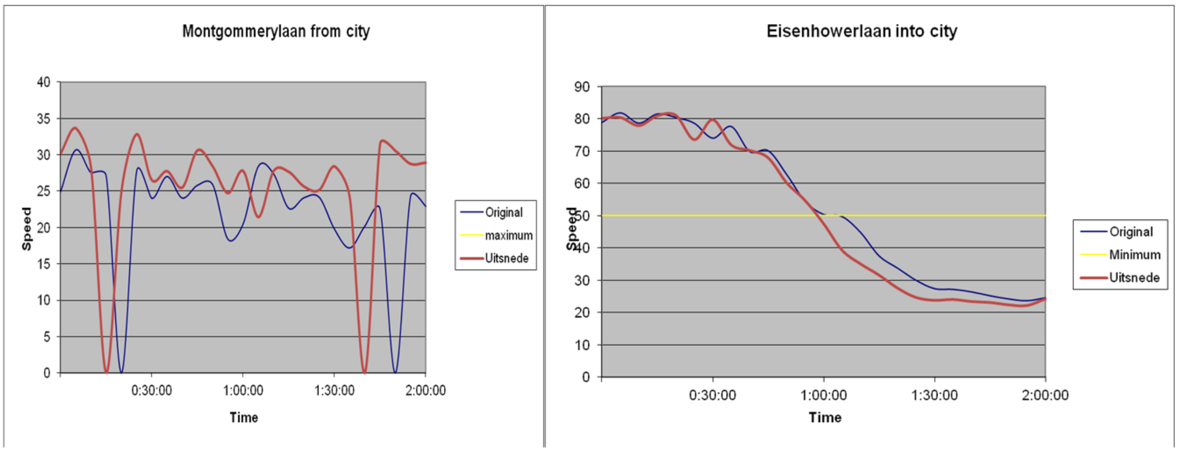

Figure 4.4: Route times over time compared between the two models at the Montgommerylaan and Eisenhowerlaan. Each line represents a 3 run average.

Route choice validation

In order to verify the validity of the route choice in the model, the amount of through traffic measured in the model is compared with the amount of through traffic that was measured in the license plate research in 2011 [5].

Route costs in the model are calculated by adding all separate link costs of that route. The formula which is used to determine the link costs is shown in equation 4.1.

$$C = L_{cost}(1 * T + 0.25 * D) \tag{4.1}$$

Where:

$$\begin{aligned} L_{cost} &: \text{Link cost factor determined the roadtype} \\ T &: \text{Link travel time} \\ D &: \text{Link length} \end{aligned}$$

The link cost factor is determined by the link specific road type, it can vary between 0.8 and 1.2.

When the model results are compared with the survey that was executed, it can be seen that through traffic estimations in the model are relatively low compared to the survey counts. In table4.4 the comparison between counted and predicted route choice of the 10 most used routes through the city centre has been made.

Table 4.4: Comparison between actual traffic counts (KTO research, [5]) of through traffic and predicted through traffic by the model itself over the 10 most popular OD pairs for through traffic during the busiest hour of the morning peak.

	# of cars through the Centre	
Route	**Survey**	**Model**
Kennedylaan - Eisenhowerlaan	50	0
Eisenhowerlaan - Kennedylaan	29	
Noord Brabantlaan - Eisenhowerlaan	29	9
Karel de Grotelaan - Kennedylaan	29	6
Aalsterweg - Kennedylaan	28	
Leenderweg - Montgommerylaan	25	14
Eisenhowerlaan - Bosdijk	23	16
Kennedylaan - Karel de Grotelaan	23	36
Eisenhowerlaan - Karel de Grotelaan	20	2
Karel de Grotelaan - Eisenhowerlaan	19	3

No traffic over the ring was measured in the survey. Ring traffic can thus not be compared with the traffic in the model. To compare total traffic volume between the survey and the model, traffic volumes at the Mauritsstraat can be analysed (see figure 4.5). Traffic flows in the model are higher than traffic flows in measured in the survey. The model is expected to have more traffic since there will be a growth of traffic towards 2020. When analysing through traffic in the model, a similar growth might be expected, but this is not necessarily the case, since a trend breach is possible. In the model, there is a relatively small amount of through traffic compared to the survey (see table 4.4). From this observation it can however not be concluded that the route choice function that is implemented has to be reconsidered. It is possible that the rise in through traffic and the rise in total traffic volume is not equal since traffic patterns can change as the network gets towards its capacity. It is thus not possible to validate the route choice for 2020 based on measurements originating from 2011.

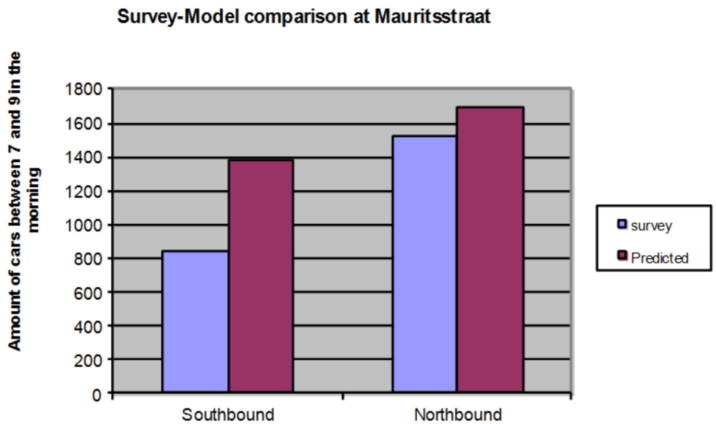

Figure 4.5: Comparison between KTO survey of 2011 and the model predictions for 2020

Validation conclusions

In this part, the GEH statistic has been used in order to validate the model. It has led to the conclusion that out of a small sample of the new created zones, the GEH statistics are all below the limit of 5. As well as 94% of all 11589 links in the sub-area model. Bottom limit for this percentage has been determined to be 85%. It is not possible to validate the model based on measurement, since there is no data available to compare route choice. This together makes that the sub-area model that has been developed for this report is considered valid.

4.3 Sample size

Equation 4.2 shows the formula that is used in order to determine the desired sample size for this model. In this section, each variable is discussed separately. Based on test runs the sensitivity of 4 important parameters can be calculated and a choice on the desired sample size is made.

$$n > \frac{Z^2}{d^2}\sigma^2 \tag{4.2}$$

Where:

n : desired sample size.
Z : value depending on desired confidence interval.
d : size of the confidence interval.
σ : the standard error of the sample.

z-value

The sample value that is chosen co-determines the desired sample size, checking the sample size for all sample values is not possible. If the desired confidence level is 95 percent confidence with a two tailed distribution, this value is set at 3.182. In case of a normal distribution (an infinite sample size), this would be 1.96. Z values can only be used for normal distributed variables. When the distribution is not known, the two sided t statistic can be used.

d

The confidence interval should be as small as possible. An accuracy value of 60 seconds with a 95 percent confidence level means that it can be said with 95 percent certainty that the true value lies within 60 seconds of the measured average. This means the value could be within 60 seconds of the average, at both size. Thus, the total confidence interval will be 120 seconds. The effect of the chosen d on the desired sample size is quite large, this will be explained in the following.

σ

Standard error can be calculated using equation.

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

where:

- N is the sample size, in this case 3.
- x_i is the sample value
- μ is the sample average

Variable selection

Ideally the confidence interval needs to be determined for every relevant traffic variable that is measured in the model. With a model of this size, this is however not possible and the desired number of confidence intervals can only be determined for a limited number of variables. These variables need to be representative for the variables that are going to be measured in the model. Some relevant variables which indicate the general traffic state in the model are relevant, but also variables specified to the specific problem locations. In the problem analysis, it was indicated that the flows in the city centre are relevant, for measurement of city centre flows, the flow on the Fellenoord is measured. Also the minimal trajectory speeds for the roads outside the city centre are relevant. For this, the average speed on the Kennedylaan is measured. The following specific items are measured:

- The averaged trip time in seconds between 7:50 and 8:10 in the morning (general statistics).

- Average link speed in km/h over all links (general statistics).

- The flow on the busiest part of the Fellenoord averaged between 8 and 9 in the morning in cars per hour (accessibility).

- Average speed on the Kennedylaan between 7 and 8 in the morning in km/h (minimal trajectory speeds).

In this case the t-statistic needs to be used since a normal distribution of the variables can not be proved. Samples consist of 4 values collected from 4 different model runs. This makes the degrees of freedom for the used t-value 3. Note also that for most variables that will be measured for the further analyses, the confidence interval will not be known.

Results

The formulas presented in this section can be applied for model results for the reference situation. Based on these results, confidence intervals can depending on sample sizes can be calculated. There is two ways of determining the desired sample size for significant model results. The desired (95 %) confidence interval can be the leading indicator, or the number of model of model runs determines the specific confidence interval. In this case it has been chosen to let the confidence interval depend on an acceptable amount of model runs. In figure 4.6 the sample size is plotted against the confidence interval that is met with this sample size. The shape of the line implies that the first couple of extra model runs lead to a steep decrease of the confidence interval, which is desirable. As the sample size increases, extra model runs only result in a very small decrease of the confidence interval.

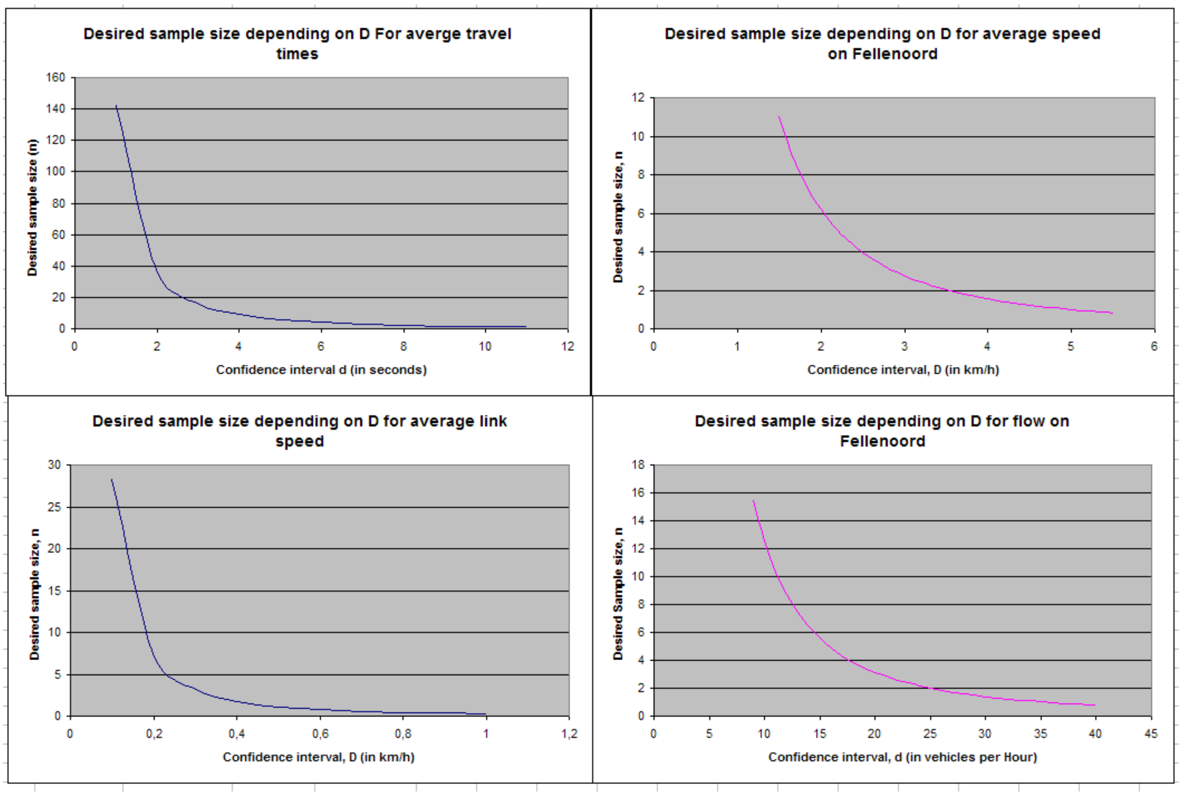

Figure 4.6: Effect of confidence interval on desired sample size on the different measured factors. As the confidence interval gets smaller, the desired sample size increases quickly

All graphs in the figure show a clear bend. This is for the average link speed, average speed on the Kennedylaan and average flow on the Fellenoord around a sample size of 3 to 5 model runs. In order to limit the calculation time needed, the sample size should be as small as possible. The confidence interval for the four factors considered with a sample size of three are shown in table 4.5. These are acceptable confidence intervals, thus the sample size does not have to be larger than 3.

Table 4.5: Confidence intervals of the tested variables with a sample size of 3 runs

	Average	Standard Deviation	3 run Confidence interval
trip time (s)	792.2	28.1	7
Flow on Fellenoord(cars/hr)	860.0	29.3	21
Average Link Speed(km/h)	33.2	5.8	0.4
speed Kennedylaan(km/h)	51.2	7.2	2.9

4.4 Model design summary

Given the dense urban network that is considered, the microsimulation tool Paramics is used to develop a model suited to model the instruments that are designed in this research and measure their performance at the indicated problem locations. As a basis for this model, an existing model for the traffic situation in the greater Eindhoven area forms the basis which is reduced to a smaller network size which decreases calculation times.

Out of a small sample of the new created zones, the GEH statistics are all below the limit of 5. As well as 94% of all 11589 links in the reference model. Bottom limit for this percentage has been determined to be 85%. Also route times in both models are similar. Route choice is built in to the model but cannot be validated due to the fact that there is no useful data available to verify the route choice in the model.

Based on a test batch of the created reference model, the desired sample size is determined to be 3.

Chapter 5

Assessment framework

In order to be able to successfully assess the performance of the proposed instruments *and* alternatives, key performance indicators have to be determined in order to do this. The policy goals are translated into traffic variables which can be obtained from the simulation model. The reference values of the performance indicators are determined based on model results. The reference values form the basis of a multi criteria analysis in which all instruments and alternatives can be compared. A framework for the general performance of the network is presented in this chapter. The research question that is answered in this chapter is:

What method and which indicators can be used to assess the traffic performance for the city centre of Eindhoven?

In consultation with the municipality it has been concluded that car accessibility is the main factor to be optimized. This should be optimized under certain preconditions. This means the NO2 concentration should nowhere exceed 40μg/m3, also the accepted trajectory speeds in BBZOB should always be met. In this chapter a framework is built in which these factors can be effectively measured and compared between several model set ups. In section 5.1, the accessibility indicators are discussed, part of this section focuses on traffic flow, also the amount of through traffic is considered. Section 5.2 discusses how the minimal trajectory speeds must be monitored. How the vehicle emissions must be measured is discussed in section 5.3. Slow mode accessibility indicators are described in section 5.4. How these factors can be combined into a multi-criteria analysis is shown in section 5.5.

5.1 Accessibility

This factor has the highest priority and should be the main goal of a traffic management strategy. Indicators for accessibility are route speed, flow and through traffic. These are relevant for the area within the ring. Because the goal is to reduce the traffic flow at the main roads in the city centre, a distinction has to be made between the roads in the city centre, and the Ring roads and other arterial roads outside the city centre.

Outside the city centre, only BBZOB agreements are important. If roads leading towards the city centre or outside the city centre get less accessible, this is accepted as long as the BBZOB agreements are not violated; the goals for roads outside the city centre have been established in the agreements within the BBZOB program. These boundaries should be considered, and are discussed in section 5.2.

5.1.1 Travel time and traffic flow

Because a large network is considered where route choice is included, the flows on the measured roads are not equal throughout the alternatives. Making it impossible to combine the factors travel time and traffic flow into one factor. In order to indicate the accessibility of a solution, travel time averages and flow averages need to be considered separately.

Both in the city centre and on the ring traffic flows and vehicle travel times are measured on various trajectories. The roads for which this is done are the most important distributor roads in the city centre where the speed limit is 50 km/h. Next to the travel times on the distributor roads within the city centre, the ring around the city centre is also considered. In line with the policy goals, the target values are reduced flow on the distributor roads, and increased flow on the ring roads. The paths that are measured in order to indicate accessibility in the city centre are shown in figure. 5.1.

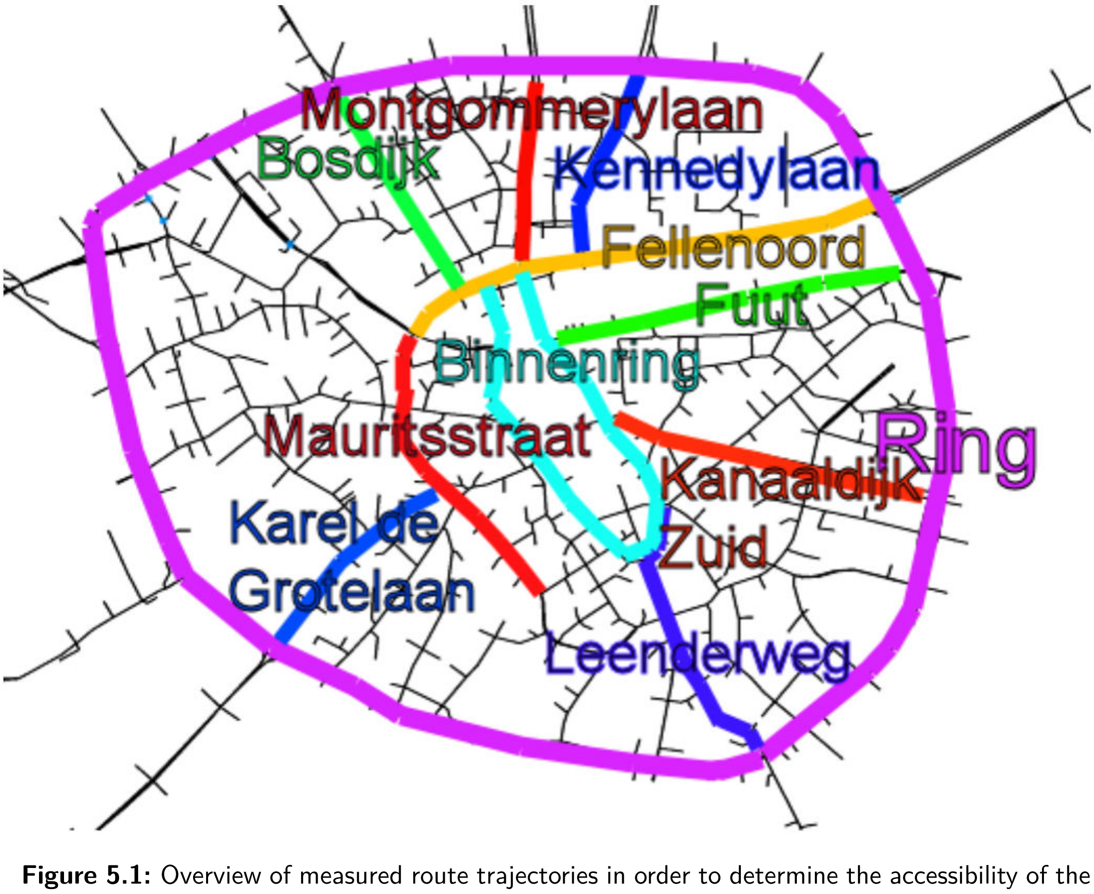

Figure 5.1: Overview of measured route trajectories in order to determine the accessibility of the city centre

The flow on the measured route is determined by averaging the flow on each link in the route. The link length has to be taken into account when averaging the route flow; the longer the link length, the higher its impact on the route flow.

The second indicator for accessibility in the centre are travel times over important routes in the city centre. In order to calculate the average travel time over all measured distributor roads, the flow on the several travel times also needs to be included. A travel time should impact the average travel time equal to the flow on the specific route. Equation 5.1 is used to calculate the average travel time per alternative.

$$TT_{average} = \frac{\sum_{routes}^{n} (TT_{routespecific} * flow_{routespecific})}{\sum_{routes}^{n} (flow_{routespecific})} \tag{5.1}$$

Using this method, accessibility results for the reference situation are shown in table 5.1. In order to compare these numbers with the results of the alternatives; in the comparison, these numbers will all be indexed at a 100 for the reference situation. This puts the results into proportions and makes them better comparable.

Table 5.1: Accessibility results in the reference situation

	City Centre	Ring
Morning		
Travel time (s)	189	1246
Flow (Vehicles/hour)	701	1005
Afternoon		
Travel time (s)	249	1637
Flow (Vehicles/hour)	656	1095

5.1.2 Through traffic

Through traffic in the model focusses on two routes, In the West to East direction, there is through traffic over The Fellenoord and Mauritsstraat, and in the North to South direction, there is through traffic over the Boschdijk and Binnenring (figure 5.2)

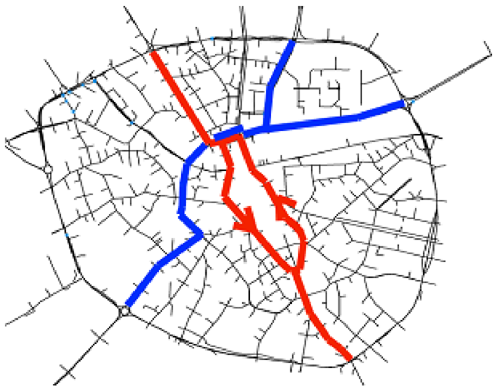

Figure 5.2: Common routes used by through traffic

Through traffic over these routes is measured by looking at route choice behaviour the traffic in both directions. This is done with the use of selected link analyses. Traffic on these routes has 2 options: using the ring road or using the roads in the city centre, which one they choose depends on the travel time on both alternatives. Results for the reference situation are shown in figure 5.3. During the morning rush most vehicles are measured over the ring, whereas most road users during the afternoon use the city centre roads.

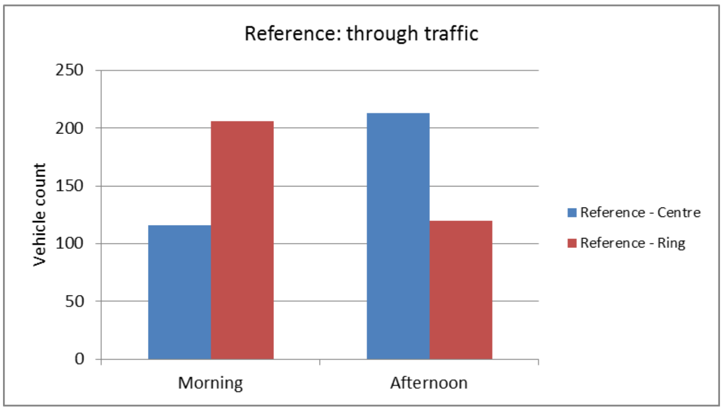

Figure 5.3: Through traffic in the reference situation during the morning- and afternoon rush.

5.2 Minimal trajectory speeds

In the strategic mobility agenda for the region of South East Brabant, Beter Bereikbaar Zuid Oost Brabant (BBZOB, [6]). Minimum speed goals for the main arterial roads are set, average speeds on the roads should always be higher than this minimal speed. If the average speed on a route does not match the minimum speed, it is defined a bottleneck route (Dutch: kneltraject). This means policy has to be made in order to improve flow over that stretch of road [6].

Figure 5.4: Overview measured BBOZB routes

A total of 16 potential bottleneck routes has been defined in this part of the network, these routes are shown in figure 5.4. Travel speeds can become too low during the morning rush and or the afternoon rush. Furthermore, a distinction will be made between an occasional unacceptable drop in travel speed and an average below the minimum speed, indicating the severity of the situation. These rules are applied to a rating system: for every route a point will be assigned if:

- The average speed on the route during the morning rush is above the critical value.
- The minimal 5 minute average speed on the route during the morning rush is above the critical value.
- The average speed on the route during the afternoon rush is above the critical value.
- The minimal 5 minute average speed on the route during the afternoon rush is above the critical value.

By adding all points that are earned in an alternative, the minimal trajectory speed score can be indicated per alternative. Per route, a score of 4 could be assigned, with 16 routes, this amounts to a total conceivable score of 64.

The five minute average speeds are used to represent instantaneous speeds. Average low speeds score twice the amount of points of instantaneous low speeds. Only measuring either instantaneous- or average speeds would also be possible. The two point system is chosen to conserve more of the original travel time variation and still consider each location separately.

Along the trajectories of these roads, travel speed measurements for individual cars can be done in the model. The results for the reference alternative for minimal trajectory speeds are shown in figure 5.5. A total score of 33 is achieved in the reference model, this equals 52% of the maximum score.

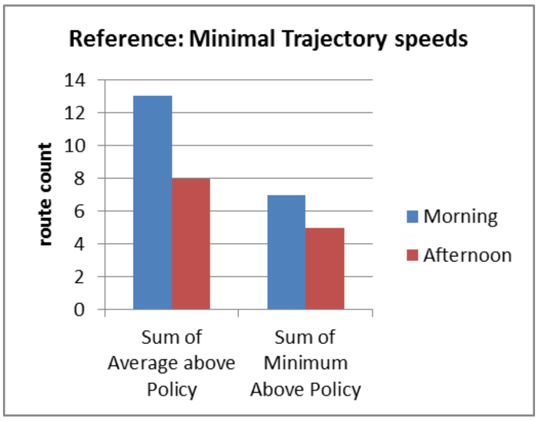

Figure 5.5: Indication of the measured route count where the minimum speed is met (the total possible score is 32).

5.3 Vehicle emissions

The emissions could change in the entire affected area. Also problem locations outside the city centre of Eindhoven should be taken into account.

In order to monitor the environmental effects, traffic flow at the problem locations is the best indicator. However no exact knowledge about concentrations of hazardous gases in the air cannot be deduced from traffic flows, since there is no exact information about emission levels available. Traffic conditions can be measured and can also give an indication of the changes in emission levels. The traffic indicators that will be used in order to assess the environmental developments around the problem locations, the total amount of vehicles for every single location is measured.

The average flows at the environmental locations in both directions are shown in figure 5.6. In order to be able to compare these values between alternatives, just like with accessibility, they will be indexed at 100.

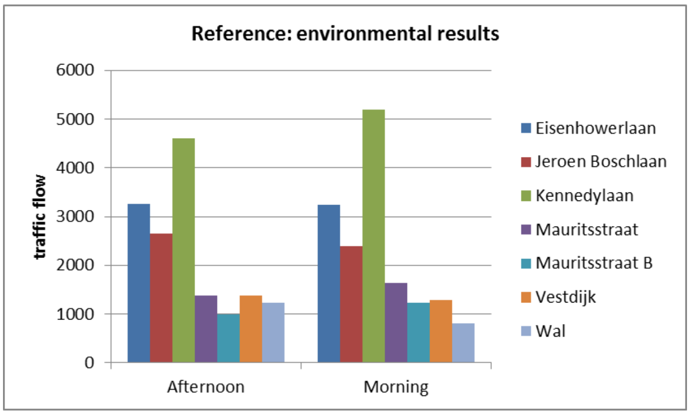

Figure 5.6: Overview of flows at environmental locations

A deterioration of the indicators does not immediately lead to unacceptable concentrations of NO2 and PM10 in the air. But they are the best indicators that are available. At The Kennedylaan the values found in the reference situation are an absolute maximum, at the Jeroen Boschlaan, the Keizersgracht/Wal and the Eisenhowerlaan, pollution values have almost no room for deterioration, so these values are also absolute maxima. Only at Vestdijk and Mauritsstraat a slightly worse situation is within accepted bounds. For environmental locations, a target should be set which has to be the benchmark to assess an alternative or instrument. Some detail is lost in the multi criteria analysis since all information on vehicle emissions is summarized in one number. This number includes traffic flow at all environmental locations averaged over morning- as well as afternoon rush. The target for this average is 95% of the average traffic flow at environmental locations measured in the reference situation. Averaged over all locations, the traffic flow should be 2125 vehicles/hour. This number only shows the average performance of the tested scenario. Individual environmental locations should still be analysed in additional traffic analyses.

5.4 Slow mode Accessibility

The two intersections which are selected to indicate slow mode accessibility in this research are Boschdijktunnel - Mathildelaan and Vestdijk - 18 Septemberplein. In the beleidsnota verkeerslichten [3], the accepted quality of pedestrian and bicycle crossing time is defined by the average waiting time in seconds, depending on the characteristics of the crossings. Both selected intersections are marked as ‘zeer drukke voetgangersstromen’. Which means the accepted average waiting time is 20 seconds [3] and part of the ’primair fietsroutenetwerk structuur’, which means that the accepted average waiting time for cyclists is also 20 seconds. Since pedestrians and bicyclists are not simulated in the model, average waiting times cannot be indicated. What can be indicated is the average flow at the critical intersections. Average waiting time for slow traffic, is strongly dependant on the traffic flow on the road.

The flow in the reference situation is the starting point for estimating the critical flow. From observations at the intersections themselves, it seems that the cycle times during rush hour are about 75 seconds, where the average green-time is on average 17 seconds. These data can be linked to the average flow at an intersection if linearity is assumed. The average waiting time can be deduced using Cycle time and greentime data using equation 5.2

$$T_{wait} = \frac{T_{Cycle} - T_{Green}}{T_{Cycle}} * (T_{Cycle} - T_{Green}) * \frac{1}{2} + \frac{T_{Green}}{T_{Cycle}} * 0 = \frac{(T_{Cycle} - T_{green})^2}{2 * T_{Cycle}} \tag{5.2}$$

Where:

- T_{Cycle}= Average Cycle time
- T_{Green}= Average Green time

In table **??** the observed data is summarized and based on these, average waiting times during the off peak period, a simulation that is done between 10:00 and 14:00, and the (afternoon) peak period have been calculated using equation 5.2. For both intersections, also the flow averaged over all turns at the intersection is measured for both intersections. These are reference flows in order to estimate a linear function where this average flow is dependant of average waiting time. Linear equations can be deduced from this data. Equations 5.3 and 5.4 show the resulting formulas which can be used to estimate the average waiting time for pedestrians in the alternatives.

Table 5.2: pedestrian crossing time calculation inputs.

Period	Off - Peak	Peak
T-cycle (s)	60	75
T-green (s)	17	17
T-wait (s)	15,41	22,43
Flow 18 Septemberplein - Vestdijk (veh/hr)	162,46	409,9444
Flow Boschdijktunnel (vey/hr)	63,38	90,24

$$T_{waitVestdijk} = 0.028358 * flow + 10.80126 \tag{5.3}$$

$$T_{waitBoschdijktunnel} = 0.2686275 * flow - 1.1535 \tag{5.4}$$

5.5 Multi-criteria analysis

In this chapter, it has been described how the separate indicators can be measured using the model input. To compare these indicators in a single overview, the multi-criteria analysis is used. In this section, a total of 5 different indicators have been discussed: Accessibility, through traffic, minimal trajectory speed, vehicle emissions and slow mode accessibility. There are no critical values for accessibility and through traffic. For these indicators, the highest value is chosen. The higher these values the better. For minimal trajectory speed, vehicle emissions and slow mode accessibility, limit values have been determined in this chapter. This multi criteria analysis only gives a global insight in the performance of the alternatives. For each aspect, performance is indicated with one or two indicators, making the information very compact, some detail is lost this way. The multicriteria analysis for the reference is shown in figure 5.7. In this overview, all actual values are presented, in the actual multicriteria analyses, the relative changes compared to the benchmark or reference values are considered. In the explanation below, the calculation method for each criterion is discussed. This assessment framework is used for analysing the separate measures in chapter 7.2 and also for analysing the aggregate alternatives in 8.

Indicator	Benchmark	Reference
Accessibility	Sample optimal result	
City centre flow	Decrease	679 veh/hr
Flow on Ring	Increase	1050 veh/hr
Through traffic	Sample optimal result	
City centre traffic	Decrease	329 veh
Ring traffic	Increase	326 veh
Minimal trajectory Speed	Maximum score = 64	-48%
Vehicle emissions	Target flow < 2125 veh/hr	5%
Slow mode accessibility	Target average < 20s	10%

Figure 5.7: Performance indicator values for the reference situation and benchmark values.

Accessibility For accessibility, both flows and speeds are important. In the city centre, goals primarily relate to traffic flow, and traffic speed is a tool to reach a lower traffic speed. As the traffic flow becomes lower (positive), the traffic speed will also go down (negative). With this strong correlation, it has been chosen in the multi criteria analysis to only consider traffic flows. In more extensive analysis of the results, the traffic speed on these roads should not be forgotten.

Flows on the Ring and flows through the city centre are considered separately. A high average flow on the ring, and low average flows through the city centre are the goal. There is no benchmark value for the factor accessibility, instead the indexed change of traffic flow compared to the reference situation indicates the performance. Since the reference situation logically does not deviate from the reference situation, this makes the reference situation automatically score 0%. The indexed change of traffic flow on the ring and the indexed change of traffic flow in the city centre are added up in order to indicate a total accessibility score.

Through traffic Same as for accessibility, there is also no benchmark value for accessibility. The through traffic values in the reference model thus also form the benchmark value. This is done for the city centre route and the route over the ring, where the count over the ring route needs to increase, and target for the city centre is to decrease the vehicle count. These scores must be added up in order to get an overall through traffic indicator.

Minimal trajectory speeds For this indicator, the amount of routes per alternative is measured where the minimum and/or average speed is above the minimal trajectory speed for that route, this is done for both morning and afternoon rush. For case in which the minimal speed is exceeded, the score for the measured alternative goes up by one. An optimal score would be 64. The performance indicator is the percentage of the highest possible score that is reached in the tested measure or alternative.

Vehicle emissions The environmental score represents the decrease in traffic flow averaged over all environmental locations. The benchmark environmental score is 2125 vehicles per hour. The performance indicator shows the indexed deviation from this benchmark.

Slow mode accessibility The minimal average waiting time is calculated based on the total flow at all intersection lanes. The goal is to achieve an average waiting time of 20 seconds. The average waiting time is an average value of the two measured intersections.

5.6 Assessment framework summary

In this chapter, a framework is built based on which the performance of the instruments and alternatives to be tested can be measured. The central element in this framework, is the multi criteria analysis. There are 5 main criteria which have to be met:

1. Accessibility, consisting of traffic flow in the city centre and traffic flow on the ring.
2. Through traffic; containing cross-city centre traffic taking city centre roads, and cross-city centre traffic taking the ring road.
3. Minimal trajectory speed, where the number of rushes is counted per road where this minimal speed is met. The maximal score for this benchmark is 64.
4. Vehicle emissions; represented the flow averaged over all 7 environmental locations. The benchmark flow is 2125 veh/hr on average.
5. Slow mode accessibility; the average waiting time for pedestrians over the two measured intersections. The benchmark waiting time is 20 seconds

This multi criteria analysis can be used when the instruments and alternatives are compared. In order to compare the values of instruments and alternatives, index values must be used.

Chapter 6

Traffic analysis

In this step a detailed analysis of the traffic state in the reference situation is done; bottlenecks and possible buffer locations are analysed. The result of this step is an overview of the different actual bottlenecks and problem locations for the different traffic phenomena. The following sub-question is answered in this chapter:

Which problem locations in the city centre of Eindhoven can be identified for considering the traffic management goals?

The analysis in this chapter checks all performance indicators in more detail. First an overview of traffic speeds in the reference situation is presented; this is done based on the assessment framework. After this, specific bottlenecks are analysed in order to see where low travel speeds can arise. In the section on options for redirecting, first traffic is categorized in order to identify whether there are chances for the redirection of traffic. After this, an overview of the strategic routes in the network and their attractiveness is presented, in order to specify roads which are suited for traffic management and redirection options.

6.1 General traffic analysis

In this section, average traffic speeds and -flows for the reference situation on important roads in the network are discussed. This is done separately for the city centre roads and the arterial roads around the city centre.

6.1.1 City centre

For the city centre it can be seen where major points of congestion are looking at local mean speeds. In figure 6.1, only road sections with a 70km/h speed limit and a 50 km/h speed limit are shown where measured speeds in the reference model are at least 20 km/ under the speed limit. It is important to notice that these are local speeds and traffic lights could have a high influence on these measurements.

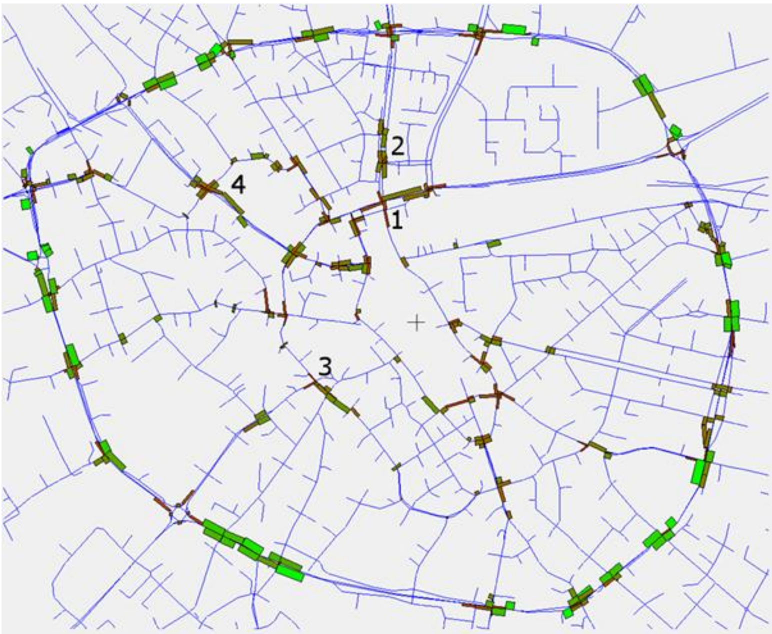

Figure 6.1: Locations in the city centre where modelled local speed is at least 20 km/h lower than the speed limit, averaged between 8:00:00 and 8:15:00.

At Multiple locations on the ring road, as well as in the city centre congestion is occurring. The most important Congestion areas in the centre are Fellenoord (1), Mongommerylaan (2), Mauritskade (3) and Mathildelaan (4) (see figure 6.1).

In the assessment framework, route travel times are all summarized in one number, in order to see where problems could occur, separate route travel times and flows need to be considered. Table 6.1 summarizes the travel times and traffic flows on the important city centre road for the entire period. Detailed travel time developments of these routes can be found in appendix 10.2.

An important axis through the city centre is The Fellenoord – Mauritsstraat axis. Travel times on the Fellenoord are stable and limited, with average speeds at about 30 kilometers per hour. Given the permitted speed of 50 kilometers per hour this might seem low, but a 50 kilometer per hour average will never be met given the effect of the controlled intersections. At the Mauritsstraat, travel times are acceptable, during the morning, although they vary more; but in the Afternoon, they drop by 10 to 20 kilometers per hour, which is too much.

The second important axis in the centre of Eindhoven, is the Binnenring. In both directions of the Binnenring, travel times in the afternoon are significantly smaller. On the Eastern part of the binnenring, where traffic is going towards the northern direction (the Binnenring is a one way ringroad). Travel times in the morning are also slightly decreasing towards the end of the rush hour.

Table 6.1: Travel times and traffic flows on roads inside the city centre, this is the collection of routes which is used in order to determine accessibility.

	Flow (veh/hr)		Travel time (s)	
	Morning	Afternoon	Morning	Afternoon
Binnenring East	1085	1228	219	290
Binnenring West	852	1128	189	288
Fellenoord Eastbound	677	1142	278	331
Fellenoord Westbound	1027	799	274	275
Fuut	288	270	117	126
Kanaaldijk Zuid	257	360	104	139
Mauritsstraat NorthBound	751	663	193	275
Mauritsstraat Southbound	606	492	226	391
Karel de Grotelaan	502	468	220	264
Kennedylaan	1187	774	95	104
Leenderweg	805	492	219	197
Montgommerylaan	477	564	115	128
Bosdijk	685	522	155	251
Prof. doc. Dorgelolaan	883	454	120	118
Strijp S	404	438	268	303
Average City Centre	701	656	189	249
Average Ring	1005	1095	1246	1637

Two other roads in the city centre where travel times need to be improved are the Bosdijk and Karel de Grotelaan. Both have a minimum accepted speed according to the BBZOB agreements, and both do not reach this speed in one or more occasions [6]. On the Karel de Grotelaan, the differences are the biggest. However, this is a 50 km/h road with a 35km/h minimum speed, and as we have seen in the earlier examples on the Fellenoord and Mauritsstraat, it is very hard to even reach 30 km/h on a 50km/h urban road with controlled intersections. But the speeds that are reached now on the Karel de Grotelaan both during the morning, as well as the afternoon rush, can be significantly improved. On the Boschdijk, travel times during the morning situation is not entirely stable, but speeds are not alarmingly low, in the afternoon however, speeds are very low and they drop below the 20 km/h minimum accepted speed at that location.

Although in the examples given above it may seem that travel times on 50 km/ roads in the city centre can never actually reach travel speeds towards 50 km, this is not the case. At the roads Kanaaldijk Zuid and fuutlaan, average speeds of almost 50 are reached. This is probably due with the fact that there are no controlled intersections on both these routes. At the Kanaaldijk Zuid, it can be seen that the travel time speeds are most critical in the morning rush hour, contrary to what is seen in most data in the City Centre.

6.1.2 Arterial roads

Important information about the roads outside the city centre is the question whether minimal trajectory speeds are met on these roads. In table 6.2, average and minimal speeds on these roads have been compared with the bottom limit speeds on these roads. It is clear that there is a lot of work to do in order to get speeds on all these road sections above the minimum limit, since the minimum speed is only met in 32 out of a hundred measurements. Furthermore, it can be concluded from this table that the larger part of speeds below the minimum occur during the afternoon rush. It seems very unlikely that all official congested roads (kneltrajecten) will improve sufficiently in any alternative; however, a reduction of the number of congested roads can be realized in multiple alternatives. Detailed speed-time graphs are shown in appendix 10.2.

Table 6.2: Minimal trajectory speeds that have been measured for the reference situation, both average travel speeds over two hours and the 5 minute averaged minimum have been considered.

Road	Morning	Afternoon	Morning minimum	Afternoon minimum	Morning average	Afternoon average
Kennedylaan into City	45	45	59.0	22.5	63.1	36.1
Kennedylaan From City	45	45	72.9	51.3	74.6	68.4
Bosdijk Into City	-	35	36.4	22.0	39.7	30.0
Bosdijk From City	35	-	37.9	22.1	42.3	33.0
Tilburgse weg into City	45	35	62.3	51.2	67.9	64.3
Tilburgse weg from City	35	45	76.9	76.8	77.6	77.5
Meerenakkerweg into City	35	35	25.8	17.1	29.0	21.9
Meerenakkerweg from City	35	35	28.8	25.6	31.2	29.5
Karel de Grotelaan into City	40	40	30.8	23.5	32.6	27.2
Karel de Grotelaan into City	40	40	32.3	29.3	34.6	32.2
Leenderweg Into City	35	35	32.9	17.8	39.1	24.9
Leenderweg From City	35	35	33.6	34.0	37.8	38.2
Eisenhowerlaan into City	50	45	22.6	62.7	51.0	77.2
Eisenhowerlaan from city	45	50	82.6	82.0	87.1	85.1
Karel de Grote Inside City	35	35	23.5	20.5	28.4	25.5
Ring Clockwise NE	35	35	30.0	28.0	39.5	36.3
Ring Clockwise SE	35	35	29.2	16.2	33.7	20.4
Ring Clockwise SW	35	35	24.5	26.9	30.9	31.7
Ring Clockwise NW	35	35	45.9	13.8	50.8	29.4
Ring Counterclockwise NE	35	35	20.9	13.0	25.8	23.0
Ring Counterclockwise SE	35	35	17.1	12.0	20.6	14.4
Ring Counterclockwise SW	35	35	23.1	13.2	28.9	18.1
Ring Counterclockwise NW	35	35	28.2	26.4	36.6	32.5

Ring Road

On the entire ring road around Eindhoven there is a BBZOB limit of 35 km/h, combined with a 70km/hr maximal speed. In a non-congested situation the minimum average traveling speed of 35km/h over the ring can be met. In most cases however, speeds on the ring are very low. The ring has been divided into four sections over which average speeds have been measured.

As is the case for the most roads in the network, the ring road is at its busiest during the afternoon rush hour. Most notable congestion occurs on the Southeastern ring in both directions, and on the counter-clockwise part of the south western ring. At the northwestern ring, the travel speed over the rush hour for the clockwise direction is stable and traffic conditions are acceptable. In the counter-clockwise direction, the travel speed drops towards the end of the rush hour in both morning and afternoon rush hour. In all cases, the average travel speed during the afternoon rush drops below the 35km/h minimum speed limit. The northeastern part of the ring has the largest amount of traffic on it, but speeds in clockwise direction are slightly above 35 km/hr. At the counter-clockwise part, speeds are too low.

In-bound arterials

Traffic conditions on the Kennedylaan are only instable during the morning rush in the direction into the city. Speeds on the montgommery laan are low; this could also be due to the fact that on this route, also speeds inside the city are measured. Further analysis is needed in order to be able to indicate whether there is really a congestion problem on this road. On the Bosdijk, problems are limited. Only towards the end of the afternoon rush hour, the traffic speeds in both directions drop below 35km/hr minimum speed. Remarkable is that the average speeds from the City towards the A2 over the Tilburgse weg, exceeds the 70 km/hr speed limit in all occasions.

On both western roads, Meerenakkerweg and Karel de Grotelaan, speeds are permanently below the 35km/h and 40km/h limits. With on the Meerenakkerweg a really bad situation during the morning rush for traffic into the city centre, and on the Karel de Grotelaan during the morning rush for traffic coming from the centre.

On the Leenderweg, minimum speeds are never met, because of the small differences between the maximum and the minimum speed limit on this road, and the presence of controlled intersections of this route however, it is unlikely that these minimum speeds can be met in the future. The unstable character of travel speeds over time however shows that travel speeds on this road could be increased by reducing congestion. Travel speeds during the Morning rush on the Eisenhowerlaan are instable and collapse from around 80 kilometers per hour in the beginning of rush hour towards only 20 km/hr at the end.

6.1.3 Interim conclusions

From this section, the following preliminary conclusions can be drawn;

- For most routes travel speeds are higher during the morning peak than during the afternoon peak. Exeptions are Karel de Grotelaan outside the ring, Meerenakkerweg and Leenderweg

- Average travel times at The Karel de Grotelaan inside the city and Boschdijk inside the City are too high and can be improved

- In a majority of the cases, the minimal trajectory speeds are not met. It seems very unlikely that these will all be reached in any alternative.

- The Southeastern ringroad is particularly congested; speeds on this road are espessially low during the afternoon rush hour.

- The traffic conditions on the Eisenhowerlaan towards the city during the morning rush collapse completely.

- On the Montgommerylaan, Meerenakkerweg and Karel de Grotelaan, speeds are unacceptably low.

6.2 Bottleneck analysis

A bottleneck is a location where travel times become unnecessarily low and traffic has to wait for more than one VRI cycle before an intersection can be passed. A bottleneck can be an evident cause of a capacity drop or even cause spillbacks to intersections up stream. Several recurring bottlenecks can be identified in the model. Both the Morning and afternoon situations are considered. During the afternoon rush bottlenecks appear to be worse than during the morning peak. In this part these locations are summarized and possible causes are mentioned. It is possible that there are quite simple measures available to upgrade these bottlenecks.

Eisenhowerlaan

Spillback of traffic occurs at the intersection between the Eisenhowerlaan and Wolvendijk. Traffic from Helmond on the Eisenhowerlaan has to wait more cycles before it can pass this intersection. It is also observable that during the morning rush, travel speeds on the Eisenhowerlaan towards Eindhoven reach very low values towards the end of the morning rush and do not recover until after 9:00:00.

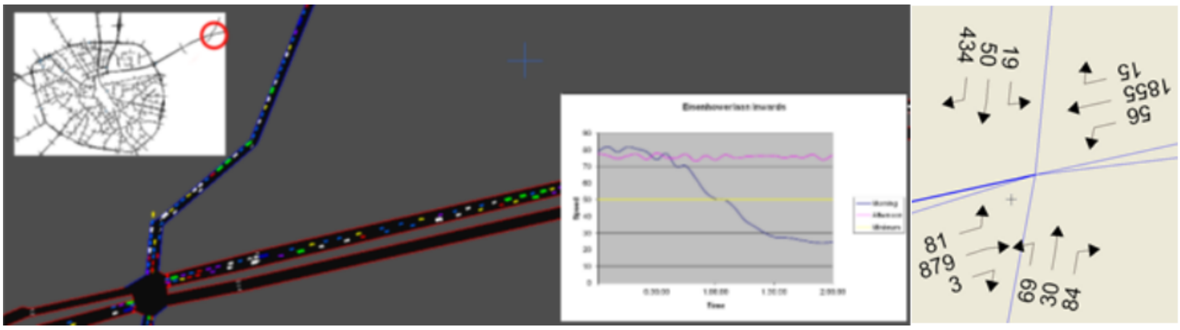

Figure 6.2: Situation Wolvendijk - Eisenhowerlaan in the reference model,8:30 With Total turn counts between 8:00 and 9:00 in the morning

As can be seen in figure 6.2, traffic in the afternoon is less congested. There is however a bottleneck in the opposite direction on the Eisenhowerlaan in the afternoon, however this one is a less heavy bottleneck. It is shown in figure 6.3. The bottleneck occurs closer to the ring at the intersection with the van Oldebarneveldlaan.

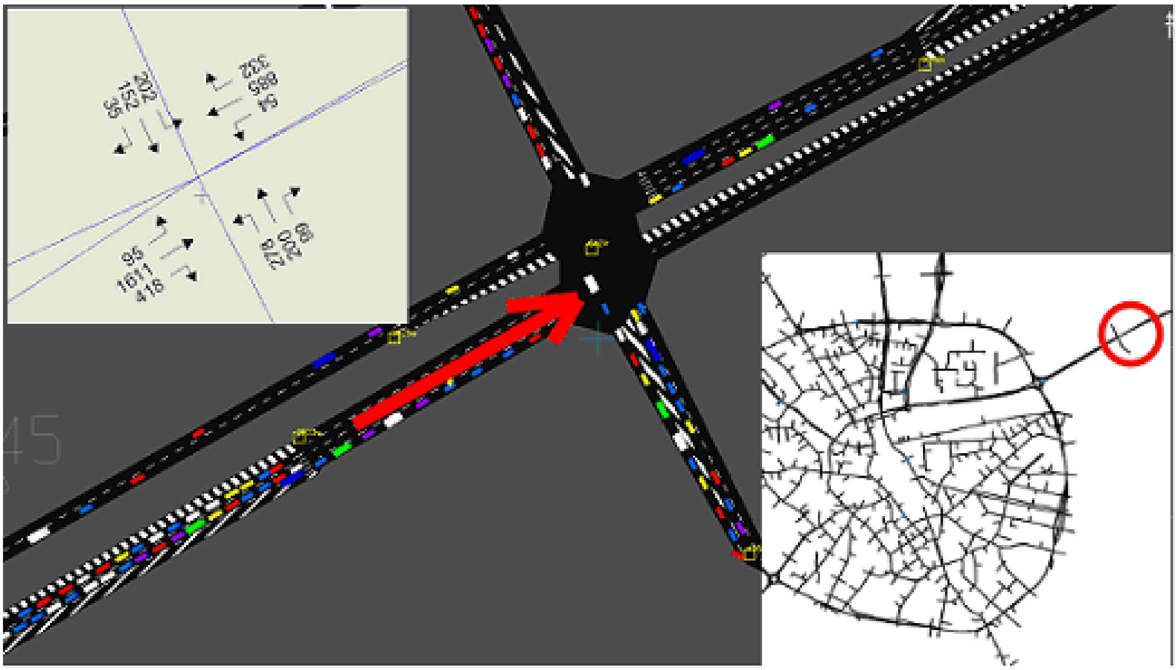

Figure 6.3: Crossection betweenvan Oldebarneveldlaan and Eisenhowerlaan at 17:30 in the afternoon, Traffic towards the intersection on the leftside blocks back all the way to the intersection with the ring at the Berenkuil, 900 meters away.

Karel de Grotelaan-Mauritsstraat

At an important environmental reference point congestion is also Occuring. Traffic from the Karel de Grotelaan towards the centre is delayed at the intersection between the Mecklenburgstraat, Mauritsstraat and Edenstraat. Traffic from other directions at this intersection also has to wait more than one cycle. When the travel times on this road are considered (see figure 6.5) it can also be observed that there is quite some room for improvement on this intersection. Both in the morning as well as in the afternoon this location forms a bottleneck. This is also resulting in decreasing travel times during the rush hours on both the Karel de Grotelaan and the Mauritsstraat as can be seen in figure 6.4.

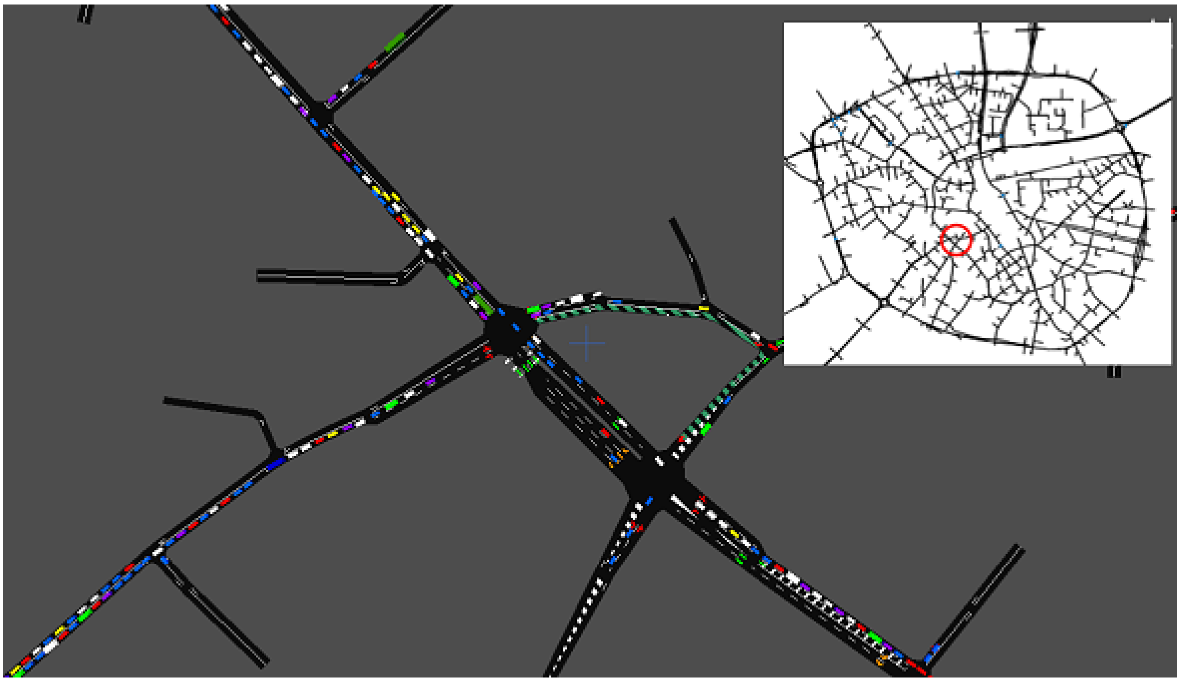

Figure 6.4: Considerable congestion also occurs at the Mauritsstraat this is a snapshot of the location during the afternoon rush hour.

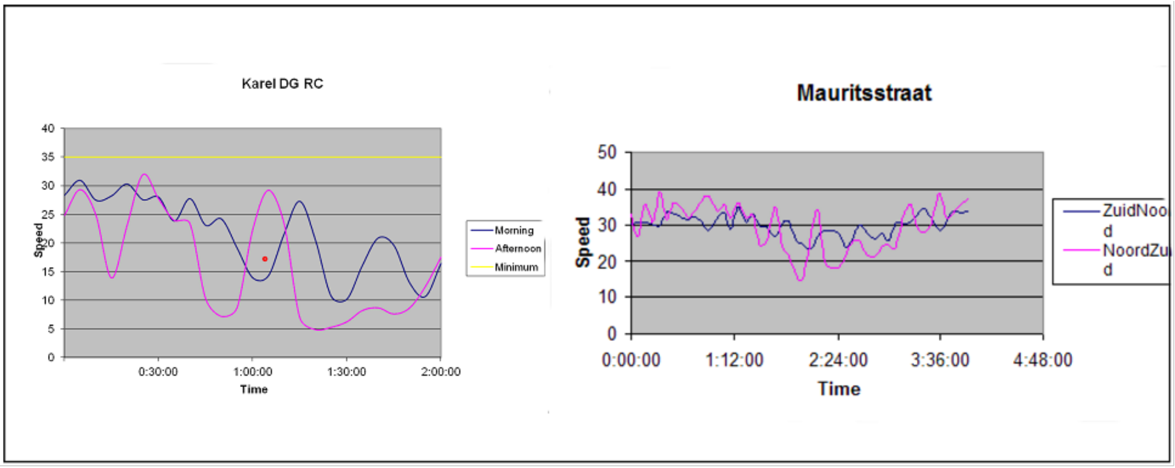

Figure 6.5: Travel times on the Karel de Grotelaan during morning and afternoon rush hour and Mauritsstraat in both directions during the morning rush hour.

Binnenring

During rush hour speeds on the Binnenring drop to around 25 km/h where doing 50 is allowed. On the eastern part of the Binnenring several points can be named which partly cause this drop in speeds and where bottlenecks can be identified. These locations are Geldropseweg – Vestdijk, Stationsweg – Vestdijk and Fellenoord Vestdijk. On the western parts bottleneck locations are less evident.

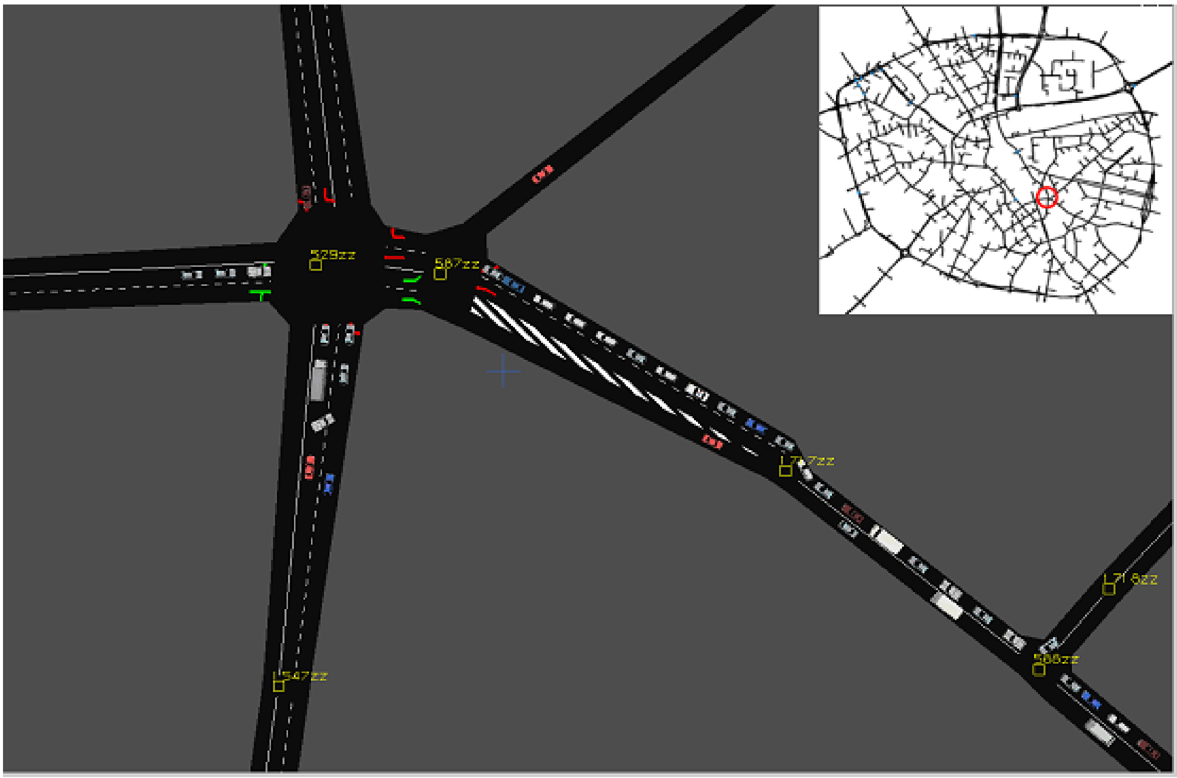

Figure 6.6: Intersection between Geldropseweg (from bottomright) and the Vestdijk (Binnenring). Mainly the waiting times on the geldropseweg can become large.

The first bottleneck, between Geldropseweg and Vestdijk (figure6.6) apparently has a low impact on the speeds on the Binnenring, but where unnecessary delays occurs the intersection between the Vestdijk and Geldropseweg. At this intersection mainly the traffic from the Geldropseweg is delayed. On the Vestdijk and Hertogstraat, both part of the Binnenring, less congestion occurs. Reason for this is that they are both two lane roads in contrast to the one lane Geldropseweg. There is however a two lane section right before the intersection, but this is too short. Another cause could be the double lights because of the merging Tongelrese straat.

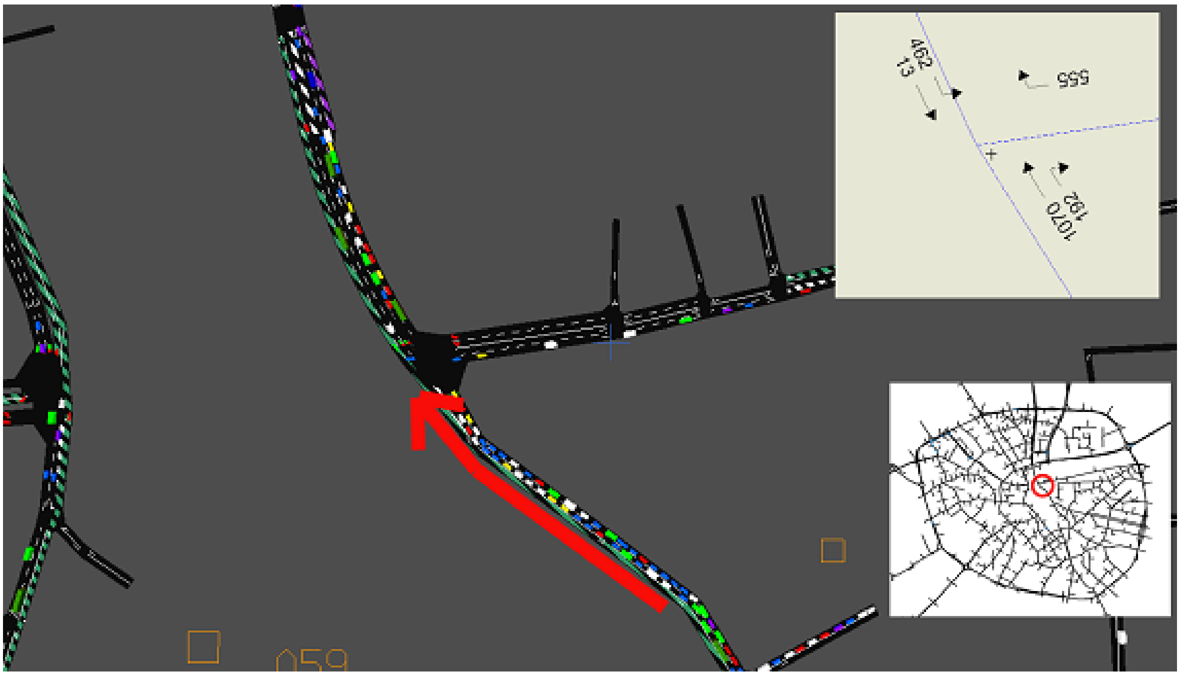

Figure 6.7: The East side of the binnenring, with traffic going North is very congested, this is the situation at 17:30 in the afternoon at the intersection between Vestdijk and stationsweg.

Further to the north, at the intersection between the Vestdijk and the Stationsweg (figure 6.7), a bigger bottleneck occurs. In the morning, traffic at this location is not really congested, but in the afternoon longer waiting times occurs, especially for traffic coming from the south over the Binnenring.

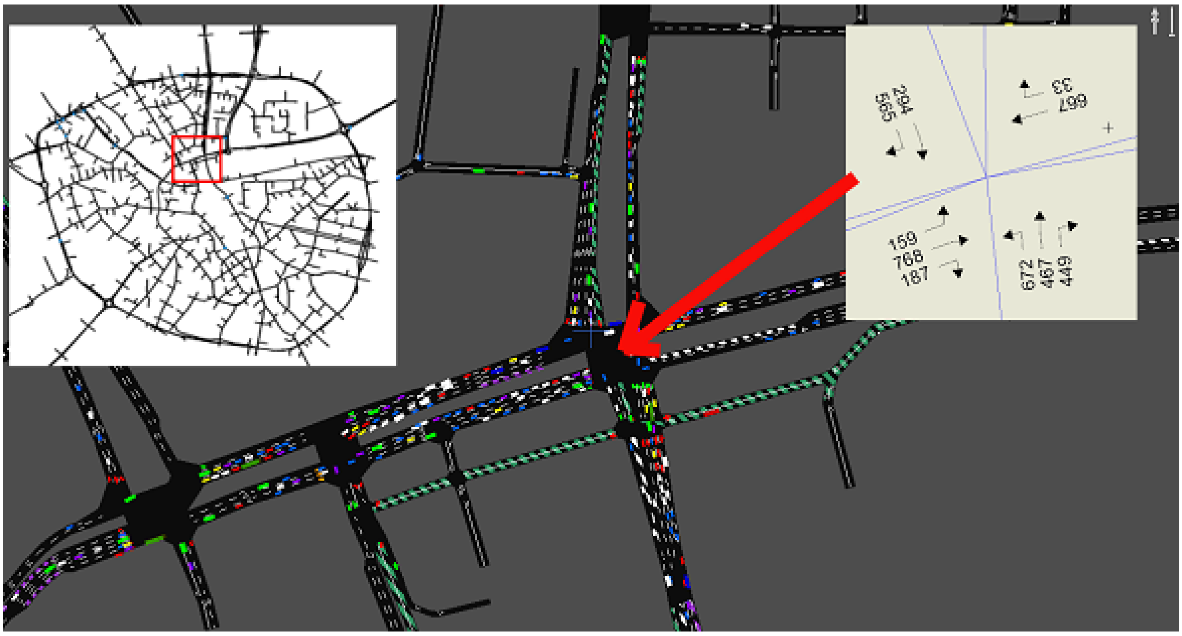

Figure 6.8: The Congested Binnenring ends on the Fellenoord, this is the situation at 17:30 in the afternoon.

The final location where traffic on the Binnenring is Congested is the intersection with the Fellenoord (figure 6.8), again, this location is mainly congested during afternoon rush hour. The Fellenoord in itself however has enough capacity, the traffic from the Binnenring does generally not experience too much delay, mainly in the afternoon however, speeds may really increase.

Ring

On and around the Ring there are also some bottlenecks which can be improved. The ring is mainly congested in the afternoon. The three bottlenecks that are discussed here are Tongelresestaat – Insulindelaan(figure 6.9), Kadebrug Jeroen Boschlaan (figure 6.10) and Kennedylaan – Onze lieve Vrouwestraat (6.11).

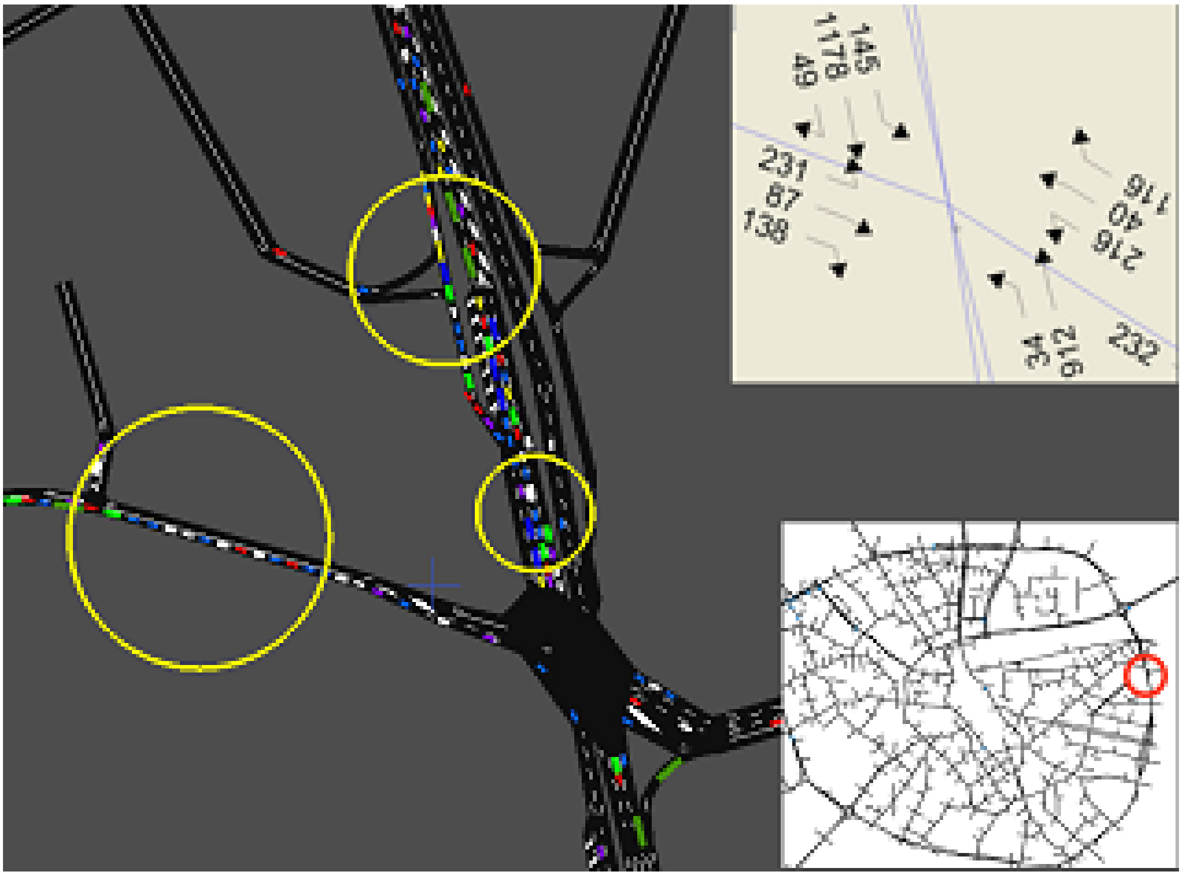

Figure 6.9: Insulindelaan tongelresestraat 17:30 and counts 17:00 - 18:00

At the intersection between the Tongelrese straat and the Insulindelaan (Ring), high volumes of traffic from the Tongelrese straat are turning left onto the Insulindelaan causing long waiting times on the tongelresestraat. Since the Tongelrese straat is not a major road this is problem doesn't have a high priority. But also traffic on the insulindelaan experiences extra waiting time on this section.

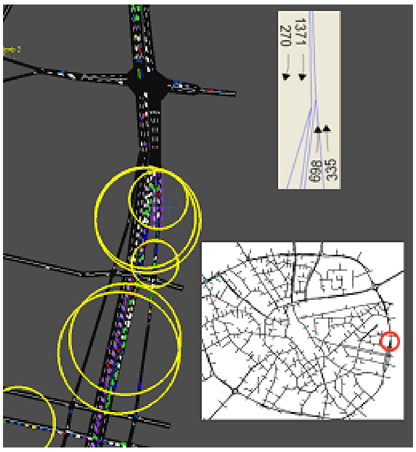

Figure 6.10: Jeroen Boschlaan –Kadebrug between 17:00 and 18:00, situation at 17:30

On the Southeastern ring in Northbound direction, also a clear bottleneck can be observed. At the intersection between the Kadebrug and the Jeroen Boschlaan (figure 6.10), traffic is alternately allowed on the Ring, causing considerable waiting times upstream on the Ring.

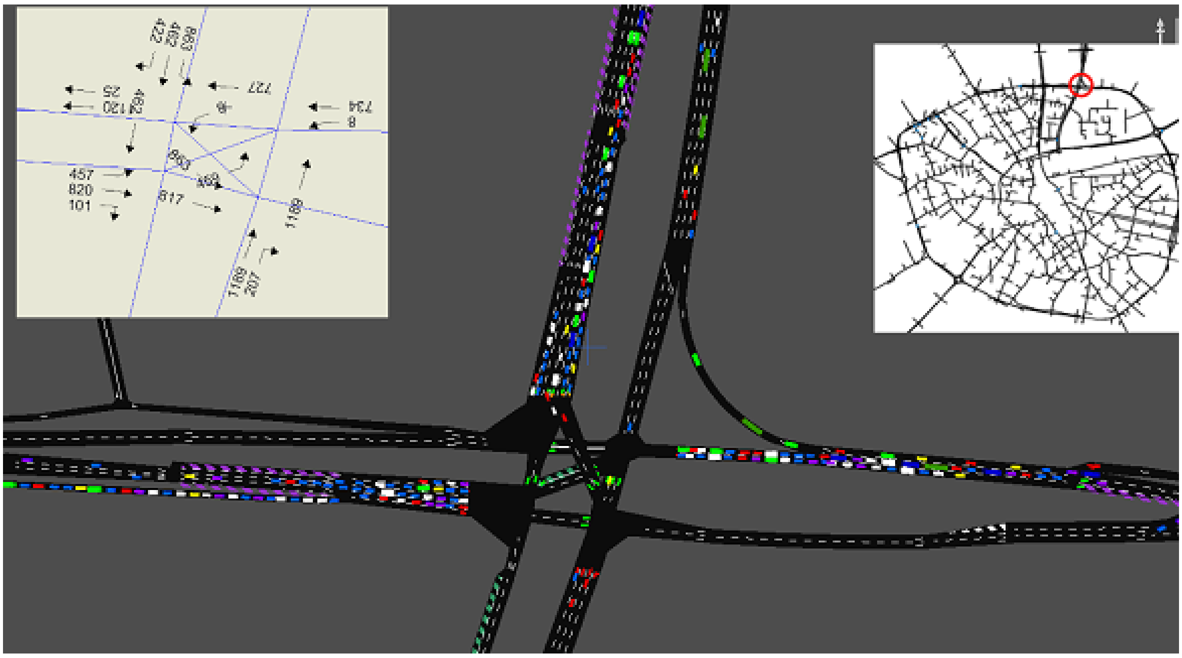

Figure 6.11: The Ring is also congested very congested in the Afternoon, this is the intersection between the kennedylaan and the ring at 17:30 in the afternoon. There is also congestion towards the City Centre in this case, but this is caused by traffic that is turning onto the ring.

The intersection between the Kennedylaan and the ring, particularly in the afternoon is also congested. This intersection has enough capacity in itself. High volumes of traffic come from the city centre in direction of the Kennedystraat, this flow crosses with the traffic flow over the Ring.

6.3 Spreading of traffic over the network

Redistribution of traffic over the network can be very useful to prevent congestion on the network. In order to do this strategically, insight has to be gained in the route choice of road users. Many road users in do not really have a choice what route to take, because one particular route is clearly the best option, or the route is too short for there to be more options. But also a part of the road users has a choice. Getting some insight in the route choice that these people have can make redistributing traffic over the network a lot easier. In order to get such an insight, it can be useful to analyze the origins and destinations of road users. If results are hopeful, a more detailed route analysis can be performed in order to get a specific overview of several route redirection options.

6.3.1 Categorization of road users

In order to identify the possibilities of the redistribution of traffic over the network, first a quick scan of road users is executed. Therefore a more aggregate approach has been chosen. In this approach traffic users are divided into 9 groups, which indicate whether or not they are sensitive for certain types of measures; this subdivision is shown in table 6.3.

Table 6.3: Road user categorization

		Destination		
Origin		City Centre	Outside City Centre	Outside Eindhoven
	City Centre	No steering probabilities	Traffic control measures	Redirecting traffic
	Outside City Centre	Traffic control measures	Traffic control measures	Redirecting traffic
	Outside Eindhoven	Redirecting traffic	Redirecting traffic	Redirecting traffic

Generally speaking, it can be argued that traffic from outside the modelled area (or traffic heading outside the modelled area) approaches from the motorway and can be guided from further away to a destination in the city. This part of road users can be redirected to another route in order to divide traffic better over the network. A second group of traffic users stays in the greater Eindhoven area; this is a group that generally lives close to one of the arterial roads and will therefore most likely use one specific arterial road. This makes this group of traffic users very hard to redirect, but once on the arterial roads, they can be managed using traffic control measures. The final group of road users only travels within the City Centre, and coordinated influencing this group is not really possible.

Figure 6.12: Geographic representation of subdivision of road users.

This subdivision leads to the road user categorization as shown in the table below. Only the morning matrix is analysed in this table al traffic departing between 7:00:00 and 9:00:00 is considered in this subdivision. The table shows that there is only a small portion of road users that stays within the city centre and which cannot be guided. The portion of traffic which comes from outside the city is with a total of 70563(green coloured in the table) road users the largest portion. And the part that has part of its trip outside the city centre is with a total of 55598 (purple coloured in the table) trips the second largest category. Another conclusion that can be drawn from this categorization is that only a small part of the total traffic volume actually has either their origin or destination within the city centre. It is however hard to draw any conclusions from this observation, since it is not known which part of this traffic forms the total amount of traffic in the city centre. With this analysis it can be expected that both redirecting traffic as well as traffic management on isolated roads influence enough traffic in order to be successful approaches.

Table 6.4: Quantitative results of road user categorization.

Morning Matrix 1	Centre	Municipality	Outside Eindhoven	Total
Centre	5618	6774	2234	14626
Municipality	13058	35766	12230	61054
Outside Eindhoven	5247	15090	35762	56099
	23923	57630	50226	131779

There are some drawbacks to this categorization approach. By aggregating the road users in such general groups, analysis becomes less comprehensive, but a lot of the information is also lost. The largest category in the analysis for instance, is the group travelling between two zones in the municipality of Eindhoven, outside the city centre. Further analysis is needed to find out which specific routes are suited for the named measures. This section identifies several popular routes through the city.

6.3.2 Route analysis

There are some difficulties in to the categorization of road users. By aggregating the road users in such general groups, analysis becomes less comprehensive, but a lot of the information is also lost. The largest category in the analysis for instance, is the group travelling between two zones in the municipality of Eindhoven, outside the city centre. Further analysis is needed to find out which specific routes are suited for which types of instruments. This section identifies several popular routes through the city.

Globally speaking there are two options in this network for redirecting traffic. The first one is redirecting traffic from the edge of the city towards their destination in the city centre; this group can be divided into four groups, traffic from/to the West, South, East and North. Also traffic through the city Centre could potentially be guided around the city centre.

Traffic from outside Eindhoven

There are several main axes around the city of Eindhoven from where a lot of external traffic enters the area and also leaves again. They are shown in figure 6.13. In The North there are the A50 connecting Arnhem and Nijmegen and the A2 from Den Bosch and Utrecht. Traffic from these directions globally has 3 options to enter the city which are the Bosdijk, Montgomerylaan and Kennedylaan. From The West, there are the A58 from Tilburg and Breda and the A 67 from Turnhout and Antwerpen. Traffic from the west can approach the City Centre from the Karel de Grotelaan, Meerenakkerweg and Tilburgseweg. Traffic from the A58 could also use the Northern options and traffic from the South could also use the Southern options. In the Subarea model, traffic choice from the south has been left out with the simplification, this part is considered out of the focus area. For the sake of this overview: there are three main roads from the south into the City: the Aalsterweg, Leenderweg and Geldropse weg. Traffic from the east comes mostly from Helmond. In the model, there is little choice between several routes towards the city Centre of Eindhoven. There are options towards the North of the model either over The Europalaan or over the Eisenhowerlaan (the van Oldebarneveldlaan was not included in the subarea model) but given the scope of this research these options are

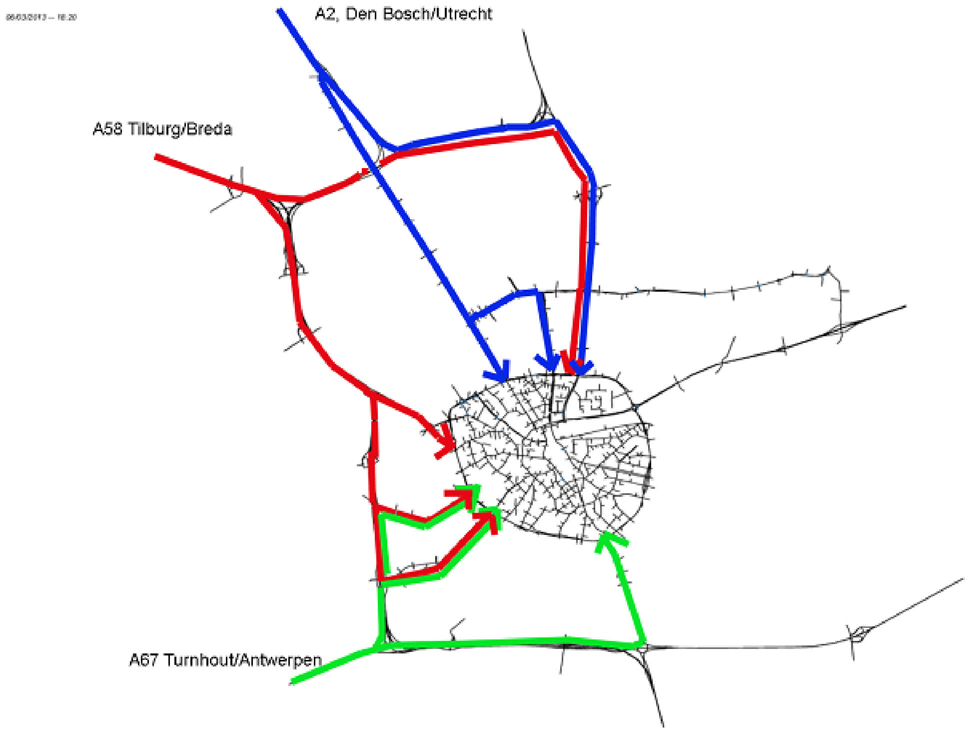

Figure 6.13: Route alternatives towards the centre from different directions from Eindhoven.

less relevant.

Table 6.5: Comparison between the main routes into the City Centre. Next to path length, and average journey time, the total amount of trips on a route gives an indication of the attractiveness of a specific route.

Path Name	Path Length (m)	avg Journey Time (s)	Speed	Total trips on route
A2 - Bosdijk	7038	658	39	204
A2 - Kennedylaan	10556	536	71	769
A58 - Tilburgseweg	8589	408	76	665
A58 - Meerenakkerweg	10972	749	53	7
A 58 - Kennedylaan	13387	618	78	112
A67 - Leenderweg	9035	549	60	15
A 67 - Karel de Grotelaan	5361	450	43	175
A67 - Meerenakkerweg	6305	512	45	73

The Northern and western Route Choice are in this analysis the most hopeful directions to analyze. The two most important routes from the North are the Routes over the Boschdijk and The Kennedylaan the route via the Montgommerylaan is actually not used, the costs for these routes are calculated according to the method used in the model, results are presented in table 6.5. Both routes are popular, depending on their exact destinations road users might choose either route. However the Boschdijk is the shorter option, it is not the quickest option. The speeds when driving via the Kennedylaan are clearly higher; this makes these two routes competitors. Depending on the speeds on both routes a Drip installation on the A2 from the North could be an option.

Boschdijk Inside the Ring area

Table 6.6: Percentage of traffic on the city centre part of the Boschdijk originating from the A2 in the North

	Origin A2	Total on link	%
7 - 8	59	648	9%
8 - 9	80	846	9%

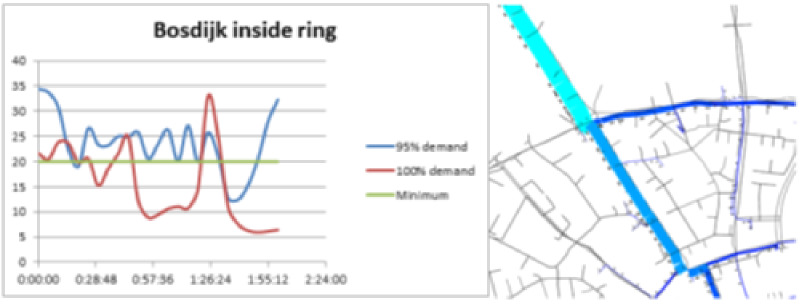

Figure 6.14: This graph shows the travel time gain when the total traffic demand would drop 5%, problems at the Boschdijk would become considerably less, speeds become acceptable. Delay in travel time on this road section is about 50 seconds. These are 1 run samples. On the left side it can be seen that traffic from A2 from the Boschdijk goes over the part of the Boschdijk inside the ring.

The choice for a certain route outside the city, also makes that a car enters the city at a different point. Congestion in the city is therefore also interesting when considering route options towards the city Centre from outside the City. Looking at delays inside the City, the Boschdijk is a critical point where speeds become too low during the afternoon rush, travel times at this road should be improved. From figure 6.14 it can be concluded that a smaller flow can lead to an improvement of the traffic speed on the City Centre part of the Boschdijk. What also can be concluded on the basis of model results is that about 9% of the traffic on this part of the Boschdijk originates from the northern A2. This leads to believe redistributing traffic to the ring, can improve the traffic situation on the Boschdijk.

Through traffic routes

Next to the route options which are available from the outskirts of the city, there are also several options for traffic to drive past the city Centre. Through traffic could be a cause of congestion in the City Centre. In order to get a clear overview of the through traffic in the City, information from the license plate research in the municipality of Eindhoven can be used.

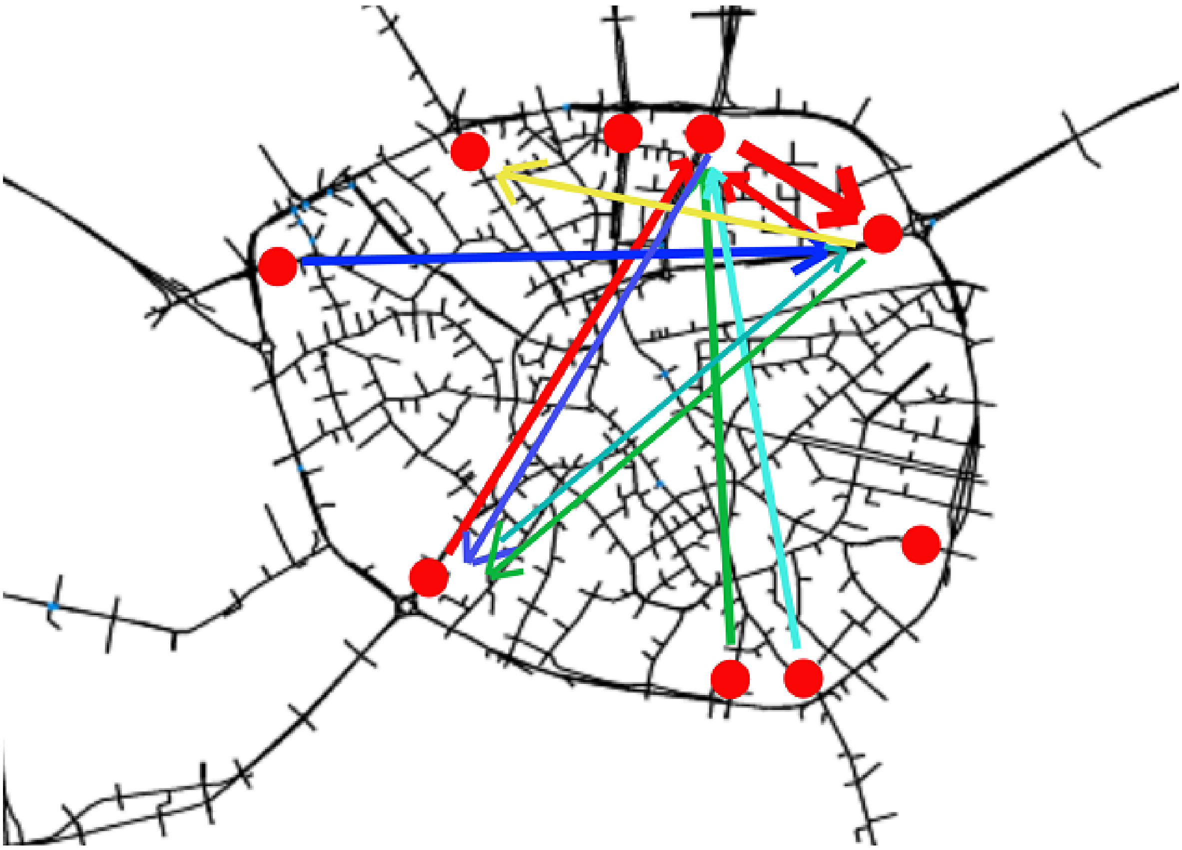

Figure 6.15: Ten routes through the city centre where the most through traffic has been counted. Arrow thickness represents the proportion of traffic during the morning Rush hour.

On Thursday January 20th 2011, a registration plate research has been carried out investigating the through traffic in the Centre of Eindhoven (KTO Eindhoven [5]). During this research traffic counts have been executed on several key locations in the City Centre of Eindhoven. Among others, this research led to an overview of through traffic in the city centre of Eindhoven. Overall, the percentage of through traffic is 6% of the total amount of vehicles between 7 and 10 in the morning and 5% in the afternoon. There are however some routes where higher percentages of through traffic are signalized. The highest percentages of through traffic are measured between 8 and 9 in the morning. When the percentage is about 15% with at the Dorgelolaan even 37%. For the sake of redirecting traffic, it is useful to know how this traffic is built up and what routes the trough traffic is mainly following. Figure 6.15 shows the ten routes that are used most. 8 out of 10 most used routes by through traffic start or end at the proffessor Dorgelolaan (Eisenhowerlaan). At the Congested Mauritsstraat also 4 different routes can be measured .

Table 6.7: Through traffic counts during the morning rush between 7 and 9 as measured in in the model.

	Route count (veh)	
OD-pair	**Centre**	**Ring**
Leenderweg - Boschdijk	18	54
Boschdijk - Leenderweg	168	9
Eisenhower - Karel DG	37	91
Karel DG - Eisenhower	54	45
Karel DG - Kennedy	15	48
Kennedy - Karel DG	37	79

The results from the registration plate research give an indication of through traffic in the city. From the identified routes, two roads can be indicated in the city Centre where a number of routes come together, the Prof Doc Dorgelolaan, which was already mentioned in the registration plate research introduction. Delays on this road are however small. With the purpose of redirecting traffic, this might not be the best option. A road where traffic is more congested, and 4 different through routes pass by, is the Mauritsstraat. Traffic between Mauritsstraat and Eisenhowerlaan in both directions and Mauritsstraat and Kennedylaan in both directions passes this road, while there are also very valid options over the ring. When traffic in the model between 7 and 9 in the morning is considered, most through traffic flows southwards towards the Mauritsstraat (See table 6.7).

6.4 Traffic analysis summary

In this chapter, problem locations for the indicated performance indicators have been found, also the most important through traffic flows through the City centre are identified. An overview of the problem locations is presented in figure6.16. Also the most important through traffic routes are indicated in this figure with green lines. The through traffic routes can roughly be divided into two route: in the North-South direction over the Boschdijk, the Binnenring and the Leenderweg; and on the West-East direction on the Karel de Grotelaan, Mauritsstraat, Fellenoord and either the Prof. doc Dorgelolaan or the Kennedylaan. The measures that are developed in Chapter 7 focus on the problem locations as found in this analysis.

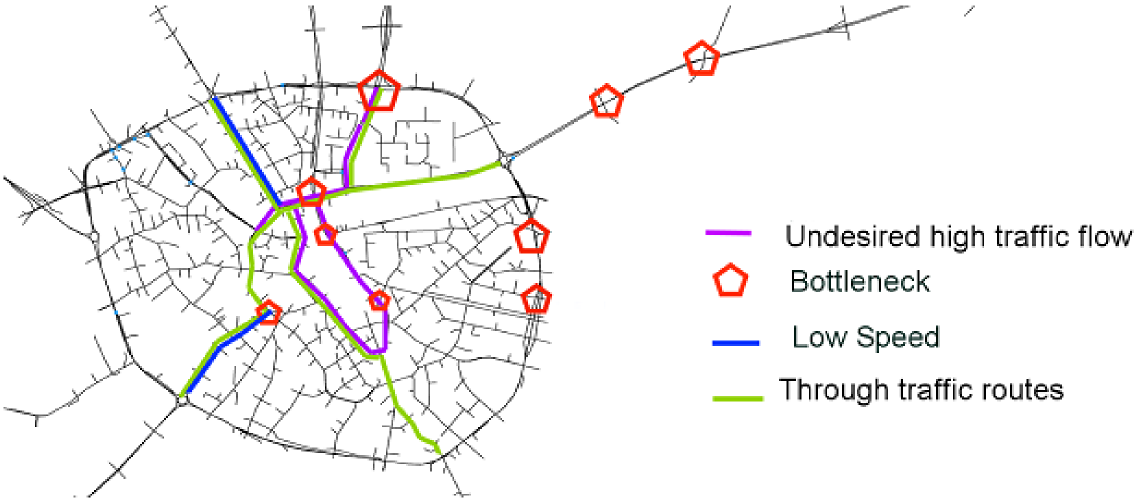

Figure 6.16: Problem locations as found in the traffic analysis

Chapter 7

Instrument design and -testing

In this chapter, individual traffic management instruments are developed. The bottleneck overview of the traffic analysis, and the performance indicators in the assessment framework form input. The design framework must be used to select available instruments. These instruments must be selected and tested. Based on the test results, the instruments need to be further improved. The result of this step is a collection of individual measures which contribute to the improvement of the traffic network goals. A multi-criteria assessment is used to compare the measures with each other. In this chapter, the following research question is discussed:

How can the instrument framework be used to design traffic management instruments for the Eindhoven city centre?

First, several instrument are designed in section 7.1, in section 7.2, the results of these separate measures are analyzed resulting in a multi-criteria assessment. The goal of this chapter is to get an overview of tested measures which can be combined into several different traffic management strategies using the traffic management strategy design approach and tested in Chapter 8.

7.1 Instrument design

This section focuses on how the instrument design framework can be used to come to useful traffic management instruments. This this is done on basis of the analyses done for Eindhoven and traffic management instrument design approach. Since only an off line-application of measures is tested in this research, measures which can only be used dynamically are not considered. In chapter 2, four different instruments are introduced extensively, these will also be tested for the Eindhoven network: gating, speed reduction, blocking roads and changing the amount of lanes. In this section, the developed theoretical framework on instruments is to be linked to the traffic situation that exists in Eindhoven.

7.1.1 Input from previous steps

For the municipality of Eindhoven the goals are not only focused at traffic optimization as described in the traffic measure framework. For Eindhoven, it is also very important to keep the city centre attractive, leading to goals opposing optimal traffic conditions, flows on certain roads need to be kept small, and focus should be on redirecting traffic towards the ring.

In the traffic analysis, values for the several indicators have been identified for the city centre in Eindhoven. Figure 7.1 shows the locations where undesired situations occur in the city centre. Bottlenecks, indicated with a red pentagon and routes with low speeds can be viewed as traffic optimization goals. The analysis of through traffic routes is somewhat more difficult, since here a spatial element is also important. In this research it can be stated that a change in the route choice is positive when traffic changes routes through the city centre towards the ring, irrelevant of possible negative results on for instance total travel times averaged on the city centre goals, this is also a result of the way policy goals are formulated.

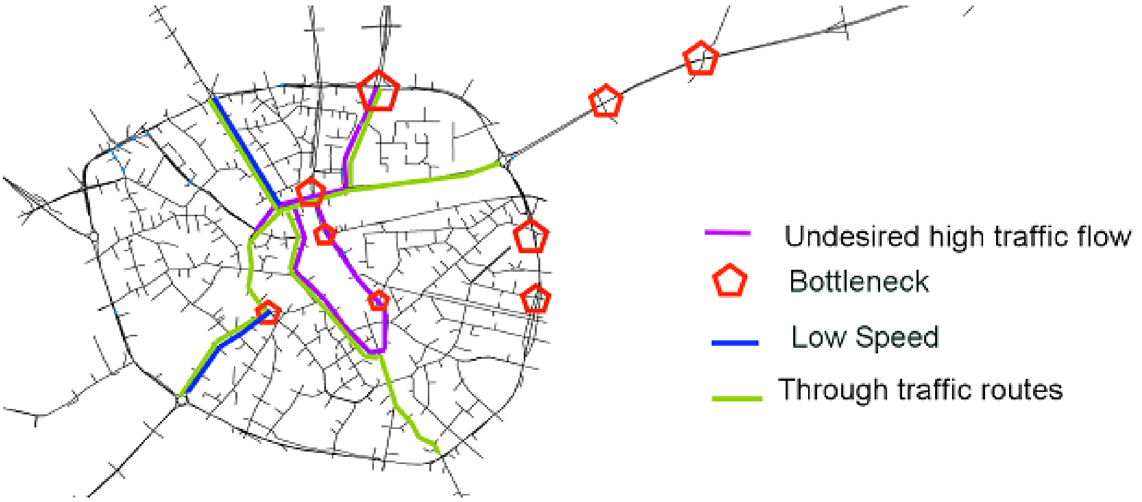

Figure 7.1: Visualization of the traffic situation in the reference model as assessed in the Traffic analysis. On basis of this visualization, traffic goals can be determined.

The overview resulting from the traffic analysis shows that the found problems are centred in a specific area of the City. Based on the policy goals and the traffic analysis, an implementation area (figure 7.2) is determined indicating where traffic measures can best be implemented. Although some bottlenecks on the ring and outside of the ring have been indicated in the traffic analysis; they are not included in the implementation area because the negative spillback effects are located on the ring, and in two cases on the Eisenhowerlaan.

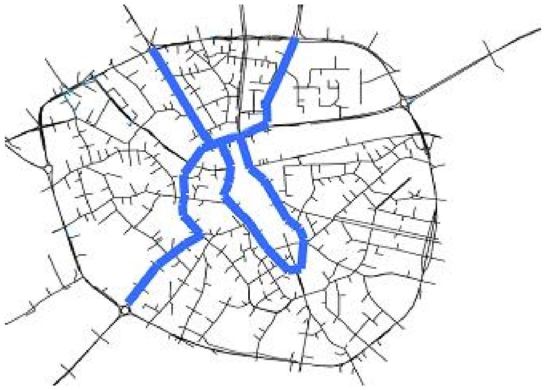

Figure 7.2: Implementation area for the measures.

Based on the traffic management goals that have been determined for Eindhoven, the traffic analysis and the focus area, the following specific traffic management goals can be formulated:

- Decrease travel time loss on Karel de Grotelaan and Boschdijk.
- Decrease the traffic flow in the city Centre on the Fellenoord and Binnenring.
- Reroute traffic on the Binnenring, Fellenoord, Mauritsstraat and Karel de Grotelaan towards routes over the ring

Using the traffic management overview, specific measures for these goals can be found. Also, the effects on the traffic system of the measurements can be assessed; the way these measures are filled in is shown figure 7.3. Below the measurement level, measure specific indicators are shown. Below that level, the problem locations in Eindhoven for which these indicators are relevant are shown. The indicators in the blue boxes will be the primary aim of the measures links to them. This will be the first attribute of the measure to be assessed. When the desired effect can be proved; other attributes can also be assessed. The red arrows indicate where the proposed measures would apply to the traffic engineering logic of the assessment framework.

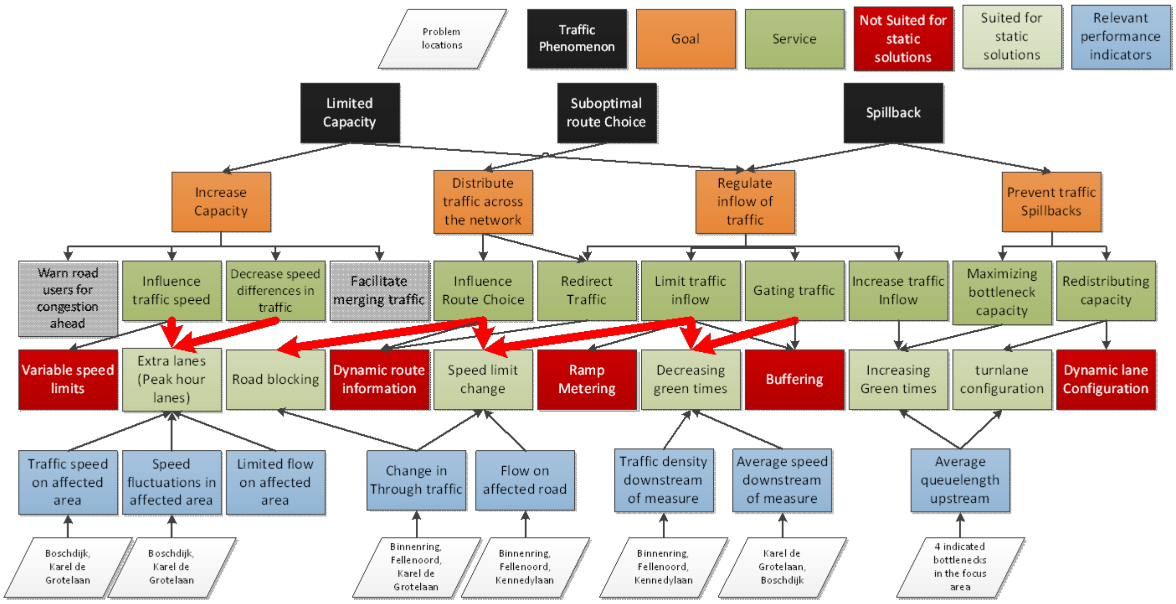

Figure 7.3: Framework for implementation of traffic management measures, with the identified problem indicators added.

Using this framework, the effects of measures on traffic optimization factors can be explained for specific measures. This can be illustrated with the use of an example; a specific policy goal is to decrease flow on several roads in the City Centre, in this case the Binnenring, Fellenoord and Kennedylaan. The path that is followed with this measure through the framework is shown in the overview in figure 7.4. In order to decrease the traffic flow, the speed limit is lowered encouraging road users to choose other routes. Lowering speed limits is often counter-productive in traffic engineering terms, but can be useful for the municipality of Eindhoven. This does however not mean that all traffic phenomena are worse off; another effect of lowering the speed limit is that through traffic routes become less popular and traffic can be better divided over the network.

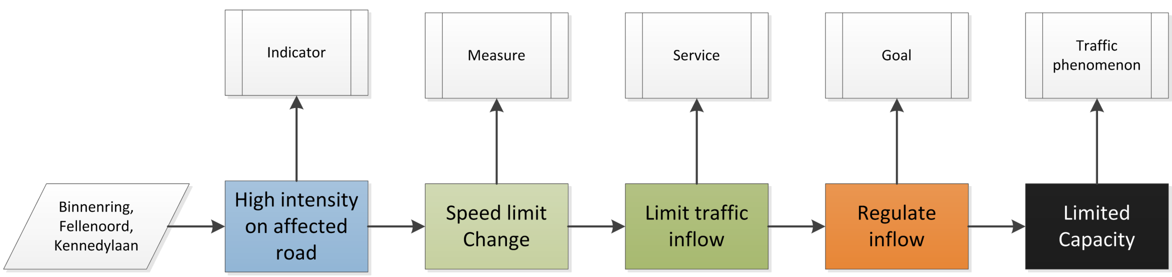

Figure 7.4: Example of how the effects of a specific measure can be assessed using the traffic measure framework

The previous shows how the measures from the traffic measure framework can be linked to the goals in Eindhoven. The design variables which are available can be used in order to optimize the instrument effects an overview of these variables is shown in table 7.1.

Table 7.1: Overview of the available design variables for the measures.

	Gating	Speed Adaptation	Adding Lanes	Blocking roads
Instrument	Gating locations	Affected roads	Roadblock location	Location of added lanes
location	Buffer locations			
Instrument	Greentime adaptation	Speed difference	Affected vehicle types	Number of added lanes
Impact	Phase structure adaptation		Roadblock method	Turnlane layout
				Allowed vehicle types per lane

7.1.2 Gating traffic

In the framework, two main indicators of gating are named: the downstream intensity and downstream speed. The idea of gating is thus to improve the capacity of the affected area. A negative side effect of this measure is that spill-back can occur upstream of the gating location.

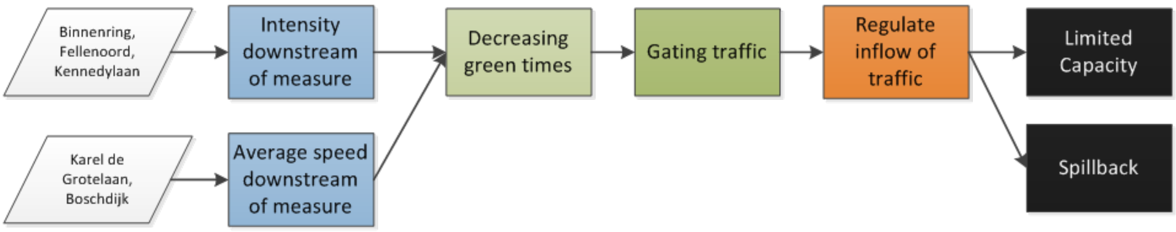

Figure 7.5: Possibilities for the application of gating in Eindhoven.

Green times in the model are traffic-dependent; every time a vehicle is detected in the direction currently having green, the green time is extended. The sign becomes red again when either no more vehicles are detected or the maximum green-time is reached specified for that direction; by decreasing this maximum green-time in the model; capacity for a certain direction can be decreased. It is important to note that most green-time phases apply to more than one direction. Changing a maximum green-time should not have a negative effect on other directions which are also influenced by the adaptations. By implementing the measures along the edges of the critical parts of the network; the measures can be implemented in a coordinated fashion improving the traffic situation in the inner city.

Locations where gating would be applicable follow from the traffic analysis: Binnenring, Fellenoord and Kennedylaan for the sake of lowering intensity; and Boschdijk and Karel de Grotelaan in order to increase speeds on these roads. On the basis of this information, two different alternatives gating are selected and tested. The first alternative includes buffer locations favoured by the municipality. The second alternative is less favourable by the municipality because of possible negative spill-back effects on the ring.

Gating alternative 1

The municipality of Eindhoven favours a strategy of buffering traffic where the traffic is buffered around a small area in the city centre, leaving the traffic on the ring not affected. Consisting of the Boschdijk, right before the Fellenoord, the merge of Aalsterweg and Leenderweg, before turning onto the Binnenring, and the Kennedylaan before turning onto the

Fellenoord. These locations are indicated in figure 7.6. The table indicates the proposed decreased green-times for this measure. Traffic on these locations is not likely to hinder other traffic. Disadvantages of these locations are that traffic which is going from west to east through the Centre is not hindered in any way. Also the Boschdijk within the ring, already appointed as part of the focused area, will only get more hindrance. Whether this is desirable is very doubtful. This measure will in the following be called gating 1.

Figure 7.6: Gating locations for the gating 1 measure.

Intersection	Adapted phase	Initial max greentime	Adapted max greentime
Leenderweg - Binnenring	2	15	5
Kennedylaan - Fellenoord	3	40	30
Kennedylaan Fellenoord	5	40	30
Boschdijk - Fellenoord	1	28	18

Gating alternative 2 In order to be able to include all desired roads of the research into the gating alternative, an extra gating option is included. At 4 strategic points on the busy routes of Bosdijk, Karel de Grotelaan and Fellenoord the maximum greentimes have been adapted. The proposed maximum greentime adaptations are shown in the table. The Locations are shown in figure 7.7. Advantages compared to the first alternative are that traffic entering the focus area from the west is also buffered; also traffic on the Bosdijk inside the ring is not extra delayed. Problems could occur however if traffic on the ring is also hindered by buffering the traffic on the edges of the Karel de Grotelaan and the Bosdijk. This is not favored by the municipality.

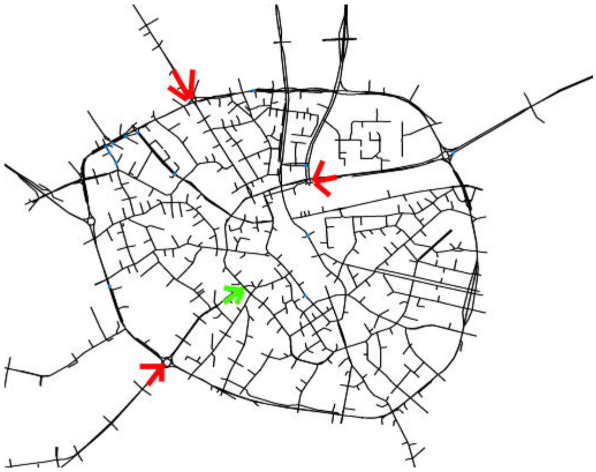

Figure 7.7: Gating locations for the gating 2 measure.

Intersection	Adapted phase	Initial max greentime	Adapted max greentime
Karel de Grotelaan - Limburglaan	1	35	20
Mecklenburgstraat	4	20	40
Fellenoord Kennedylaan	4	40	30
Boschdijk - Ring	1	35	20

7.1.3 Speed Adaptation

The goals of decreasing the speed limit are to change route choice towards alternative routes and to lower intensity on the affected routes. As concluded in chapter 6.3.2, unwanted through traffic is mainly signalized at the Boschdijk, Binnenring Fellenoord and Karel de Grotelaan; there are alternatives for all these roads. On the Binnenring and Fellenoord is also too high. The goals are schematized in figure 7.8 The function of the Binnenring is specifically to

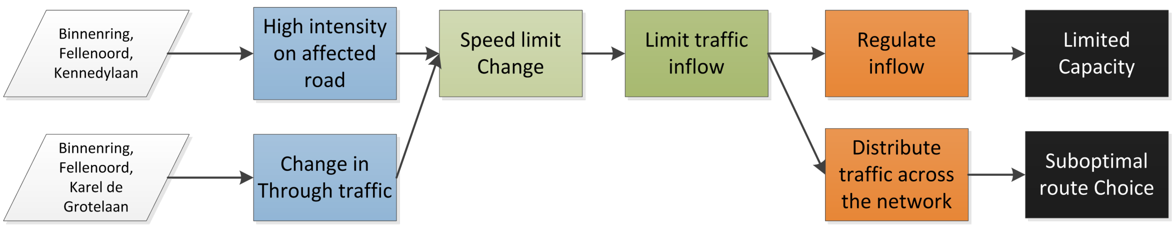

Figure 7.8: Possibilities for the application of speed reduction in Eindhoven.

accommodate destination traffic for the Ring. It might therefore be argued that 30 km/h is a desirable speed for this part of the network. A combined speed limit of 30km/h on the Fellenoord and Mauritsstraat could also be effective against through traffic. The third option is to implement a speed limit on the Boschdijk. An overview of the tested measures for 30 km/h structures is given in figure 7.9. From left to right, alternatives speed reduction 1, 2 and 3 are shown.

Figure 7.9: Roads which have been tested with a 30km/h speed limit.

7.1.4 Blocking Roads

The goal of blocking roads in this context is to avert through traffic (figure 7.10). Through traffic is a problem at the Fellenoord, Karel de Grotelaan and Binnenring. The Fellenoord and Mauritsstraat are however too important in the road structure within the ring. The best road to test the effects of road blocking is the Binnenring.

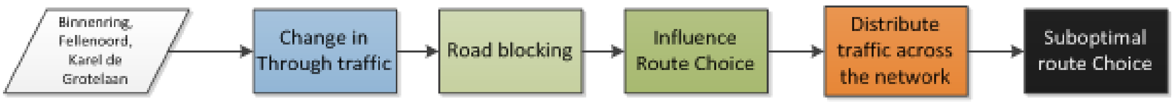

Figure 7.10: Possibilities for the application of blocking roads in Eindhoven.

Currently the Binnenring is a one way, counterclockwise ring around the heart of the city, making it a very attractive road of travelling through the city Centre. Cutting the Binnenring can be a very effective tactic of denying access for through traffic. In this case, cutting the Binnenring is done by removing the option of travelling the entire North – South direction and South – North direction over the ring. This is illustrated by traffic between the Boschdijk in the North and the Leenderweg in the South, which is choosing the Binnenring as route in all cases.

For the blocking roads measure, the Binnenring structure is cut up into two separate two way roads, in such a way that it cannot be entered from the Leenderweg in the South anymore (figure 7.11). This is done by turning normal roads into bus lanes, removing normal traffic from these sections. The two separate roads are opened into two way roads.

It should be stated that the municipality is opposed to cutting the Binnenring into two sections. Results of this instrument should thus be interpreted very carefully. For the sake of the research and the theoretical framework however; the effects of cutting the ring into two sections results are very interesting.

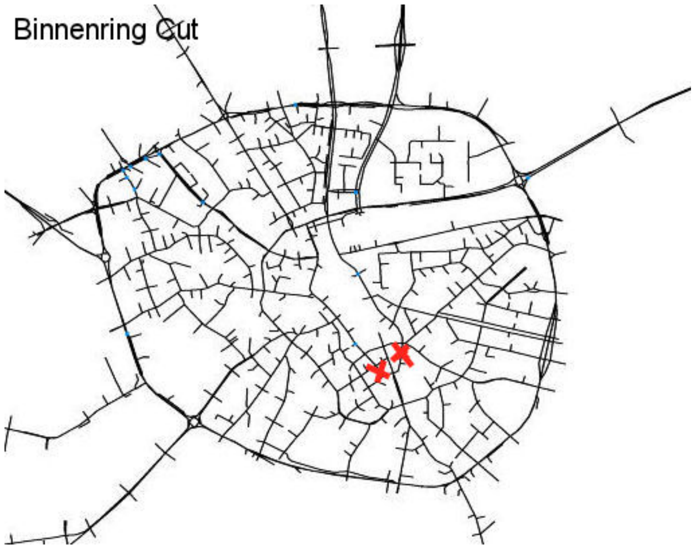

Figure 7.11: Locations where the Binnenring is being cut.

7.1.5 Adding lanes

In the focus area, the most travel time loss is experienced at the Boschdijk and the Karel de Grotelaan (figure 7.12). In an attempt to improve travel times over these roads, an extra lane can be added, making both roads entirely 2 lane roads. The locations of these roads is shown in figure 7.13 For the Boschdijk, adding a lane might not be politically possible since there is

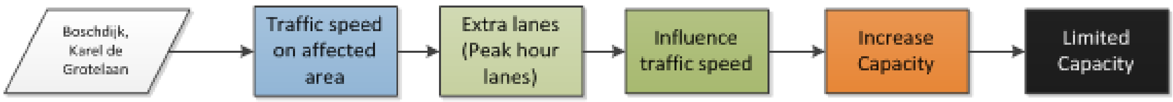

Figure 7.12: Possibilities for the application of adding lanes in Eindhoven.

strong opposition from the residents about this measure. The residents have also put effort into reducing the number of lanes on this road when this was done. The measure has been tested for the sake of the instrumental framework, but will not be implemented. Widening of the Karel de Grotelaan might experience less opposition. But this road is already almost entirely a two lane road; so the effects on the travel time might be less. The widening of the roads in both cases will only be in one direction, coming from the ring into the city centre. At all intersections on these roads, there are already multiple turn-lanes, the lay-out of these turn-lanes remains unchanged.

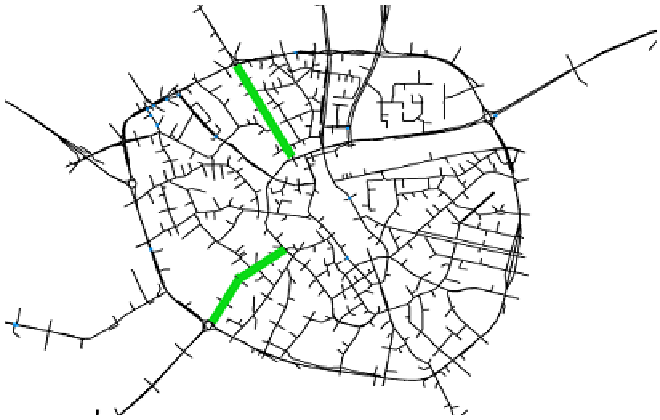

Figure 7.13: Karel de Grotelaan and Boschdijk inside the Ring, turn-lanes do not change from the reference situation in this alternative

7.2 Testing the proposed instruments

All instruments that have been designed in section 7.1 are tested in Paramics, the results are elaborated in the following analysis. The goal of this analysis is to assess the primary and secondary effects. Primary effects are the effects at which the measures are focused at. The secondary effects are the side effects which can also affect the policy goals. Secondary effects can be for instance environmental effects; spill-backs and new bottleneck locations. These results can also be used to quantify the impact of the design variables as described in chapter 2.

7.2.1 Gating

Primary goals of gating are to decrease intensity within the City Centre area and also increase the maximal speed. A secondary effect that could occur is spillback of buffered traffic onto main roads. This risk exists mainly in the gating 2 option where gating locations border the Ring road.

Primary results

The two primary indicators for the effectivity of traffic gating are downstream intensity and downstream traffic speed of traffic. Downstream traffic is indicated by the affected area of these alternatives in the case of gating 1, Enhances the Mauritsstraat, Fellenoord and Binnenring, and in the case of Gating 2, this will be Boschdijk, Mauritsstraat, Fellenoord and Karel de Grotelaan these areas are indicated in figure 7.14

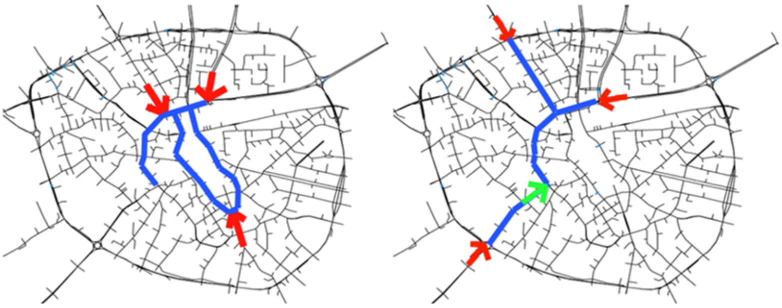

Figure 7.14: Areas affected by the two gating alternatives

Figures 7.15 and 7.16 show the total flow and travel times effects for these two alternatives in the affected area shown in figure 7.14. The roads over which the flows and travel times are measured are only the roads within the affected gating area. This means that for gating on, only the Fellenoord and Mauritsstraat in the westbound direction are measured. The reference situation for these values has been indexed at 100. The diffrences thus indicate percentage deviations between the measure and the reference situation.

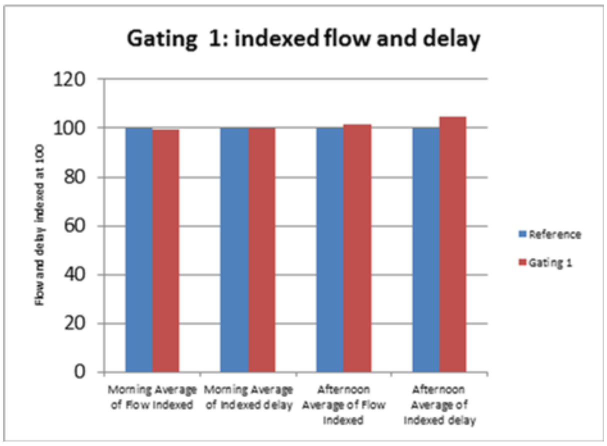

Figure 7.15: Primary gating results for the gating 1 measure

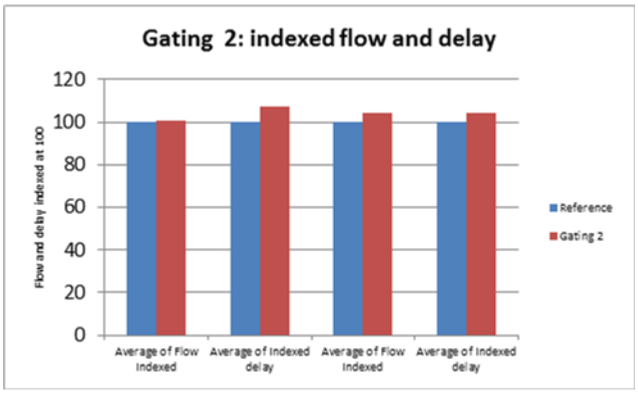

Figure 7.16: Primary gating results for the gating 2 measure

The gating 1 measure shows very little changes, the gating 2 alternative causes an average decrease in travel time of 5% within the affected area; at the same time the average flow within this area increases about 5% during the afternoon.

An effect which can be observed when the capacity is not maximal is that less traffic is inclined to use the trough traffic route, and flows increase less, or even decrease. This can be explained by the fact that the travel time gain that could be realized is less.

Also the differences in speed between the measures are notable. In the gating 1 alternative; travel times in the gated area increase, whereas they decrease in the gating 2 alternative. There is a couple of factors which could explain these differences: the difference in green time change could influence the effect, but also the measured roads, which differ between the alternatives. When the gating 2 results are broken down into travel times per route, differences within this alternative show where the inter-alternative differences originate from (see figure 7.17). In the gating 1 alternative, the Karel de Grotelaan and Boschdijk are not affected, these are the roads where travel time is reduced the most in the gating 2 alternative. It is also notable that the travel time difference that is seen on the Karel de Grotelaan, is less clear on the Boschdijk, differences between these two roads is that at the end of the Karel de Grotelaan, the amount of greentime for the traffic leaving the road is also increased.

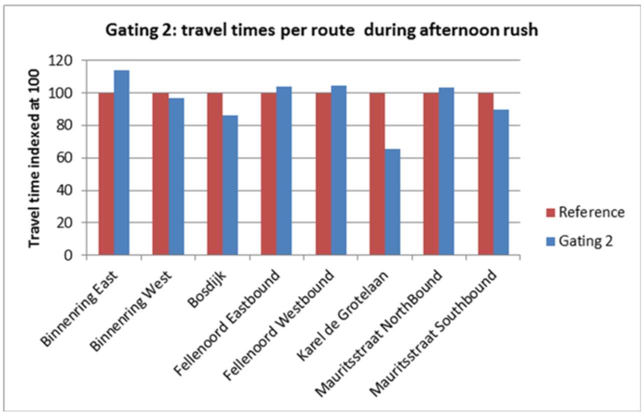

Figure 7.17: Travel times for the gating 2 alternative within the primary affected area

secondary results

Upstream Bottlenecks In this section these spillbacks effects are tested, buffer locations might cause spillback upstream. Locations for which this can be problematic are the locations at the Boschdijk and the Karel de Grotelaan which intersect with the ring. Figure 7.18 shows the traffic state at the intersection between the Boschdijk and the ring both in the reference situation at 17:45, as well as with the gating 2 measure applied. In the gating 2 situation, a new bottleneck west of the intersection occurs caused by shorter greentimes in the eastern direction.

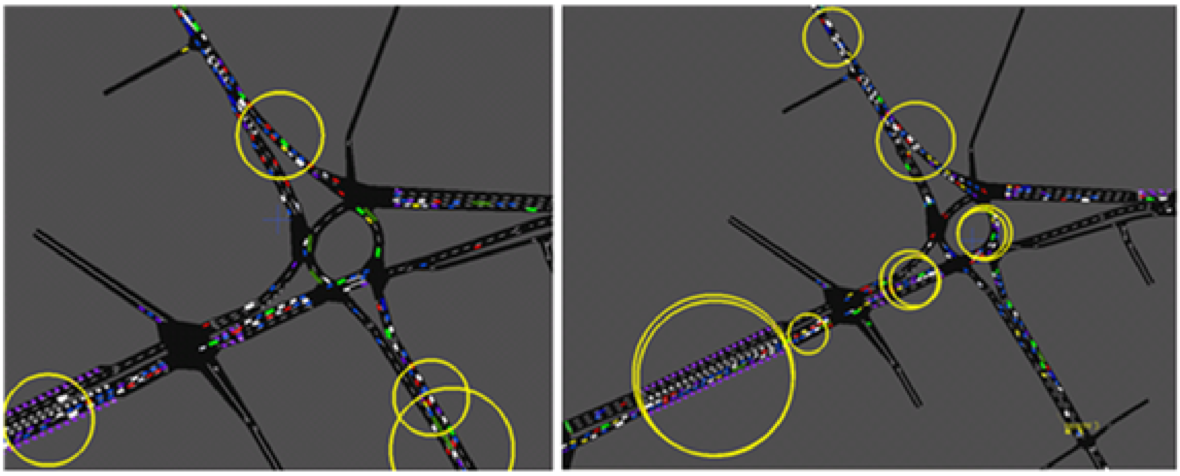

Figure 7.18: Traffic state compared between the reference situation and gating 2 near the Boschdijk.

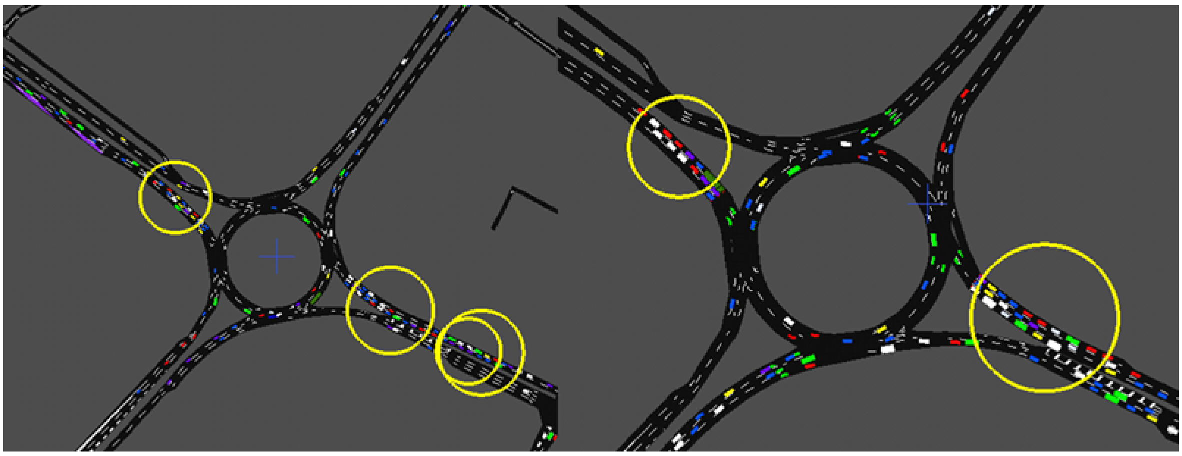

Figure 7.19: Traffic state near the Karel de Grotelaan compared between the reference situation and gating 2.

Figure 7.20 shows the travel time differences for the reference and the gating 2 travel time results for the Northwestern- and Southwestern parts of the ring in Clockwise direction, these are the parts of the ring where traffic is buffered before entering the City Centre. On the Northwestern ring (near the Boschdijk), the average travel time goes up by 60 seconds which is unacceptable for the arterial ring road. For gating on the Karel de Grotelaan, no upstream bottleneck can be confirmed. The location where travel times drop the most, Karel de Grotelaan, negative spill-back effects do not occur there are no negative secondary effects for this part of the gating alternative.

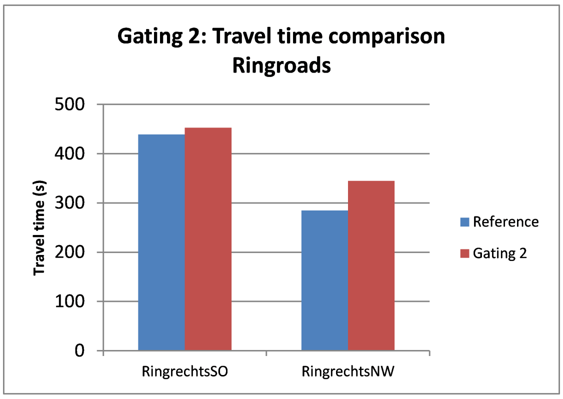

Figure 7.20: Travel times on the Ring Roads compared between the reference situation and Gating 2

Environmental effects There are 4 possible locations where the two gating alternatives could affect the environmental indicators; the two measurement locations on the Mauritsstraat, and the two locations on the Binnenring: Wal and Vestdijk. It was already concluded that flows in general increase because of traffic gating; when the flows at the individual environmental locations are considered; it becomes clear that gating turns out negative for the environmental locations. Figure 7.21 shows the indexed traffic flows at the environmental locations for the gating alternatives and the reference. The gating 2 alternative has logically the worst influence; traffic flows at the Mauritsstraat locations at this point increase as much as 15 percent. Combining gating with other measures within the affected area could help limiting the environmental problems.

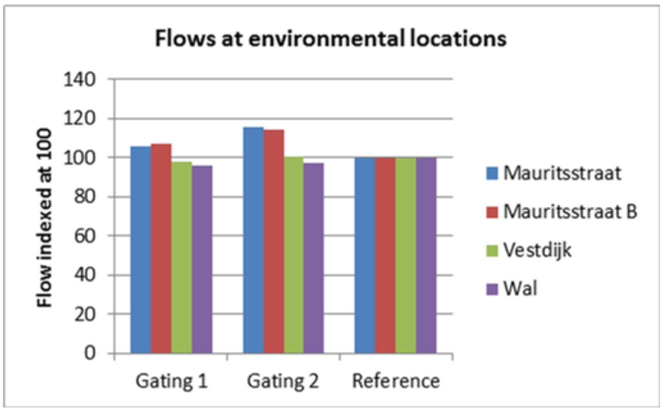

Figure 7.21: Measured flows at environmental locations for the gating alternatives.

Gating summarized

The most important gating results are:

- There is less traffic inflow into the area, congestion that used to occur in the gated area is prevented and the outflow increases. The traffic speed also increases. The net size of this effect is rather small. Gating can better be applied on congested roads with low speeds, for reducing flows, this instrument is not suitable.

- Average speeds at affected roads can only become larger if significant delays on the affected roads occur in the initial situation.
- Upstream bottlenecks do not necessarily occur in every situation; it is however important to identify risk locations and also monitor well if this will happen. For this purpose, on-line traffic control would be necessary. based on queue-length, a gating location can be either switched on or switched of.
- Effects of gating on environmental locations are not necessarily positive, if these locations lie within the affected area, counter measures might need to be taken.
- The gating alternatives as tested here do not affect accessibility on a network level.

7.2.2 Speed reduction

In this section, the 3 speed reduction alternatives that have been designed are compared between each other, and with the reference alternative.

Primary effects

The primary goals for lowering speed limits are both limiting the traffic flow on specific roads and redirecting through traffic.

Traffic flows on affected roads As a result of the decreased through traffic and different route choice for destination traffic, a reduction in traffic flow on the affected roads should also be measurable. In this analysis, both average speeds as well as average flows on the roads are being compared. Only the affected roads by each alternative are considered in the overviews presented below. Per alternative these roads are:

- Speed reduction 1: The Binnenring
- Speed reduction 2: Binnenring, Fellenoord and Mauritsstraat.
- Speed reduction 3: Boschdijk.

The results for these analyses are shown in figures 7.22, 7.23 and 7.24.

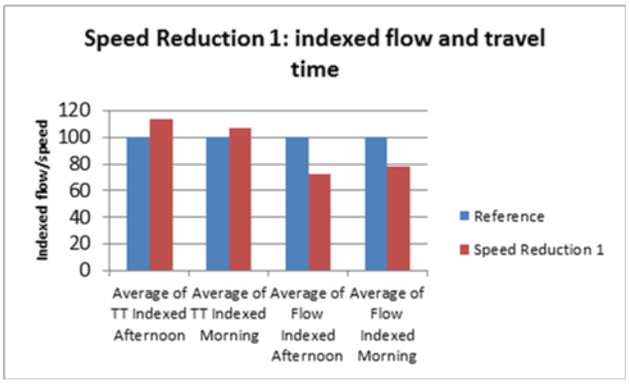

Figure 7.22: Travel times and traffic flows summarized on the directly targeted roads of Speed Reduction 1.

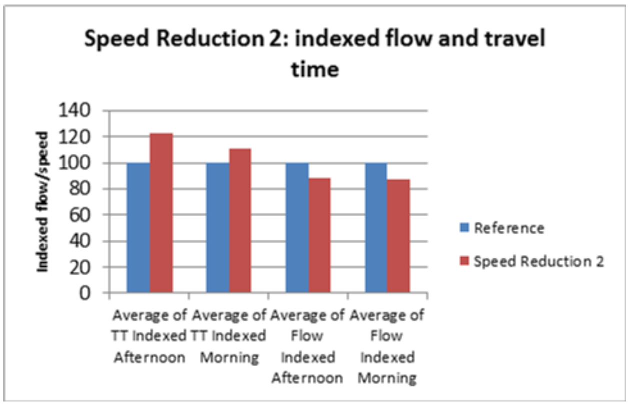

Figure 7.23: Travel times and traffic flows summarized on the directly targeted roads of Speed Reduction 2.

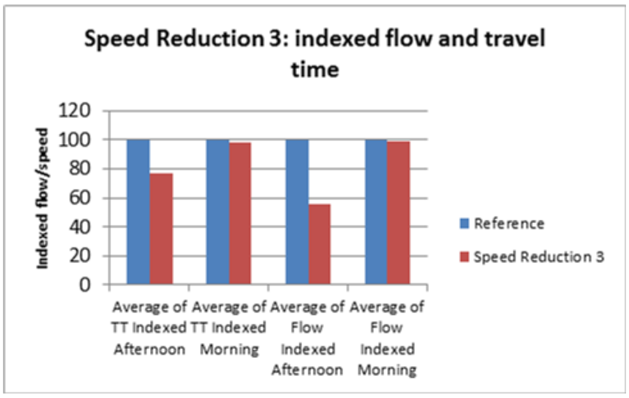

Figure 7.24: Travel times and traffic flows summarized on the directly targeted roads of Speed Reduction 3.

The travel time increase on the roads in these alternatives is on average 18% during the afternoon, and 9% during the morning. Average flows can go down around 20%. There is however a difference when the speed is reduced on the highly congested Boschdijk, as a result of the speed reduction on this road the average flow during the afternoon drops about 45%. The average travel time on the road however, also drops during the afternoon, by about 23%. This effect is shown in figure . In the initial situation, there is a high travel time peak on the Boschdijk during the afternoon; this peak is removed as a result of the lower travel time on the Boschdijk.

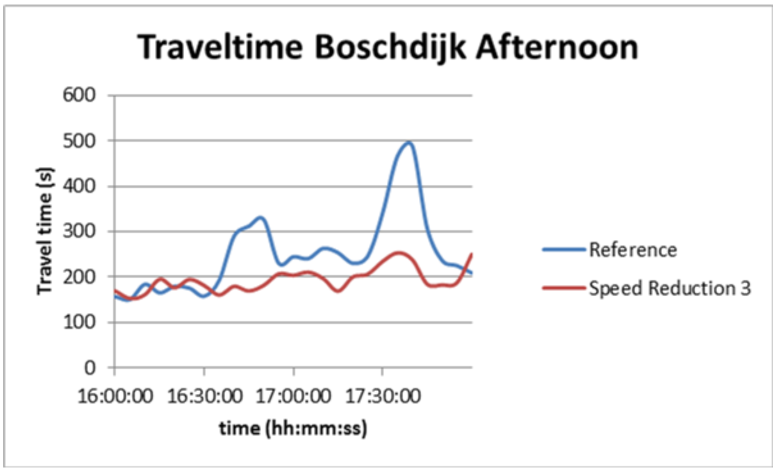

Figure 7.25: Travel time improvement on the Boschdijk as a result of speed reduction on this road.

Through traffic Speed reduction 1 and 3 should affect only the North-South because the Binnenring or the Boschdijk are being delayed. Speed reduction 2 should also affect the Blue routes The quantitative effects can be seen in figures 7.26 and 7.27.

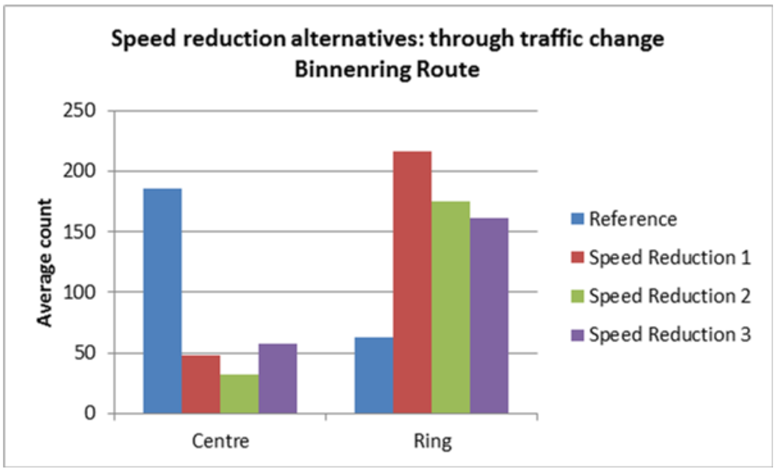

Figure 7.26: Through traffic count averaged over morning and afternoon rush over the North - South route.

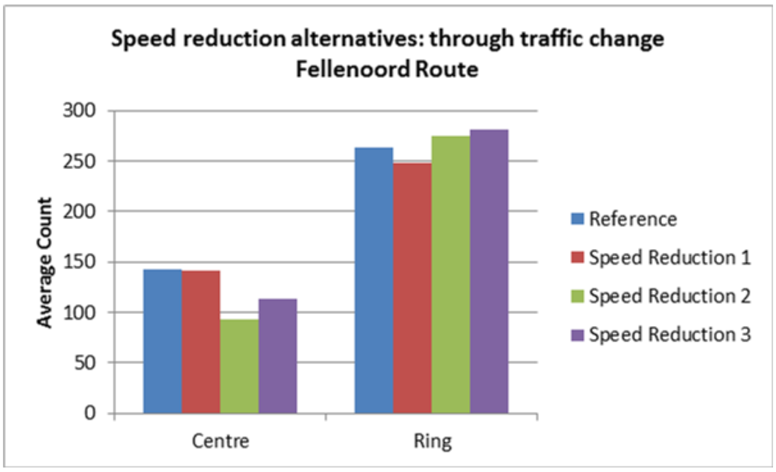

Figure 7.27: Through traffic count averaged over morning and afternoon rush over the Fellenoord route.

The main through traffic effect is gained on the Binnenring Route. In all three cases; the average through traffic count on this route drops with at least 70 percent. Reducing speed on the Boschdijk or on the Binnenring for this alternative seems to have a similar effect.

On the Fellenoord route, differences are smaller. The only alternative which really focuses on these routes is speed reduction 2. The count difference between this alternative and the reference situation is still 35%.

On the basis of these observations it can be concluded that speed difference can be a successful method for redirecting through traffic, depending on the gained travel time of the alternative routes.

Secondary effects

Environmental effects In figure 7.28 the environmental effects of the speed reduction alternatives are shown. The figure shows average values of both the morning- and afternoon rush. This is done because both rush hours show the same pattern on these results.

The locations on the Binnenring, Vestdijk and Wal, show a significant improvement when the alternatives of reducing the speed limit on the Binnenring is concerned. At the Wal, flows at environmental locations go down about 35%. At the Vestdijk this is a little less, but still a good 12%. Remarkable is that this does not go for speed reduction 3, whereas it has been concluded that this alternative does lead to a significant drop of through traffic over the Binnenring.

On the Mauritsstraat locations almost no improvements are shown. Mauritsstraat B is not part of the affected roads in any option, and the Mauritsstraat location is affected by the speed Reduction 2 alternative, for this alternative, a small improvement is shown. For the other situations can be concluded that there is a small deterioration of the environmental situation. Whether this is the result of the speed adaptations however, is hard to tell.

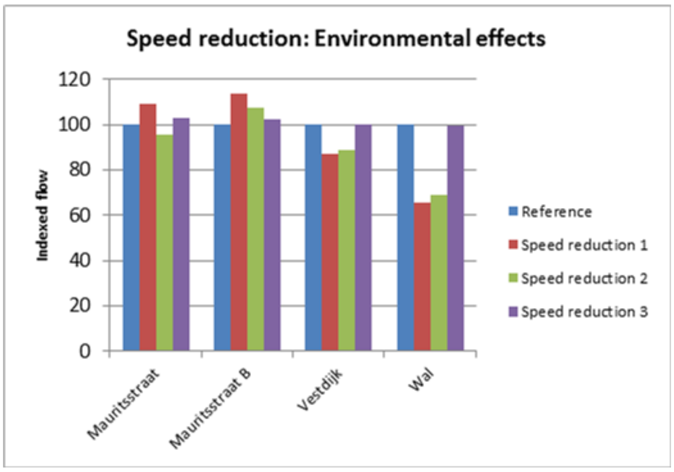

Figure 7.28: Average environmental effects of the speed reduction alternative during both morning- as well as afternoon rush hour.

Accessibility Figure 7.29 presents the accessibility results summarized for all measured routes in the city centre plus the Ring. What stands out is that the second alternative has on average higher travel times during the afternoon than in the reference situation; travel times are about 19% higher.

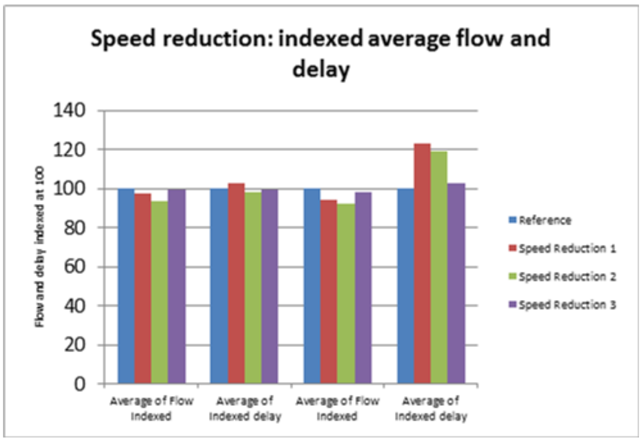

Figure 7.29: Accessibility scores for all speed reduction alternatives compared.

Not only the travel times on the targeted roads are increased, the travel time effects can also be measured upstream as shown in figure 7.30. Travel times increase up to 23% on roads upstream except for the heavily congestion on the Boschdijk. The only upstream road where travel times do not go up is the Boschdijk, which is already really congested in the reference situation.

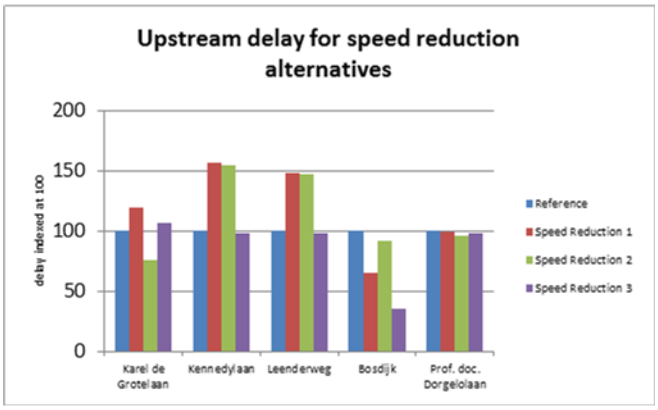

Figure 7.30: Indexed delays on roads upstream of reduced speeds compared for speed reduction alternatives during the afternoon rush.

Speed reduction summarized

The most important results for speed reduction are:

- Speed reduction on roads frequently used for through traffic can be an effective tool for redirecting traffic. In this case through traffic reductions up to 75% are measured. This effect however is very dependant on the situation, and both route alternatives should become competitive at least.
- In most situations lowering speed limits leads to longer travel times and lower flows. When initial delays are very heavy, speed reduction can also be a tool to improve travel times.
- Environmental effects are mainly positive when the environmental locations are at critical levels in the affected area.
- Accessibility analysis shows that overall accessibility decreases as speed reduction is placed.
- Travel times on roads upstream of the affected roads are also reduced.

7.2.3 Blocking Roads

Primary effects

Blocking roads has as primary goal to redistribute traffic. In this research set up, the target is to redirect through traffic from the Binnenring towards the Ring road. Figure 7.31 shows the change in the amount of through traffic over the Binnenring route. The amount of through traffic over the ring decreases with 57% in comparison with the amount of through traffic in the reference situation. The amount of through traffic on the Fellenoord route stays about the same in both alternatives.Though a 57% decrease in through traffic, more progress is gained with the speed reduction alternatives. When the route analysis is considered a relative high percentage vehicles choose cut-trough's instead, possibly causing through traffic redistribution towards routes where the traffic is also not wanted.

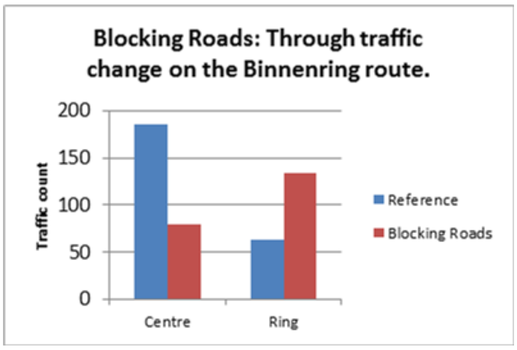

Figure 7.31: Chosen through traffic routes compared between the reference and the Blocking roads alternative.

In order to identify additional bottlenecks caused by the redirection of traffic through the city centre, the traffic state can be considered. Figure shows the actual traffic situation at around 17:30, one of the busiest traffic hours. Yellow circles indicate slow moving traffic, compared with other model runs, and also the reference, the amount of traffic around the city centre is very limited.

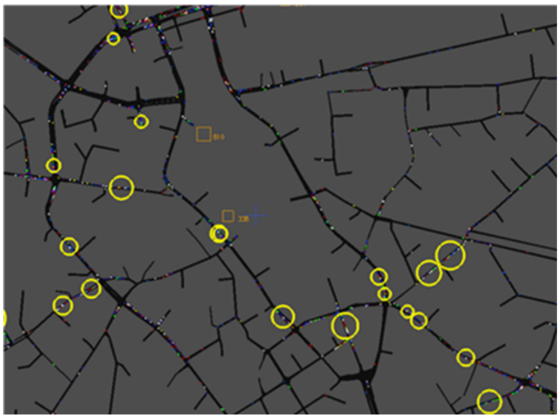

Figure 7.32: Traffic at 17:30 in the Blocking roads alternative.

secondary effects

Environmental effects Figure 7.33 shows the environmental for the blocking roads alternative. On the targeted route, the flows at the environmental locations drop 16% (Vestdijk) and 9% (Wal). On the other locations, which are not on any of the targeted routes, environmental conditions do not change as much.

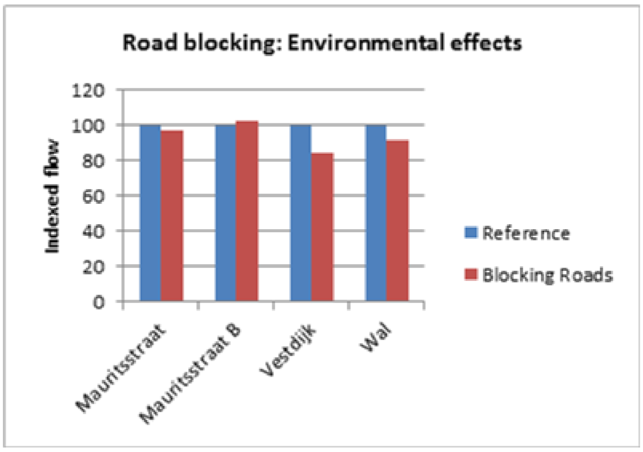

Figure 7.33: Environmental effects of blocking roads.

Accessibility effects Figure 7.34 shows the total accessibility results for road blocking. The total accessibility effect on the accessibility are positive, during the afternoon rush both travel time and flow go down, respectively with 4% and 5%. In the morning, the average travel time goes up 3%, the average flow however, goes down by 6%.

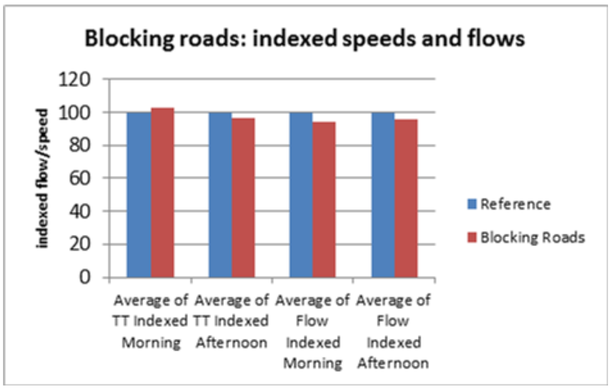

Figure 7.34: Accessibility effects of the blocking roads alternative.

In figure , the travel time effects on several important roads in the city centre in the blocking roads alternative are shown. The travel time of the Boschdijk, a directly affected route, drops by 20%. Negative effects are measured on the Fellenoord/Boschdijk Corridor, travel times on this route rise up to 15%. The flow on the Fellenoord is over twice as high as the flow on the Boschdijk in both alternatives; this implies that accessibility effects for this alternative around the affected area can be considered negative.

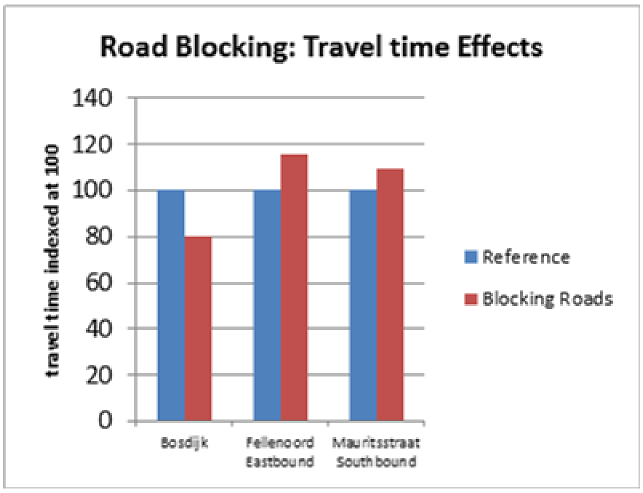

Figure 7.35: Travel time effects of road blocking.

Blocking roads summarized

The most important results for blocking roads are:

- Blocking roads is a tool which can be used to redirect all traffic from a certain road or part of the network. In the case study a 57% decrease in through traffic on the targeted routes is measured.

- Cut-through traffic does increase near the blocked location; the amount of cut-through traffic is however very limited.

- Emissions at environmental locations both downstream and upstream of blocked locations are decreased.

- The net accessibility effects are positive for the measured network.

7.2.4 Adding lanes

Primary Results

The primary goal of this measure is to increase the average speed on the Karel de Grotelaan and the Boschdijk. In figures 7.37 and 7.36 the travel time and travel flow effects of adding lanes on both Karel de Grotelaan and Boschdijk are shown, indexed at 100 in the reference alternative. For the Karel de Grotelaan, the flows are pretty constant; the travel time in the afternoon drops 13%. On the Boschdijk, the expected travel time gain is 8% during the morning rush, but it rises 4% during the afternoon rush. The traffic flow on the Boschdijk during the afternoon however, does increase by 15% during the afternoon Rush as a result of the added lane Overall it can be said that the net effects of adding lanes in this situation is not very effective.

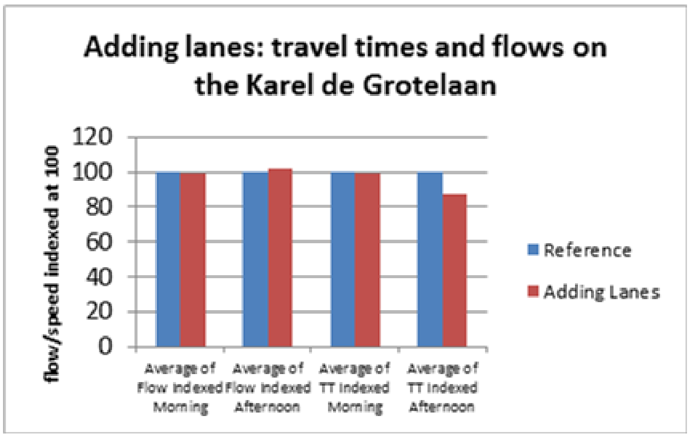

Figure 7.36: Indexed effects of the adding lanes alternatives on Traffic flows and travel times on the Karel de Grotelaan.

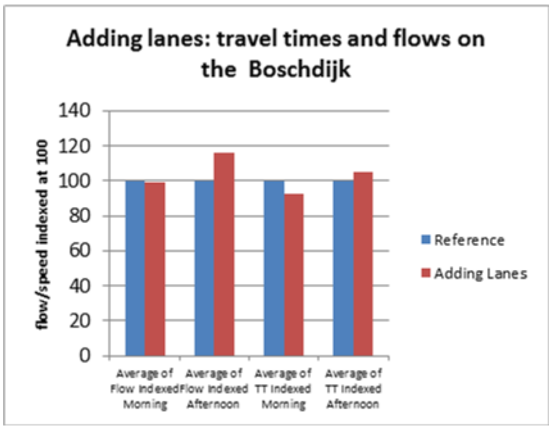

Figure 7.37: Indexed effects of the adding lanes alternatives on Traffic flows and travel times on the Boschdijk.

secondary effects

Through traffic Figure 7.38 shows the through traffic change over the Boschdijkroute. Through traffic over the Boschdijk route decreases in the adding lanes alternative. The amount of through traffic over Mauritsstraat is the same in the reference situation and the adding lanes alternative.

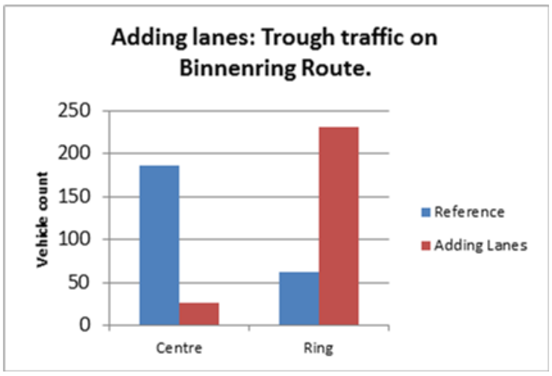

Figure 7.38: Change in through traffic on the Boschdijk route as a result of adding lanes.

Accessibility Figure 7.39 shows the total accessibility effects in the adding lanes alternative. Accessibility effects of the added lanes alternative are limited. The average travel time during the afternoon rush on all measured routes increases by 4 percent as a result of adding lanes; this is the biggest change in the total accessibility effects.

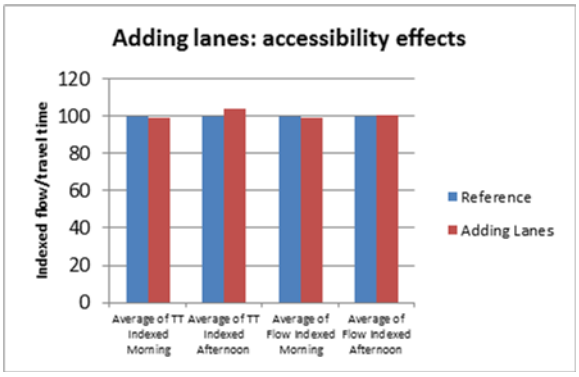

Figure 7.39: Accessibility effects in the adding lanes alternative.

Environmental effects The environmental aspect when adding lanes is mainly relevant when the afternoon situation is concerned; figure 7.40 shows the environmental situation during the afternoon situation. Flows at the two Mauritsstraat locations, which are mainly affected by the measure that is taken on the Karel de Grotelaan, increase by respectively 6% and 9%. The flows at the two locations on the Binnenring decrease by 3% and 7%.

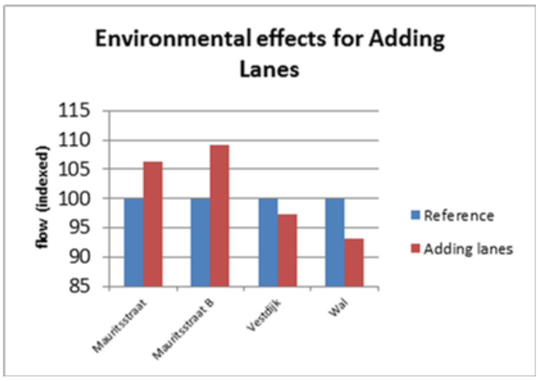

Figure 7.40: Environmental effect of Adding Lanes during the afternoon.

Adding lanes summarized

In this section the effects of adding lanes have been tested. The most important results are:

- The expected primary effects are not always clear. In the Boschdijk case the average flow increases, whereas on the Karel de Grotelaan the average travel time decreases. These are both positive effects, but a generic rule cannot be deduced from these observations.

- The amount of through traffic on the Binnenring-route decreases when the adding lanes measure is applied.

7.3 Multi-criteria analysis

In order to assess all tested instruments in a uniform way, a multi criteria analysis framework has been designed in chapter 5 Except for the adding lanes alternative, all measures have some positive effects and are suited to be used in an aggregated alternative. The instrument results can be summarized in a multicriteria assessment. For gating, the best performing measure, the gating 2 alternative has been summarized in the multicriteria analysis; for speed reduction, the results for speed reduction 2 are summarized.

The results for the multicriteria analysis are shown in table 7.2. The benchmark minimum values are shown in the first row in absolute numbers. In the other columns, the relative change from the benchmark value is shown. For the factors accessibility and through traffic no benchmark has been set; for these factors the indexed value is the value in the reference situation.

Table 7.2: Multi criteria assessment for the tested instruments

Multi criteria assessment Individual instruments						
Indicator	**Benchmark**	**Reference**	**Gating**	**Speed Reduction**	**Blocking roads**	**Adding lanes**
Accessibility	Sample optimal result					
City centre flow	Decrease	679 veh/hr	1%	-8%	-6%	0%
Flow on Ring	Increase	1050 veh/hr	-1%	-1%	-1%	0%
Through traffic	Sample optimal result					
City centre traffic	Decrease	329 veh	7%	-62%	-25%	-47%
Ring traffic	Increase	326 veh	10%	38%	-10%	52%
Minimal trajectory Speed	Maximum score = 64	-48%	-48%	-45%	-44%	-47%
Vehicle emissions	Target flow < 2125 veh/h	5%	6%	2%	5%	3%
Slow mode accessibility	Target average < 20s	10%	4%	-8%	5%	3%

For the case in Eindhoven, blocking roads and speed reduction show the best results on the optimization criterion accessibility. When all criteria are considered the most positive effects are seen in the speed reduction alternative. Gating results show that flow on the congested roads in the city centre increase, this method could possibly be applied on the ring road around Eindhoven, this is not further tested in this research however.

7.4 Instrument design and testing summary

In section 7.1, the performance indicators in the traffic management framework have been linked to the problem indicators resulting from the traffic analysis in order to come to traffic management instruments at the right locations. This link between a real life traffic network state and the theoretical can be applied for any urban network. For the Eindhoven situation, two alternative instruments for traffic gating are proposed, three alternatives for speed reduction, one for blocking roads on the Binnenring, and one for adding lanes. In section 7.2, the traffic analysis for these instruments is discussed. In section 7.2 the instruments are compared using the multicriteria analysis. In these conclusions, the results are discussed per tested instrument in the overview below.

Gating

- There is less traffic inflow into the area, congestion that used to occur in the gated area is prevented and the outflow increases. The traffic speed also increases. The net size of this effect is rather small. Gating can better be applied on congested roads with low speeds, for reducing flows, this instrument is not suitable.
- Average speeds at affected roads can only become larger if significant delays on the affected roads occur in the initial situation.
- Upstream bottlenecks do not necessarily occur in every situation; it is however important to identify risk locations and also monitor well if this will happen. For this purpose, online traffic control would be necessary. based on queue-length, a gating location can be either switched on or switched of.
- Effects of gating on environmental locations are not necessarily positive, if these locations lie within the affected area, counter measures might need to be taken.

- The gating alternatives as tested here do not affect accessibility on a network level.

Speed reduction

- Speed reduction on roads frequently used for through traffic can be an effective tool for redirecting traffic. In this case through traffic reductions up to 75% are measured. This effect however is very dependant on the situation, and both route alternatives should become competitive at least.
- In most situations lowering speed limits leads to longer travel times and lower flows. When initial delays are very heavy, speed reduction can also be a tool to improve travel times.
- Environmental effects are mainly positive when the environmental locations are at critical levels in the affected area.
- Accessibility analysis shows that overall accessibility decreases as speed reduction is placed.
- Travel times on roads upstream of the affected roads are also reduced.

Blocking Roads

- Blocking roads is a tool which can be used to redirect all traffic from a certain road or part of the network. In the case study a 57% decrease in through traffic on the targeted routes is measured.
- Cut-through traffic does increase near the blocked location; the amount of cut-through traffic is however very limited.
- Emissions at environmental locations both downstream and upstream of blocked locations are decreased.
- The net accessibility effects are positive for the measured network.

Adding lanes

- For the adding lanes measure to be effective, it is important that no severe bottlenecks occur either upstream or downstream of the affected area.
- The total accessibility is hardly affected with the measure of adding lanes.
- More emissions are measured at environmental locations downstream of the affected roads.

Chapter 8

Combination of instruments into traffic management strategies

In this chapter, a combination of the developed instruments is made in order to further improve the measure results. The end product of this step is a number of traffic management strategies which can be used to effectively improve the traffic state in the network. The traffic management strategies can be compared using a multi criteria analysis. The research question that is discussed in this chapter is:

How can the separate instruments tested for the Eindhoven case be combined into an effective networkwide traffic management strategy?

In chapter 2, possible methods are discussed for the design traffic management strategies. The method is applied to the instruments designed for Eindhoven in this chapter. The traffic management strategy design process is shown in figure 8.1.

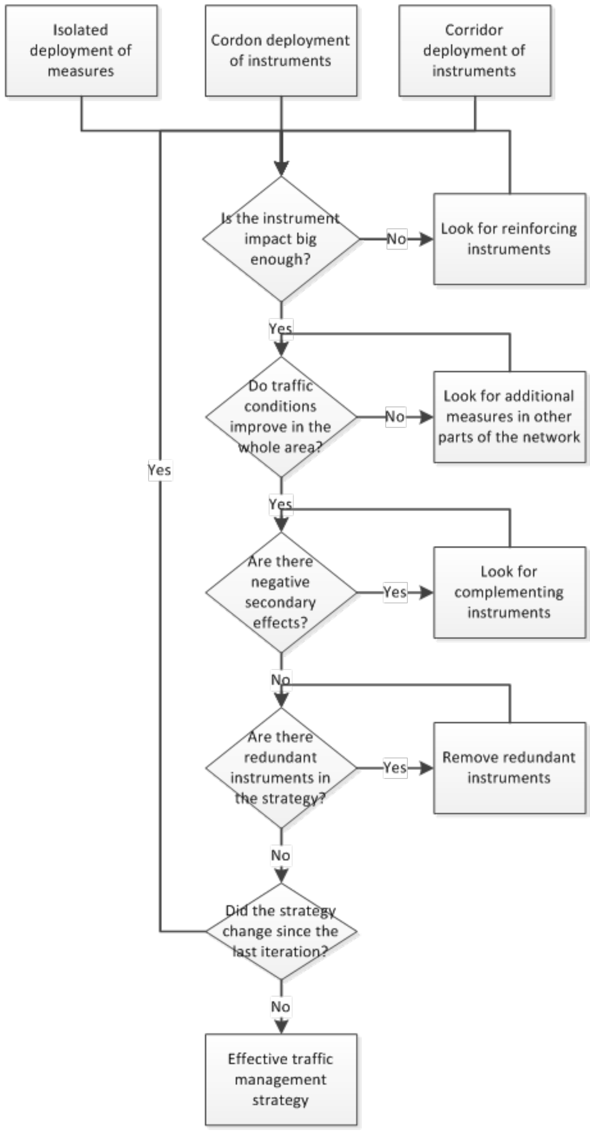

Figure 8.1: Flowchart for the combination of traffic management measures.

Additional instruments for strategies are selected based on their reinforcing capacities and the complementing properties between instruments. The multi-criteria analysis of separate instruments presented in the previous chapter can be used for ex ante assessment of the traffic management instrument effects. Also the more elaborate instrument analyses can be used.

8.1 Application of the traffic management design strategy

As illustration for the proposed method for combining instruments, a corridor focus is chosen for combining instruments. The corridor that is being focussed on is the north-south corridor consisting of the Boschdijk, Binnenring and Leenderweg, this corridor is shown in figure 8.2.

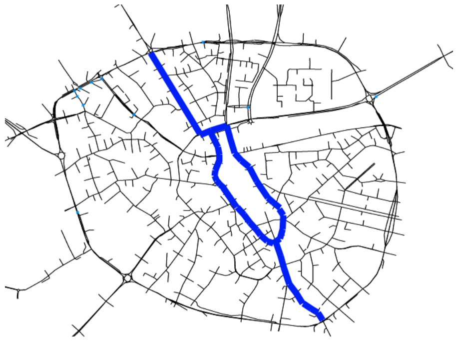

Figure 8.2: City centre corridor for which a combination of measures is tested.

The north-south corridor, or Binnenring-route, is chosen since all effective instruments are tested on this corridor, and there is a possibility to assess the effects of the combined instruments on this corridor. Gating is not tested here, however since this instrument is not effective in this particular network, it is also not suited for further testing in the network. The goal for this corridor is to reduce the traffic flow as much as possible while the area still stays accessible. Also, as an effect of road blocking, the average travel time on the Boschdijk is reduced

Based on the analyses of the instruments, it can be said that both speed reduction at the Binnenring and the Boschdijk have a positive effect on the traffic flow on the north-south route, these are both options that can be considered. For the total city centre through traffic effect, speed reduction 2 is most effective, speed reduction on the Fellenoord is part of this option, and therefore also considered for this option. Also travel times on the Boschdijk become more constant over time as a result of speed reduction on this road. And the average travel time on the Boschdijk actually goes down.

Considering the multi criteria analysis of the separate instruments (table 8.1). The best results over all results on traffic flow and through traffic are gained in for the speed reduction instrument. The flow reduction in the city centre is 8%, and the amount of through traffic is reduced by 62%. Also for both vehicle emissions and slow mode accessibility, this is the best scoring instrument. For slow mode accessibility; this is the only instrument which has waiting times at the intersections lower than 20 seconds. For blocking roads, also some positive results are obtained in terms of traffic flow and trough traffic: the traffic flow through the city centre is reduced by 6% and the total amount of measured through traffic through the city centre is reduced by 25%. Since the policy goal is to minimize the traffic flow and through traffic through the city centre, both instruments are combined in order to further decrease traffic flow in the city centre.

Table 8.1: Multi criteria assessment for the tested measures

Multi criteria assessment Individual instruments						
Indicator	**Benchmark**	**Reference**	**Gating**	**Speed Reduction**	**Blocking roads**	**Adding lanes**
Accessibility	Sample optimal result					
City centre flow	Decrease	679 veh/hr	1%	-8%	-6%	**0%**
Flow on Ring	Increase	1050 veh/hr	-1%	-1%	-1%	**0%**
Through traffic	Sample optimal result					
City centre traffic	Decrease	329 veh	7%	-62%	-25%	-47%
Ring traffic	Increase	326 veh	10%	38%	-10%	52%
Minimal trajectory Speed	Maximum score = 64	-48%	-48%	-45%	-44%	-47%
Vehicle emissions	Target flow < 2125 veh/h	5%	6%	2%	5%	3%
Slow mode accessibility	Target average < 20s	10%	4%	-8%	5%	3%

Based on the observations from the separate instruments listed above, two alternatives are tested. Three instruments have a positive effect on the conditions on the Binnenring route: Speed reduction on the Binnenring, speed reduction on the Boschdijk and Blocking roads. The first chosen traffic management strategy consists of a combination of speed reduction alternatives 2 and 3, and the blocking roads alternative. In order to indicate the separate effects of speed reduction and on the Boschdijk, there is also a strategy tested without speed reduction on the Boschdijk. Figure 8.3 shows an overview of the proposed measures for both traffic management strategies.

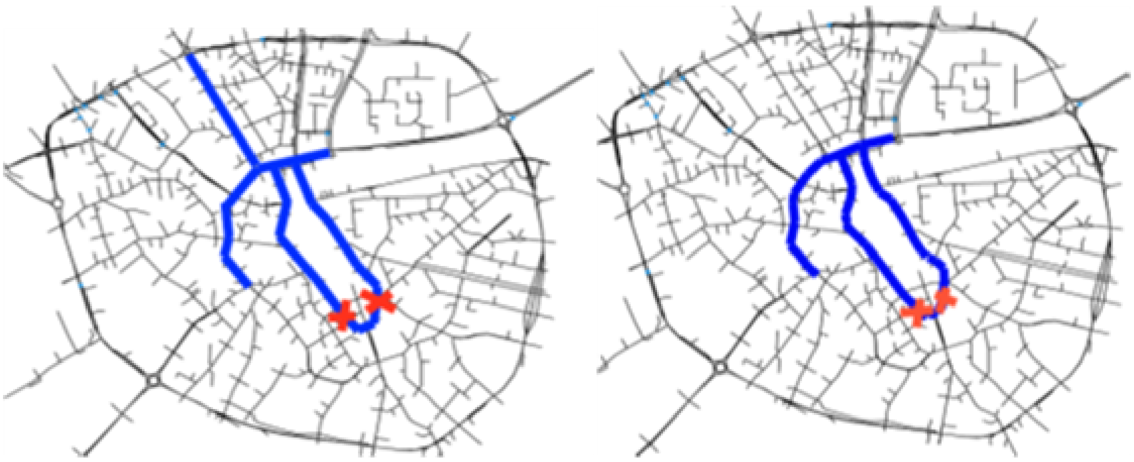

Figure 8.3: Overview of measures applied in aggregated alternatives 2 (on the left) and 3(right)

Considering the separate instrument results, several expected effects for this alternative can be assessed. Expected primary effects are:

- The amount of through traffic is decreased both under influence of the speed reduction measures, and the blocking roads measure.
- Both measures result into a considerable reduction of vehicles through the city centre. These effects reinforce each other.

Expected secondary effects are:

- Speed reduction results in an improvement at the environmental location compared to the reference situation, the expectation is that this improvement can also be seen in these aggregated alternatives

- Slow mode accessibility improves in both instrument compared to the reference situation, in the chosen traffic management strategy; this is also expected to improve. For speed reduction, the average waiting times are expected to be under 20 seconds. This is also the target for the traffic management strategy.

- Some cut through traffic might occur around the Binnenring.

8.2 Traffic management strategy results

For the traffic management strategy alternatives through traffic and accessibility of the city centre compared to the separate measures are particularly interesting. Just as for alternative 1, effects on through traffic and traffic flow and speed through the city centre are relevant for these alternatives.

8.2.1 Optimization of traffic flow and through traffic

Accessibility Figure 8.4 shows the average flows through the city centre and over the ring for the two tested strategies and their individual instruments. Changes in traffic flows over the ring are pretty small. Changes in flow through the city centre are particularly big in the afternoon. When the average flow in the city centre goes down 82% in strategy 2, this is 86%. This indicates that combining instruments during the busy afternoon rush hour can be effective in reducing the traffic flow. Contrary to the expectations the average flow on the ring does not go up.

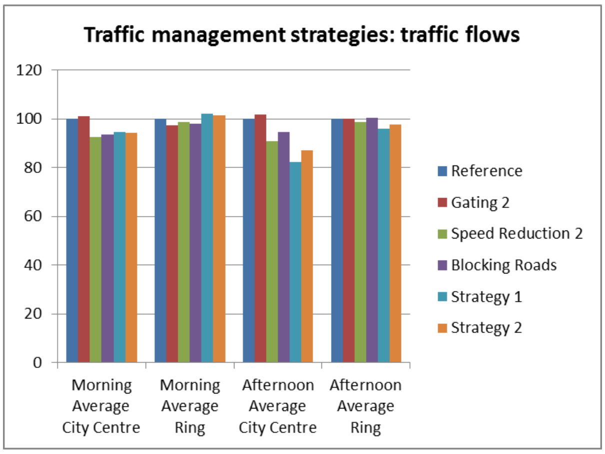

Figure 8.4: Indexed traffic in the City Centre and on the Ring compared between Alternatives 2 and 3 and their separate measures.

Both strategies have double measures on the Binnenring. As a result the average flows on the Binnenring in both alternatives drop significantly in both the morning and afternoon rush hour as can be seen in figure 8.5.

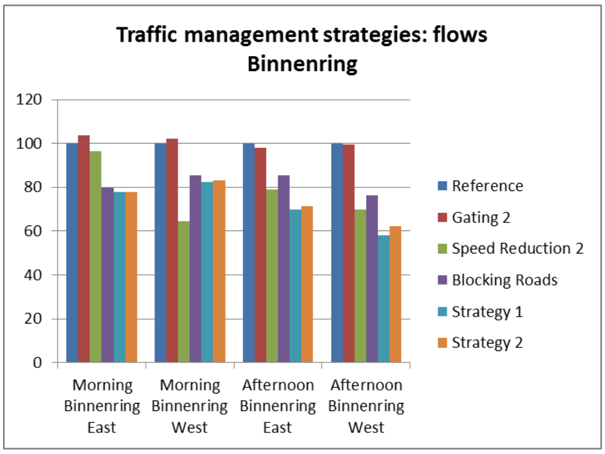

Figure 8.5: Indexed traffic on the Binnenring compared between Alternatives 2 and 3 and their separate measures.

Through traffic Figure 8.6 shows the through traffic and the traffic over the ring for all measured OD pairs combined. The instruments focus on decreasing the traffic through the centre. The total effects are similar to the results in the speed reduction alternatives. There is no increase of the total through traffic effects visible. On the Boschdijk, route, which also includes the Binnenring, the amount of traffic through the centre is slightly smaller in the aggregated alternatives than in the speed reduction measures. This effect is shown in figure 8.7.

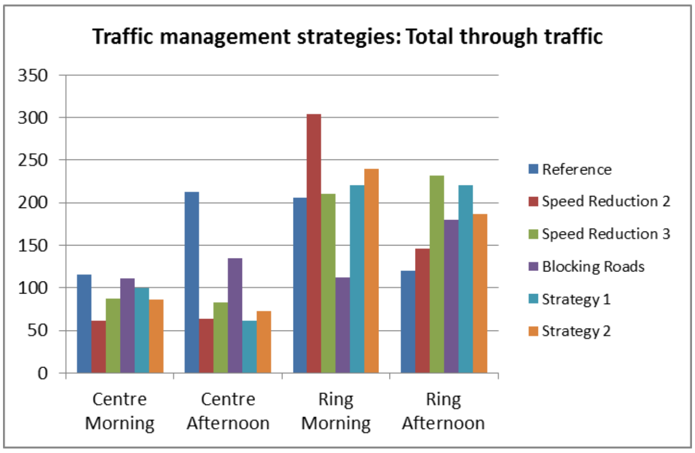

Figure 8.6: Vehicle count over all through traffic routes compared between alternatives 2 and 3, blocking roads and speed reduction.

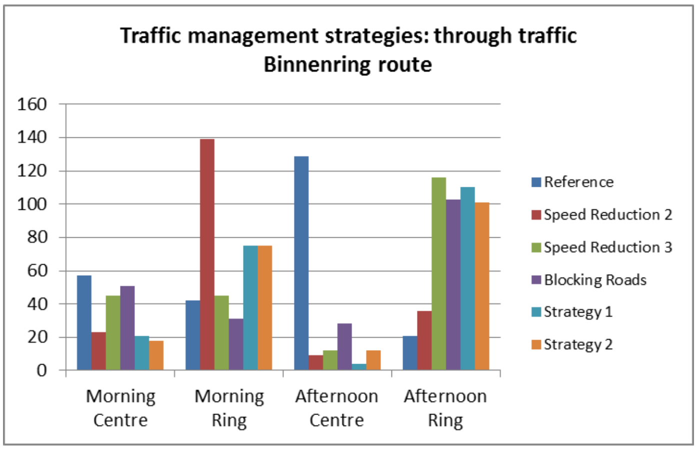

Figure 8.7: Vehicle count over the Boschdijk route compared between alternatives 2 and 3, blocking roads and speed reduction.

Traffic flows in the city centre get lower as gating and speed reduction are combined as opposed to the separate measures. For the amount of through traffic this effect is less noticable.

8.2.2 Preconditions comparison

In this section, minimum trajectory speeds, environment and slow mode accessibility are compared between the alternatives and with the reference situation.

Minimal policy speeds Figure 8.8 shows the route count compared between the strategies for the amount of routes where the average speed is above the minimal policy speed of that road. If the minimal 5 minute average speed on that road is also measured above the minimum speed, two points assessed. Overall score differences between the alternatives are small. The biggest improvement can be seen in the afternoon when the route count goes from 13 in the reference situation towards 16 in strategy 1. For all other situations, the measured impact is not that big.

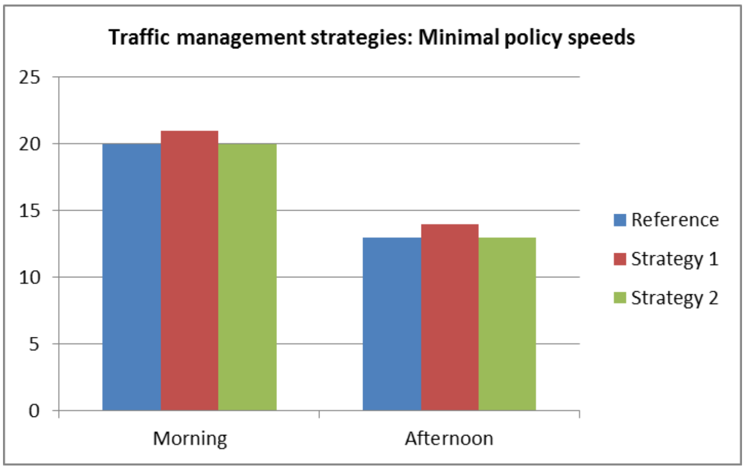

Figure 8.8: Route Count of trajectories reaching their minimal speeds

Environmental effects In figure 8.9 the averaged traffic flows over all environmental locations are indexed at 100 and compared between the alternatives. Both strategies improve the overall environmental situation. Both alternatives perform best during the afternoon rush, the average flow during the afternoon goes down by 8% and 6%.

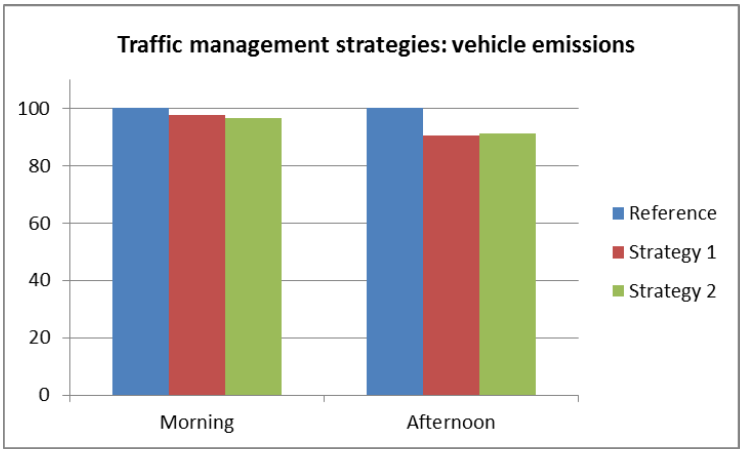

Figure 8.9: Indexed environmental results compared between the alternatives

Slow mode accessibility Slow mode accessibility has been measured on two intersections, The Boschdijktunnel - Mathildelaan and the Vestdijk - 18 Septemberplein. Flows from all directions on these intersections are used to indicate an estimation of the average waiting time for pedestrians. The results for this analysis compared between the alternatives are shown in figure 8.10. In most situations the average waiting time dercreases. Only at the Boschdijktunnel intersection during the afternoon the average waiting time increases.

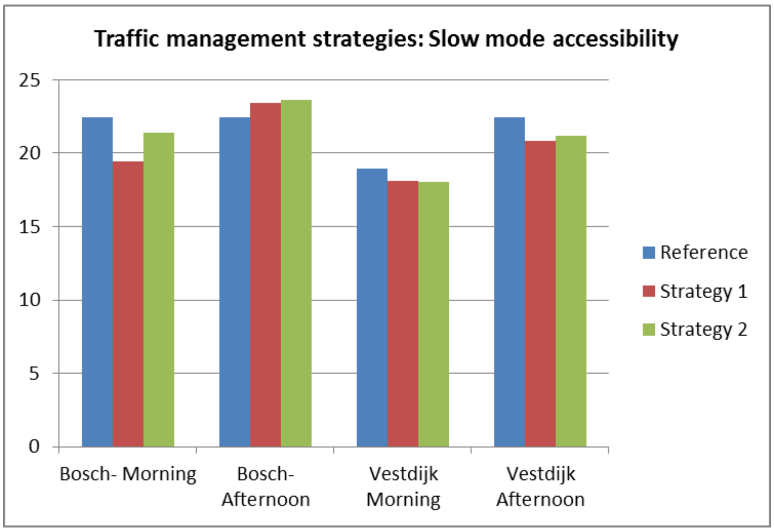

Figure 8.10: Average estimated waiting times for the alternatives compared

8.3 Multi-criteria analysis

The specific results for the alternatives are shown in the multi-criteria assessment shown in table 8.2. All performance indicators are indexed and compared between the traffic management strategies analysed in the previous sections. This results into an overview of the most important results for the case study Eindhoven.

Table 8.2: Multi criteria assessment for the aggregated alternatives.

Indicator	Benchmark	Reference	Strategy 1	Strategy 2
Accessibility	Sample optimal result			
City centre flow	Decrease	679 veh/hr	-12%	-9%
Flow on Ring	Increase	1050 veh/hr	-1%	-1%
Through traffic	Sample optimal result			
City centre traffic	Decrease	329 veh	-43%	-46%
Ring traffic	Increase	326 veh	46%	36%
Minimal trajectory Speed	Maximum score = 64	-48%	-45%	-45%
Vehicle emissions	Target flow < 2125 veh/hr	5%	1%	1%
Slow mode accessibility	Target average < 20s	10%	2%	5%

Measured overall performance indicators, the best tested solution for the Eindhoven Network is strategy 1. The accessibility in the city centre for this alternative improves the most, also for all other indicators, a limited improvement is measurable.

Blocking roads in itself is not a political favourable policy. An alternative would be to only implement speed reductions on the city centre roads, this would however make the net effects on through traffic and traffic flow less.

The test results can be diverged to morning- and afternoon rush. Separate multi-criteria analyses for both periods are shown in tables 8.3 and 8.4.

Table 8.3: Multi criteria assessment for the aggregated alternatives for the morning situation.

Multi criteria assessment morning				
Indicator	**Benchmark**	**Reference**	**Strategy 1**	**Strategy 2**
Accessibility	Sample optimal result			
City centre flow	Decrease	701veh/hr	-5%	-6%
Flow on Ring	Increase	1004veh/hr	2%	1%
Through traffic	Sample optimal result			
City centre traffic	Decrease	116 veh	-14%	-26%
Ring traffic	Increase	206 veh	7%	17%
Minimal trajectory Speed	Maximum score = 32	-38%	-34%	-38%
Vehicle emissions	Target flow < 2125 veh/hr	6%	5%	4%
Slow mode accessibility	Target average < 20s	3%	-6%	-1%

Table 8.4: Multi-criteria assessment for the aggregated alternatives for the afternoon situation.

Multi criteria assessment afternoon				
Indicator	**Benchmark**	**Reference**	**Strategy 1**	**Strategy 2**
Accessibility	Sample optimal result			
City centre flow	Decrease	656veh/hr	-18%	-13%
Flow on Ring	Increase	1095veh/hr	-4%	-2%
Through traffic	Sample optimal result			
City centre traffic	Decrease	213 veh	-71%	-66%
Ring traffic	Increase	120 veh	84%	56%
Minimal trajectory Speed	Maximum score = 32	-59%	-56%	-59%
Vehicle emissions	Target flow < 2125 veh/hr	4%	-4%	-2%
Slow mode accessibility	Target average < 20s	12%	11%	12%

The differences between the morning- and afternoon rush in travel times are already observable in the reference alternative as concluded in chapter 6. This can be an explanation for the differences found between the morning- and afternoon rush.

During the afternoon rush hour, the traffic flows change more than during the morning rush hour. Traffic flow through the city centre during the morning is less, and traffic flow over the ring is more than in the afternoon situation for the reference model. Differences during the afternoon in traffic flow in the city centre go up to a traffic flow difference of 18%, whereas in the morning, this is only 6%. During the morning rush; the second traffic management strategy, where the Boschdijk is *not* included, is most effective (6% through traffic reduction versus 5%); whereas during the morning, the first traffic management strategy, where the Boschdijk *is* included, is more effective (18% through traffic reduction versus 13%)

The difference between the alternatives in the average flow on the Ring is noticeable, negative accessibility scores on the ring road indicate that the average flow on the ring decreases, where it is expected that the amount of traffic over the ring will rise as a result of extra traffic from the city centre. It is possible that this is due to the fact that traffic uses roads further outside the city centre.

In the minimal trajectory speed statistics, it is also shown, that there are a lot more trajectories in the morning where the averages speed is met than in the afternoon, during both periods a slight improvement is shown in the first strategy compared to the reference situation.

Also the vehicle emissions- and slow mode accessibility statistics show that the traffic flow decreases much more during the afternoon than during the morning rush.

8.4 Application of the traffic management instrument combination method

The combination of instruments focused on the north-south corridor. The separate instruments that were selected for the combination of instruments; speed reduction and blocking roads, both have overall positive effects compared to the reference situation the aspects minimal trajectory speed, vehicle emissions and slow mode accessibility. Also, the traffic conditions in the city centre as a whole; measured in the multi-criteria analysis show improvements. The aspect on which to combine instruments which remains, is increasing the impact of the measures. This is encouraged by the goal of optimizing flow reduction in the city centre.

Results of the combination of the instruments show that the combination between speed reduction and blocking roads in both strategies lead to a bigger impact on traffic flow and through traffic. According to the multi criteria analysis, this goes for the whole measured area. The secondary effects minimal trajectory speed, vehicle emissions and slow mode accessibility also improve, at least compared to the reference situation for both alternatives. Based on these observations; it can be stated that all conditions for a effective traffic management strategy are met.

8.5 Combination of instruments summary

In order to combine several instruments, the traffic management instrument combination method as proposed in chapter 2.5 was used in this chapter. Two strategies for composing a network-wide traffic management strategy have been applied. Which are both a combination of speed reduction and blocking roads. The first strategy consists of a combination between the instruments speed reduction -2 and -3 and the blocking of the Binnenring. The second strategy is the same combination except the speed reduction on the Boschdijk (speed reduction 3).

Based on the model predictions, the most effective traffic management strategy is different for both rush periods. For both periods, a 30km/h speed limit on the Binnenring, the

Fellenoord and the Mauritsstraat is recommended as well as a cut in the Binnenring. During the afternoon rush however, it is more effective to also include a speed reduction on the Boschdijk. The average traffic flow reduction during the afternoon in the city centre is 18% if speed reduction on the Boschdijk is included, and 13% if it is not. During the morning rush, including speed reduction on the Boschdijk leads to an increase of city centre traffic flow of 5% versus 6% without speed reduction on the Boschdijk.

Part III

Discussion and outlook

Chapter 9

Design approach reflection

In this research it is suggested that the adaptations to the traffic management framework as proposed, represent an added value as opposed to the standard GGB framework when it is adapted in urban traffic networks. This reflection presents a view on the aspects where this added value comes up. Also some discussion about the new approach and new insights from the case study are included.

9.1 General observations

The structure of this report suggests that the case study and the theoretical framework that was developed, can be seen completely independently from each other. In reality the insights on how to develop a traffic management design strategy are gained simultaneously with the application of the case study. The design strategy is therefore a product of continuous new insights during the process itself. Walking through this process has led to new insights on how to develop traffic management strategies in urban traffic networks.

The application of traffic management strategies as proposed in this research is only one of the components in the transport policy of the municipality. Other components such as public transport- and parking policy are outside the research scope but not less relevant. These components should not be ignored in the interpretation of the research results. How this research can be seen in the light of these additional instruments can best be illustrated with an example. This research presents a number of traffic management strategies for the city centre of Eindhoven. The best performing alternatives include also the unpopular measure of making a cut in the Binnenring. This solution can reduce the traffic flow in the city centre by 12%, whereas only applying speed reduction leads to an 8% reduction of traffic flow. In order to get similar results, it could be chosen to only implement speed reduction, and combine this with additional policies which decrease the amount of road users such as improving the public transport network in order to reduce traffic flow another 4%. How traffic management strategies and other policies relate to each other is not discussed in this research.

9.2 reflection on the design framework

New aspects of the framework compared to the original GGB framework are the addition of a specific step on the design of traffic simulation models (1), the splitting up of the design of separate instruments(2) and the design of complete traffic management strategies from separate tested instruments (3). A specific framework which positions urban network traffic management instruments in general traffic management theory and which can be used to design traffic management instruments is introduced: the instrument design framework. These new steps are separately discussed in this section, also the assessment framework, and in particular the multi-criteria analysis is discussed.

Assessment framework

A multi criteria analysis was used to evaluate the performance of the proposed traffic management instruments in the model. In the determination of the criteria in this analysis, Accessibility, through traffic, minimal trajectory speeds, vehicle emissions and slow mode accessibility, a lot of source data is can be used to summarize these criteria in a single number. This leads to the fact that a lot of the information that can be deduced from the model is lost in the composition of the limited number of indicators. Therefore the assessment framework should only be used to objectively compare different tested instruments and strategies. In order to understand why the instruments work as they do and where problems occur, more detailed analyses have to be carried out.

The general challenge in making a functional multi-criteria analysis is to choose the indicators in such a way that the results are transparent and to prevent the analysis from being biased. The problems in making a good multi-criteria analysis can be illustrated with a couple of dilemmas that occurred in the application of the case study. The first dilemma occurs as multiple units can be combined in one criterion, as is the case for speed and flow in the accessibility criterion. Choices have to be made in the choice of criteria. It is important to critically consider these criteria as they determine the quality of the instrument- and strategy comparison (1). Other dilemmas that emanate from the case study are weighing factors within an indicator (2), dealing with multiple problem locations in one indicator (3), and weighing between different indicators (4).

Combining multiple units in one indicator Accessibility is measured in the case study with the use of traffic flow. However, for individual road users, travel speed might be more important. Combination of these factors however, is difficult in a network where the traffic flow on a route is not the same for each alternative, in this case because there is route choice. If the combined criterion value changes, it is not clear which of the units change and it is also not clear whether the change is positive or negative. For this reason traffic speed and traffic flow cannot be combined into a single indicator.

Weight of different factors in an indicator In the case study, minimal trajectory speeds are indicated with a score. In this, 2 hour average low speeds are valued twice as bad (score per road is two instead of one) than 5 minute average speeds. How these average speeds should be valued is not specified in the applicable policies but is valued by the problem owner.

Introducing such a score system implies a choice on the importance of the time period for which the minimal traffic speed is not met, this should be noted.

Multiple problem locations For both vehicle emissions and slow mode accessibility, a number of locations is summarized in one indicator each, eight environmental locations and two slow mode accessibility locations. How these different locations must be summarized is not obvious. There are 3 options:

- The indicator indicates the number of locations where the limit value is exceeded.
- The indicator indicates the average measured value over all relevant locations.
- There are two indicators: one for the number of locations and one for the average value.

Considering the fact that only the limiting value is relevant, the number of locations where the limiting values exceeded should be leading. This is a fair approach, for comparison between the alternatives however, this leads to very little differences. Information is lost in this number since the actual difference with respect to the limiting value cannot be deduced from this value. And the score in a two location factor would vary between 0, 1 and 2. Resulting into the fact that differences between instruments cannot be assessed with the instrument. More variation between options can be seen if the actual value over all relevant locations is averaged. This approach is however over sensitive for extreme outliers. The final possibility is to indicate both the number of locations exceeding the limit value and the average value. This way, little information is lost while the amount of indicators remains limited.

Weighing between indicators In the case study, no combination has been made between the different criteria in the assessment framework. Weighing indicators would be a method to get a single indicator for the performance of the entire solution. This could be done, but there is no objective way of weighing instruments, this will always be subjective and depends on the priorities in the policy. A method that could be used is to apply different weight scales, making for instance the environment, or the accessibility more important. The choice not to combine different indicators however, is also a valid choice.

Conclusion From this section it can be concluded that the multi-criteria analysis is a useful tool under the condition that the criteria are chosen carefully. Also the multi criteria analysis cannot be the only assessment of the model, since a lot of detail is lost as all aspects are summarised in to a very limited number of indicators. Choices have to be made when combining multiple units in one criterion, when weighing between several aspects within criteria, and when combining multiple locations in one criterion.

In order to deal with the problems that arise when the multi criteria analysis is used for the assessment of traffic management strategies in urban networks, the following solutions can be indicated for the problems mentioned in this section:

- The multi criteria analysis must be added as a part of the adapted GGB framework.
- If multiple units can be used to describe an indicator, each unit must have its owon indicator.

- Different factors in an indicator should not be weighed, they must be considered separately.

- If multiple locations are present in one indicator. The indicator must be divided into an indicator for the number of locations where the minimal value is met, and an indicator for the average value on the locations.

These recommendations lead to more indicators for the multi criteria analysis. This becomes less orderly as the amount of indicators increases.

Model selection and design

Model selection is considered an important step in the new framework. In chapter 2 two simulations were compared. Also model validation and sample size determination were considered important. In the practice of the case study, a simulation model was already available. The availability of simulation models can in reality also be a factor in the selection of a model. It must however still be made sure that the available model is suited for the research goal. In this case, the model has been adapted and validated again. Also, the desired sample size had to be still determined. In order to obtain the best possible result; it is important to execute this research step; even if a simulation model is already available.

In the case study Eindhoven several tests are performed in order to validate the Paramics model, one of these factors was route choice validation; however, the reference data used for this validation applied to the year 2011 on a very limited number of routes. It turned out that this data was not suited for the validation of the route choice in the model. Since route choice was one of the factors that was being evaluated and steered at in the model, in the through traffic analysis that is, it cannot be definitely said that these results are valid. Route choice validity is an assumption that was made for the model since face validity can be assumed and content validity can not be disproved. It is however important to consider validity of the model and to consider the method that is used to assess the model validity. If there is no route choice data available for the actual situation, it can also be an option to assess the general route choice simulation in the model, in this case the route choice in Paramics.

The route choice in Paramics is determined en-route for every vehicle every two minutes based on a utility function. Even though the route choice in a specific model can not be calculated, validity of this route choice method must still be assumed.

A specific comment considering the growth model that has been applied to the original Eindhoven model, is that it does not account for changing trends in for instance activity choice, destination choice, departure time choice and mode choice. A possible change in one of these factors over time could lead to a trend break in the growth of traffic in the network. To cope with this uncertainty, of growth scenarios must be used. This can be any number of scenarios, where 3 scenarios is recommendable, a slow growth scenario, the expected growth scenario and a quick growth scenario. For each scenario, a different traffic management strategy can be developed. The most effective traffic management strategy for the realized scenario must be applied.

Instrument design and testing

For the testing and design of instruments; the instrument design framework was used in the case study for Eindhoven. The desired effects were determined based on the policy goals, the assessment framework and the traffic analysis. Instruments that were tested are gating, speed reduction, blocking roads and adding lanes.

Important when combining traffic management instruments is the assessment of their primary and secondary effects, and the effects when different instruments are combined. The qualitative results are generic which makes them applicable in other situations. The qualitative instrument effects as found in the case study are shown in table 9.1. This table summarizes the findings from the case study an must be added to the instrument design framework in the adapted GGB framework.

Table 9.1: Qualitative overview of instrument effects

	Gating	Speed Reduction	Blocking Roads	Adding Lanes
Traffic Intensity	Traffic intensity within the gated area can be increased	Flows on affected roads can be reduced.	xxxxxxxxxxx	Average flow can increase as a result of adding lanes.
Average Speed	Average speeds within the gated area can be increased, mainly on congested routes	Average speed on both affected and upstream roads increase. Only at heavily congested roads, speed congestion can lead to a decrease in travel times.	xxxxxxxxxxx	Average speed on affected roads decreases very little on both tested roads
Change in Through Traffic	xxxxxxxxxxx	Through traffic can be largely excluded from affected roads.	Blocking traffic decreases the amount of through traffic, not as much as speed reduction though	The amount of through traffic over the affected route decreases in one situation when lanes are added
Additional Bottlenecks	Upstream of gated locations might occur, although this is not the case for every gating location, this should be checked	Speeds on roads upstream of the speed reduction measure also drop.	xxxxxxxxxxx	xxxxxxxxxxx
Flow at environmental locations	Gating at environmental locations can cause more emissions at environmental locations	Emissions on affected roads can be decreased because of speed reduction	Blocking roads can have a positive effects on both downstream and upstream environmental locations	Emissions downstream of added lane do increase
Cut-through traffic	xxxxxxxxxxx	xxxxxxxxxxx	Blocking roads causes cut-through traffic near the blocked road section.	xxxxxxxxxxx
Accessibility	xxxxxxxxxxx	In busy networks, speed reductions have a negative effect on the accessibility of the network.	xxxxxxxxxxx	xxxxxxxxxxx

Combination of instruments

For combining the individual instruments into an effective traffic management strategy; a design algorithm was discussed in chapter 2.5 and tested for the Eindhoven case study in chapter 8. The approach enhances an algorithm which tests the chosen traffic management strategy for three properties: the magnitude of the impact, the impact area and possible (negative) secondary effects. If all three aspects are accounted for in a traffic management strategy.

The strategies that were tested in the case study test only a limited combination of instruments. Application of the algorithm in this case, led to two different optimal strategies: one optimal strategy during the morning rush and one during the afternoon rush. The main goal in this research was to find an optimal traffic management strategy in urban networks. The framework that is presented in the research, can be used to design effective traffic management solutions; the optimal solution can not be proved. Not all solutions can be tested, also the definition of what is optimal is not clear. The proposed adaptations do make the design process more structured. Maintaining the overview of possible strategies is easier and this leads to a more effective way to combine different instruments. The effectiveness of the traffic management strategy is guaranteed when the adapted framework is used.

The case study results lead to the observation that application of the traffic management strategy design approach can lead to different strategies if traffic conditions differ. Correct application of the design approach is useful in finding a fitting strategy available from the tested instruments for each situation, but not the best possible strategy.

Chapter 10

Conclusions and Recommendations

The conclusions presented in section 10.1. Future recommendations and a proposal for the continuation of research on the topic is be presented in section 10.2.

10.1 Conclusions

The main research question that is relevant for this research is:

Which traffic management design framework can be used for the development of a coordinated traffic management strategy in urban networks in general and for the Eindhoven city centre in particular?

This report starts with the development of a theoretical framework for the design of traffic management strategies in urban networks. The first three research questions are about the theoretical framework and are discussed in section 10.1.1. The theoretical framework applied to a case study for the municipality of Eindhoven. The conclusions from the case study in Eindhoven are discussed in section 10.1.2. In section 10.1.3 the proposed traffic management strategies are presented.

10.1.1 Theoretical framework conclusions

Subquestion 1 The first research question relates to the framework that is used itself:

Which traffic management design framework can be used in order to design network wide traffic management strategies in urban networks?

A traffic management design framework had to be found that is suitable for application in urban traffic networks. The basis for this solution approach is formed by the sustainable traffic management approach (GGB aanpak) which is common use in Dutch traffic management practice. The policy side of the GGB approach is less relevant urban networks as there are less parties involved. 3 important steps are added to the GGB framework. These additions lead to a structured approach for the design of networkwide traffic management strategies.

Added elements to the framework are the selection and development of a suitable simulation model (1), a framework for the design of instruments (2) and an algorithm for the combination of these instruments into network-wide traffic management strategies (3).

Subquestion 2 A framework is developed for the design of traffic management instruments. This framework can be used for the design and testing of instruments and forms the answer the answer to the following research question:

Which method can be used to design traffic management instruments in urban networks?

Multiple instruments are available for traffic management problems in urban networks. For an overview of these instruments; the traffic management overview presented in section 2.3 can be used. The basis of this framework is formed by three basic traffic phenomena: capacity drop in the network, suboptimal route choice of the vehicles in the network, and spill-back caused by bottlenecks in the network. From these phenomena traffic management goals, services and instruments can be structured. Instruments are split up into an on-line and off-line applicable category. Off line applicable instruments can still be deployed for certain time instances, but turning the instruments on and of has to be done manually from the control centre.

The generic MFD theory can be used for the design of traffic management instruments in urban networks. Instruments in urban networks should not be applied to solve traffic problems at a single location, but they should serve the traffic flow through the entire network section. In order to do this, the traffic conditions in the entire network should be considered.

Traffic management instruments for off-line application are the use of extra lanes on roads, the blocking of roads by cutting them, changing the speed limit, adapting control schemes at controlled intersections for instance, for the purpose of gating, and changing turn-lane configurations in order to reduce average queue-lengths. In order to apply these instruments optimally to an existing traffic situation, for each instrument, several design variables are identified which can be varied in order to influence the instrument impact and impact location.

Subquestion 3 The traffic performance of an urban network can be further improved by combining several instruments into one traffic management strategy. The research question relating to the design of traffic management strategies is:

How can separate traffic management instruments be implemented in a coordinated way; resulting into a network wide traffic management strategy in the defined problem area in order to realize the traffic management goals?

The traffic management strategy design approach can be used to come to an effective traffic management strategy. The main component of this approach is an algorithm which can be used to come to an effective traffic management strategy. Three properties of a solution which are checked with this algorithm are impact of the instrument; impact location and the negative effects. When one of the aspects is not satisfied, additional instruments can be added to the strategy, or new instruments can be removed. For the selection of these instruments the instruments specially developed for the case study can be used; but also the qualitative instrument descriptions presented in chapter III can be used to select new instruments.

10.1.2 Case study Eindhoven conclusions

Part of the purpose of this research is to design a traffic management strategy on how to use traffic management to optimise the traffic conditions in the city centre of Eindhoven. The Eindhoven case is exemplary for future applications of the traffic management design framework that was developed for urban networks. The main question for the case study was:

How can the instrument design framework be implemented in order to reach the traffic management goals for the city centre of Eindhoven?

In this section, the conclusions for the case study of Eindhoven are presented.

Subquestion 1 The first step in the design approach is the research goal, this goal is presented by the problem owner, in this case; the municipality of Eindhoven. Based on the research goal, a problem analysis was executed in order to identify the traffic management goals and control strategy applicable for the Eindhoven situation. The research question relating to the traffic management goals is:

Which traffic management goals can be identified for the city centre of Eindhoven?

The main goal that has been determined for the city centre of Eindhoven, is to reduce the traffic flow in the city centre of Eindhoven, this in order to improve the vehicle emission rates at environmental bottlenecks in the centre, and improve the slow mode accessibility in the city centre. The control strategy that was developed based on the goals is to redirect traffic from the city centre towards the ring road. The two types of traffic that can be focussed on for this strategy are through traffic, which is part of the assessment framework, and origin and destination traffic for the city centre. For destination traffic, the distance covered within ring should be minimized. This strategy results into the deduced goal to increase the traffic flow on the ring. External factors are the amount of routes where the minimal policy speed is exceeded, and the vehicle emission bottlenecks outside the city centre.

Subquestion 2 A simulation model can be selected and adapted in order to be able to predict the performance of proposed instruments and traffic management strategies. Most important is that the important aspects in the traffic management goals for the city centre can be assessed with the model. The research question that relates to the development of this model and the assessment framework is:

What method and which indicators can be used to assess the traffic performance for the city centre of Eindhoven?

For the Eindhoven case study; the existing simulation model for the city centre could be used. Its size was reduced so that the research could still be carried out; but simulation times became shorter.

A multi-criteria analysis can be used for the assessment of model results. Reference values and benchmark values are determined using the simulation model. For minimal trajectory speeds, vehicle emissions and slow mode accessibility benchmark values are determined to indicate when preconditions are met. For slow mode accessibility and vehicles, these values are deduced from traffic flows at specific locations in the model. For accessibility and through traffic, the optimal solution is desired and the reference value is the traffic flow or count in the reference model averaged over all measured routes.

Subquestion 3 Based on the policy goals, problem locations can be identified in the city centre for which traffic management instruments can be developed. The search for these problem locations is done in the traffic analysis. The research question that was answered with this traffic analysis is:

Which problem locations in the city centre of Eindhoven can be identified for considering the traffic management goals?

The traffic analysis is performed with the reference model for the city centre. Locations in the city centre where high traffic flows form a problem are mainly the Fellenoord, the Binnenring and the Kennedylaan. Two roads inside the city centre where there is a high travel time delay are the Karel de Grotelaan and the Boschdijk.

Next to identification of the problem, the cause of traffic management problems is also analysed. Congestion is often caused at bottlenecks. Seven bottlenecks are identified in the city centre where vehicles often have to wait more than one cycle-time before they can leave a queue.

A through traffic analysis was performed to identify major through traffic routes. Relatively large flows of through traffic that have been identified which are to be monitored and redirected towards to the ring are traffic between the Boschdijk and Leenderweg in the North-South and South-North direction, and traffic between the Eisenhowerlaan/Kennedylaan and the Karel de Grotelaan over the Mauritsstraat-Fellenoord axis.

Subquestion 4 After the traffic analysis, all basic components are available for application of the instrument design framework; the following research question could be answered:

How can the instrument framework be used to design traffic management instruments for the Eindhoven city centre?

Two different set ups for traffic gating have been tested varying the design variables. For the speed reduction measure, three different set ups have been tested where the speed limit of roads in the city centre is reduced from 50 to 30 km/h. For both blocking roads and adding lanes, one set up was tested. Blocking roads is tested by means of a cut in the Binnenring, and extra lanes are added to the Boschdijk and Karel de Grotelaan inside the ring.

Blocking roads and speed reduction show the best results on the optimization criterion: accessibility. When the total assessment framework is considered most positive effects have been measured in the speed reduction alternatives. The total traffic flow in the city centre can be reduced with this measure by 8%. Also blocking roads is effective, for this measure can lead to a 6% city centre traffic flow decline. Traffic speeds on the Karel de Grotelaan and Boschdijk are increased with the application of gating. Congestion is prevented as less vehicles enter the area, the throughput is eventually bigger.

There is no tested instrument which leads to acceptable minimal speeds on all roads measured for this criterion. Differences between the instruments are very small and vary between 52%and 56% in of the total possible 100% in the score system. The vehicle emission target has been set 5% below the values in the reference situation. This 5% reduction is not met in any of the alternatives. The best reduction is met whith the speed reduction instrument; where the traffic flow at environmental locations is 2% lower at average. Speed reduction is also the best option when it comes to slow mode accessibility: average waiting times for pedestrians with this instrument, are below the desired 20 seconds. For the other instruments, as well as for the reference situation; higher waiting times are measured.

Subquestion 5 The objective of the final research question is how to combine the separate instruments into a complete traffic management strategy:

How can the separate instruments tested for the Eindhoven case be combined into an effective networkwide traffic management strategy?

For this part of the case study; the traffic management strategy algorithm was applied to the city centre network of Eindhoven with the focus specifically on the Binnenring corridor which runs North-South through the centre. The focus was initially on increasing the reduction of traffic flow on these roads. In order to do this two strategies are proposed and tested. Both consist of an application of speed reduction and blocking roads; the most successful tested individual instruments. The difference between the two tested alternatives; is that speed reduction in the first alternative is applied to the Binnenring, the Fellenoord, Mauritsstraat and Boschdijk, and in the second alternative only to the Binnenring, Fellenoord and Mauritsstraat.

Overall results for accessibility are positive; the traffic flow measured in the city centre is reduced extra as blocking roads and speed reduction are combined. In the scenario including the Boschdijk; this is a total of 12%. In the scenario where the Boschdijk is still a 50km/h road; this is 9%.

As has been predicted after testing the individual instruments; both strategies do not fit to all preconditions that are set. Although both strategies score better on vehicle emissions than the individual instruments, and scores on minimal trajectory speeds are similar.

10.1.3 Proposed traffic management strategy for Eindhoven

It is advisable to only deploy the traffic management strategies during rush hours; since they are not essential in off-peak periods, and the average speeds in the city centre are decreased by the strategies. The morning rush and afternoon rush differ from each other, the afternoon rush is more busy; and ask for a different approach. Separate multi-criteria analyses are performed for the morning rush and afternoon rush. In terms of reduced traffic flow in the city centre; strategy 2 is more effective during the morning rush and strategy 1 is more effective during the afternoon rush. This means the speed reduction on the Binnenring, Fellenoord and Mauritsstraat as well as blocking roads can be applied during both the morning- and the afternoon rush. For an optimal result the speed limit on the Boschdijk should only be decreased during the afternoon rush, when the effects of reducing the speed limit on this road lead to a lower traffic flow through the city centre.

10.2 Recommendations

In this section recommendations for future application of the framework and for further research are discussed. This is done in two parts, first suggestions for extension of the framework are done; also a general outlook is presented for integrating other topics in the application of network-wide traffic management.

Recommendations related the proposed design framework

Dynamic instruments The application of this research has been limited to the off-line testing of instruments during rush hours. The framework is also suited for the on-line application of instruments, the traffic management framework can be extended for on-line instruments and also, design variables for these instruments can be analysed. Time elements can be added to the method for combining instruments as shown in figure 10.1. These elements can be real time traffic information but also for instance known travel time or travel volume development. Also the instrument combination algorithm can be adapted for on-line instruments.

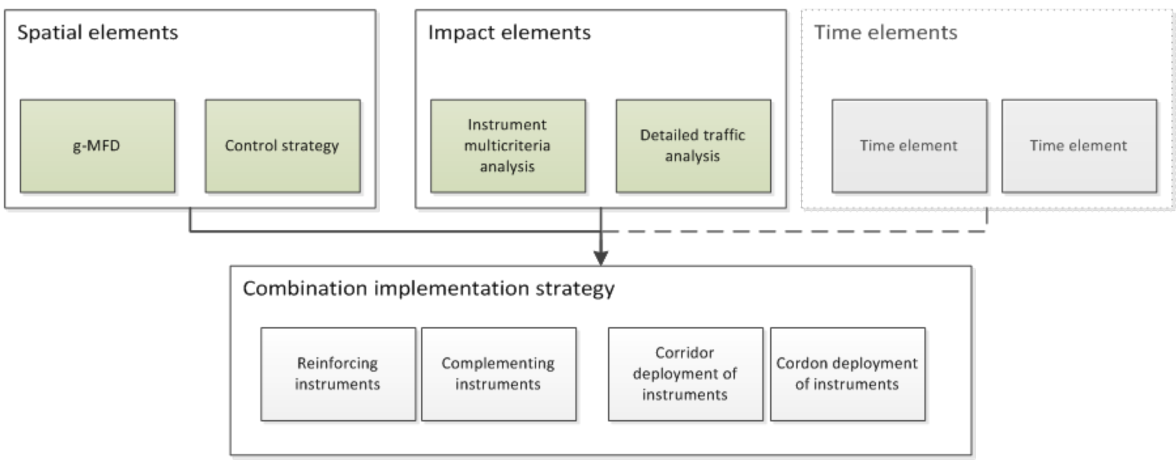

Figure 10.1: Extra time dimension can be added in case of an on-line application of the framework.

Multi-criteria analysis A multi criteria analysis is used for the evaluation of the model results in the case study. This is an effective tool, but it is not yet integrated as a step to the GGB framework. The multi-criteria analysis must be further defined in the assessment framework.

The generic MCA can replace the assessment framework in the traffic management design framework. A number of issues related to the generic method for the application of MCA in the GGB framework is already described in the reflection. The generic method must describe how criteria can be summarized and what information must be preserved. The method how to compare instruments between criteria must be described. Relevant indicators, such as emissions, minimal trajectory speeds and slow mode accessibility from this research, but also for instance traffic safety must be listed and generically described.

Experiment size The adapted GGB framework was tested in this research with a limited number of instruments. The framework must be applied for a problem with a bigger number of instruments and possibilities. This can prove the functionality of the proposed additions to the framework in bigger networks.

As an example, the case study Eindhoven can be considered. Seven bottlenecks are indicated in the framework which could be solved separately due to time limitations. For each of these bottlenecks (at controlled intersections) a new control scheme can be determined. Also, no instruments were tested to improve the flow on the ring. This shows that a network the size of the city centre of Eindhoven is suited for the application of a lot more instruments. All these instruments must also be tested, and the adapted framework must be used to design a network wide traffic management strategy. This can prove the functionality of the tested framework.

Growth scenarios For several reasons, it is concluded that it is hard to completely validate a model. In order to deal with these uncertainties. Different growth scenarios can be applied to the model, resulting into several scenario's. These scenario's can also be useful as strategies are implemented. A traffic management strategy can also be partially implemented in case a less severe growth scenario is realized for instance.

Application of the MFD The MFD has been named in this report, but it is not applied as concept in the actual case study. In urban networks, having an MFD for the relevant network can help calibrating the need for traffic management instruments in the network based on the number of vehicles measured in the network. The optimal vehicle density on the roads in the network can be determined using the MFD. When it is known on which roads this density is exceeded and on which roads there is buffer capacity, traffic can be redistributed real time over the network, for instance using VMS.

General outlook

For the design of traffic management strategies in urban networks, the instrument design framework presented in chapter 2 can be used for the initial design of separate instruments. Based on these individual instruments; the framework for combining instruments can be used and traffic management strategies can be designed.

Specific instruments have been tested in this research. It can be useful to quantify the impact of changing the design variables, this can help optimize the effects of chosen instruments. The instrument frameworks presented in this research can be used to design experimental set ups in order to test the optimal values for the design variables of the tested measures. Systematically varying the design parameter values can help to calculate the correlation between the measure parameters and their effects. When there is more insight in these correlations, triggers for scenarios can be determined more precisely, and instruments can be deployed more effectively.

On-line traffic management can also be applied using model predictive control instead of real time traffic information. The advantage of this strategy is that preventing congestion requires less extensive interventions than reaction to problems that already occur.

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Time speed diagrams for the City Centre

In this Attachment the speed time diagrams of the roads in the City Centre are presented. Figure 2 gives an overview of the locations of the measured routes in the city Centre. The ring is incuded in the next appendix.

Figure 2: Measured routes in City Centre

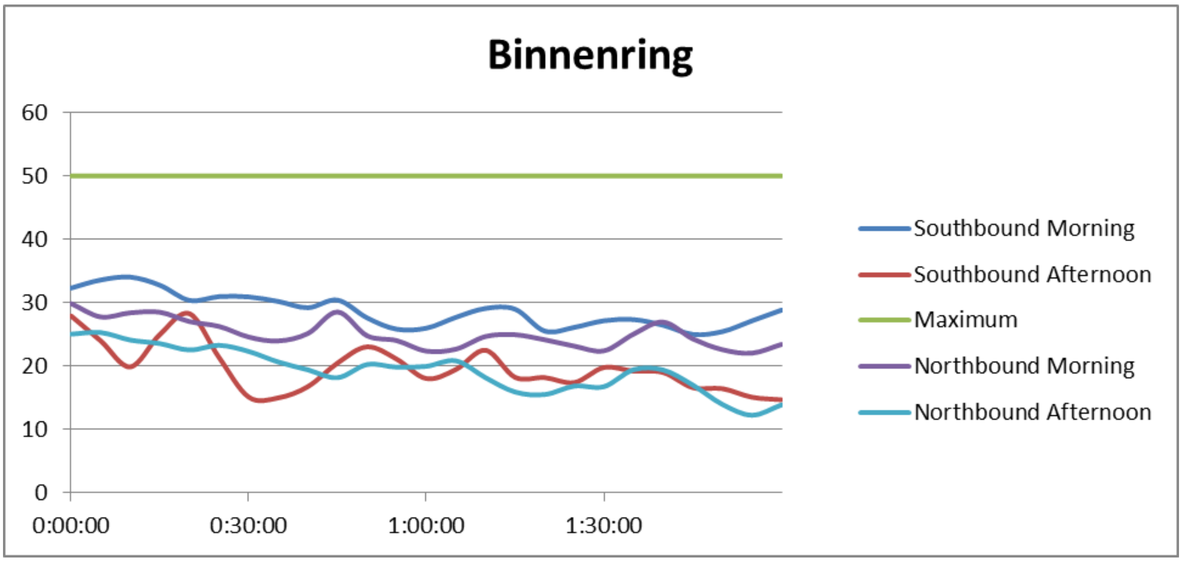

Figure 3: 3 run average speeds in both Directions of the Binnenring during Both Morning and Afternoon Rush. Speeds during the afternoon rush on this road are smaller.

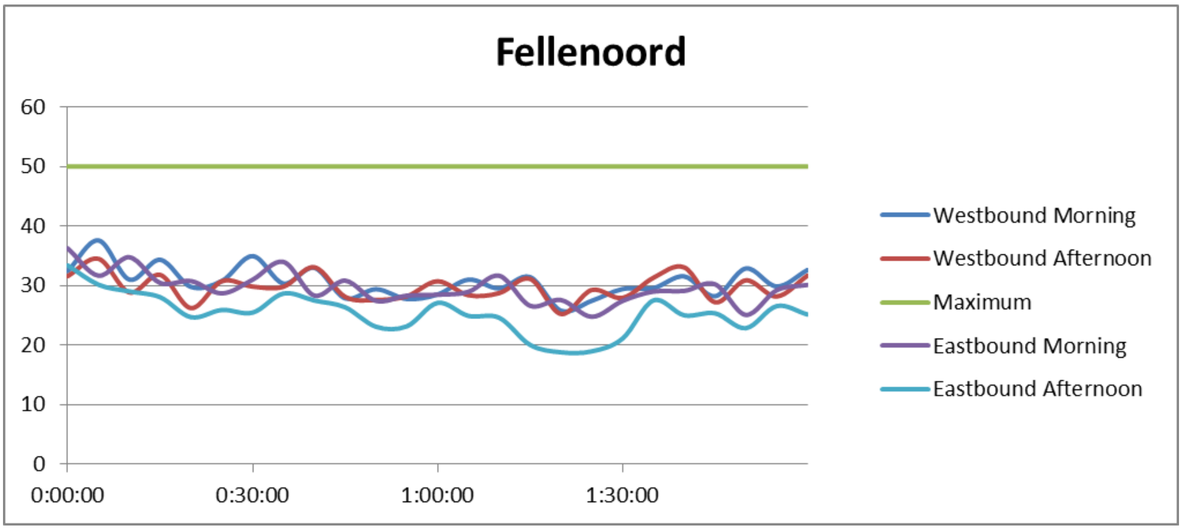

Figure 4: 3 run average speeds in both Directions of the Fellenoord during Both Morning and Afternoon Rush. Speeds on this road are reasonably constant. Speeds of eastbound traffic in the afternoon are somewhat lower.

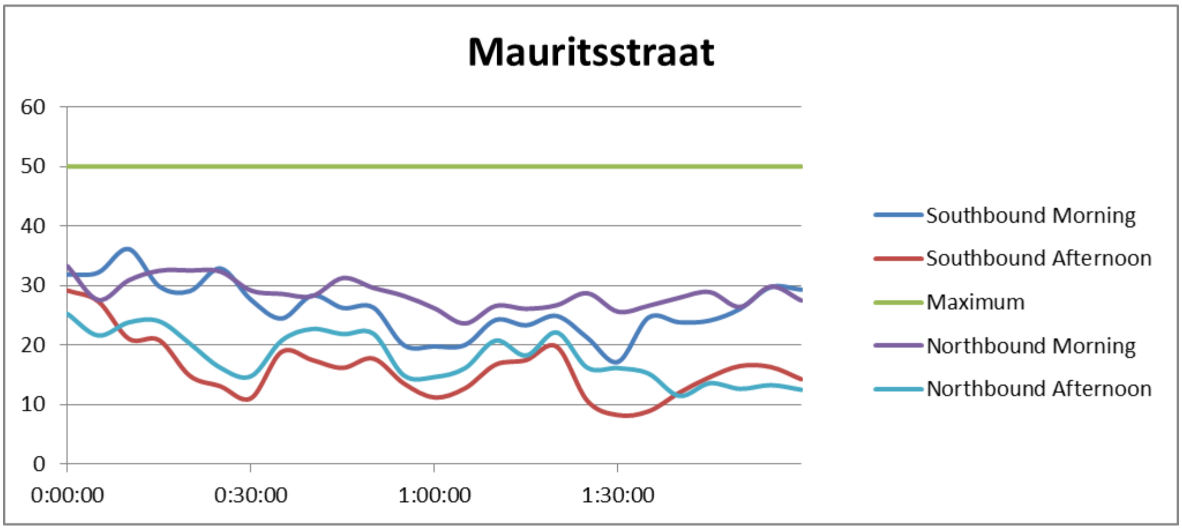

Figure 5: 3 Run average speeds in both directions on the Mauritsstraat, in both directions, speeds during the afternoon are significantly lower than in the morning rush.

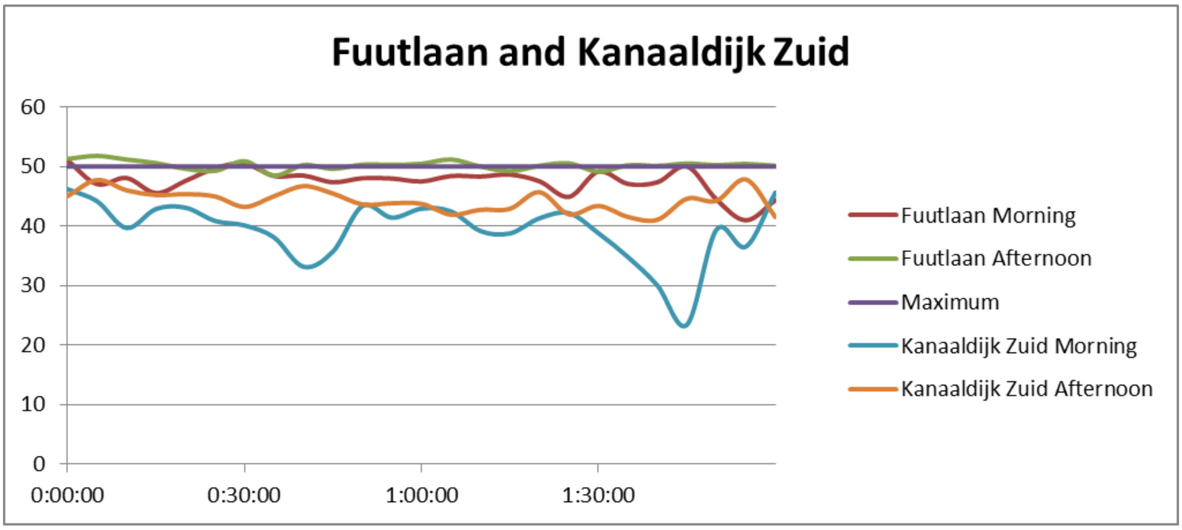

Figure 6: 3 Run average Speeds on the Fuutlaan and the Kanaaldijk. Speeds on these roads are nearing the maximum of 50 kilometers per hour. During the morning rush at the kanaaldijk, speeds are more instable and lower.

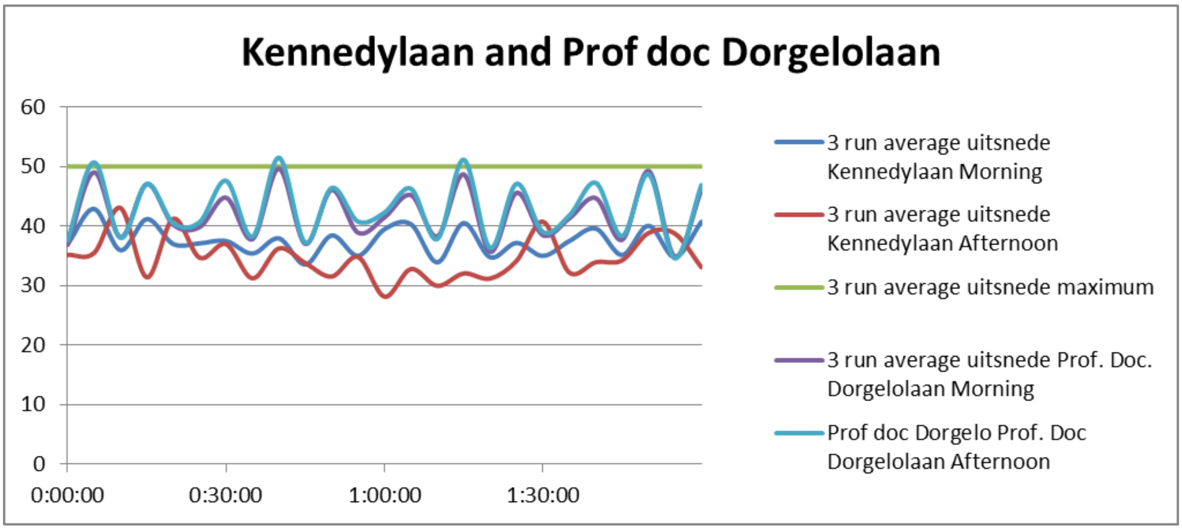

Figure 7: Routes of the Kennedylaan and prof doc Dorgelolaan both don't contain any controlled intersections in them, this results in travel average travel speeds close to the speed limit. Travel speeds at the Kennedylaan are clearly the lowest.

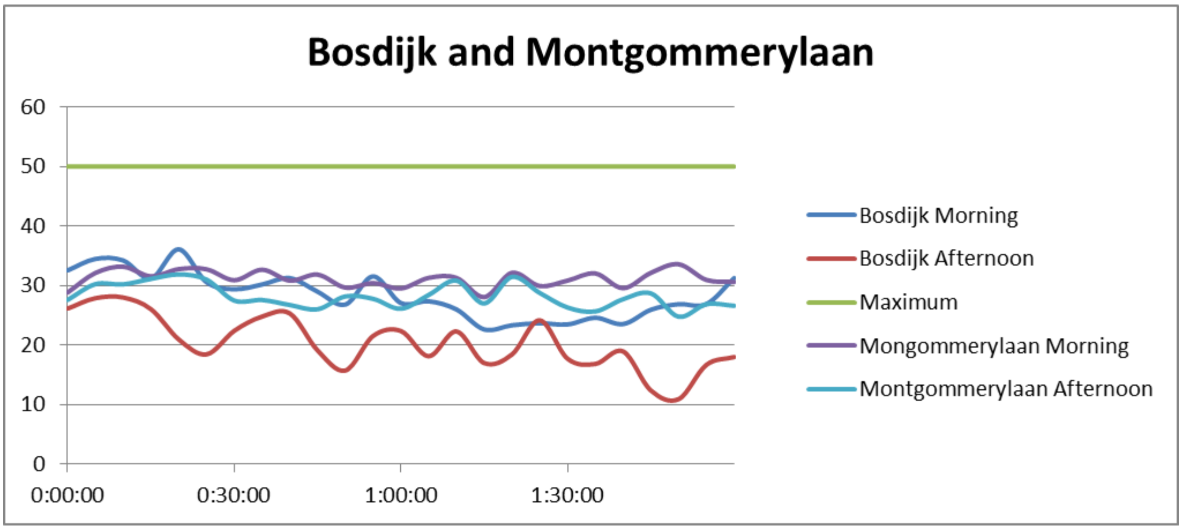

Figure 8: 3 run aggregate travel times at the Bosdijk and Montgommereylaan inside the City centre. Speeds are around 30 kilometers per hour. Speeds at the Bosdijk during the afternoon are really low.

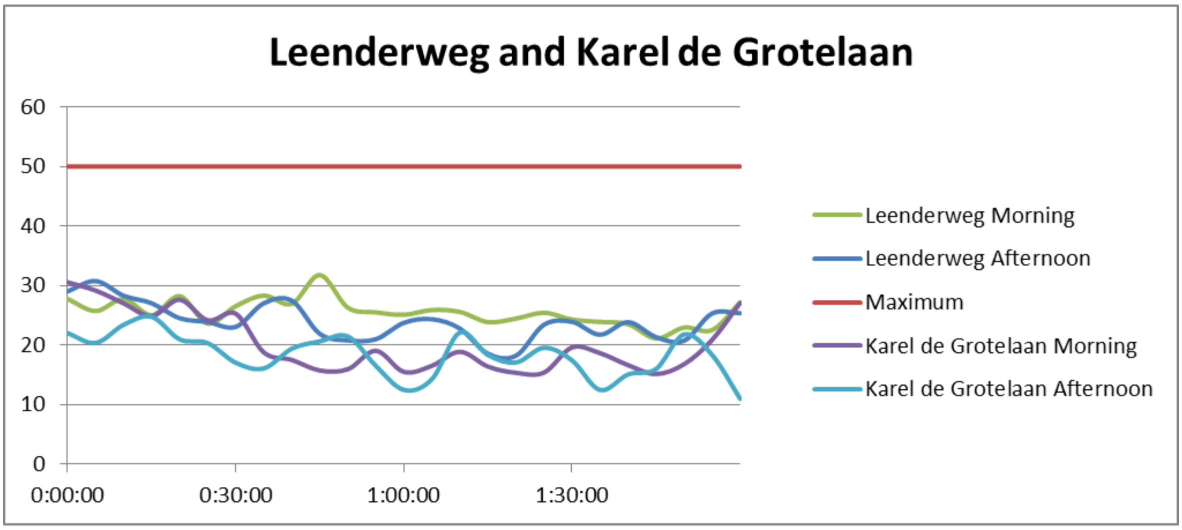

Figure 9: 3 run aggregate speeds at the Leenderweg and the Karel de Grotelaan inside the ring, especially at the Karel de Grotelaan the travel speeds are very low, this is the case during both the morning as well as the afternoon rush hour.

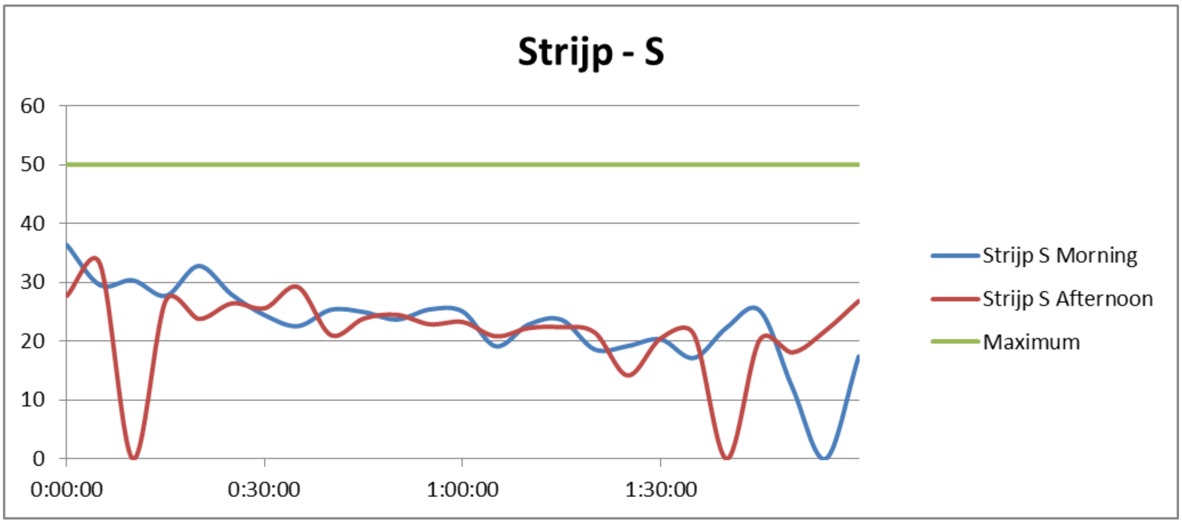

Figure 10: Travel speeds at Strijp S are instable, the fact that travel speeds sometimes drop to zero, is due to an error in the measurement.

Time speed diagrams for BBOZB routes

For the roads where minimum trajectory speeds have been defined, it can help to see the development of the average travel speeds over time. All results shown in this attachment are three run aggregates for the reference situation.

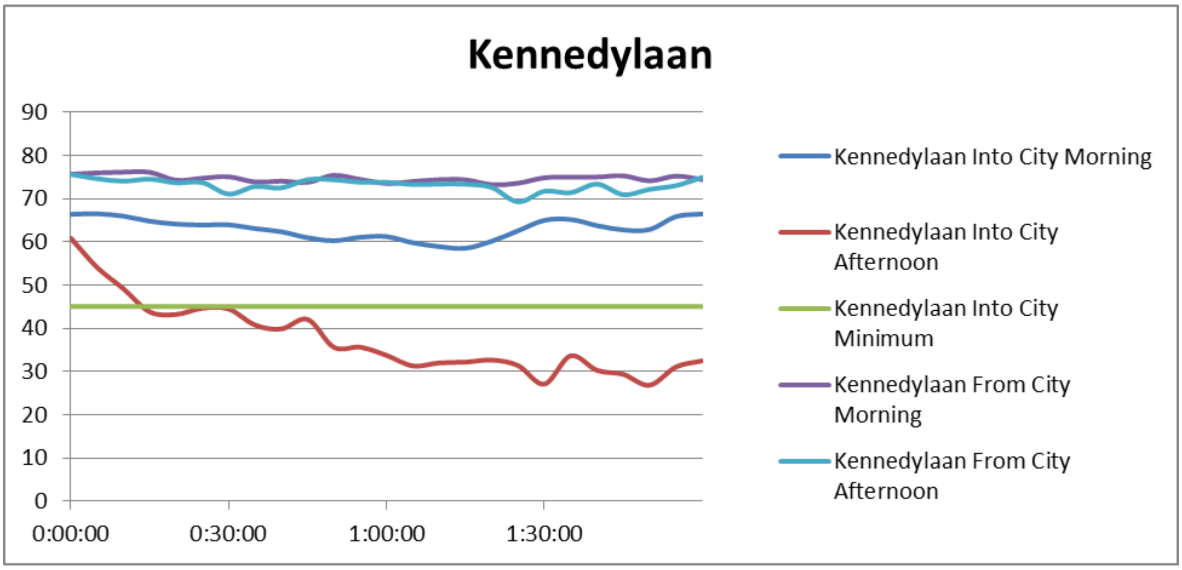

Figure 11: Three run average speed time diagram for the Kennedylaan in both directions and in both morning and afternoon rush. Only in the direction into the city during the afternoon rush travel speeds drop below 45 km/hr.

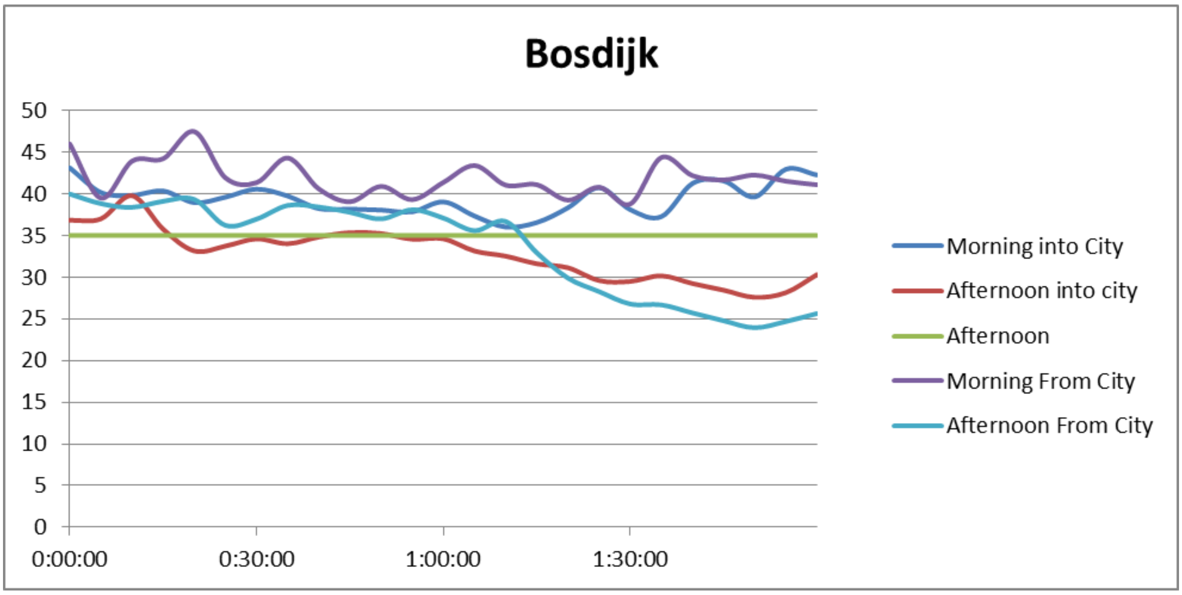

Figure 12: Three run average speed time diagram for the Bosdijk in both directions and in both morning and afternoon rush. Towards the end of the afternoon rush speeds in both directions drop below the 35 km/hr limit.

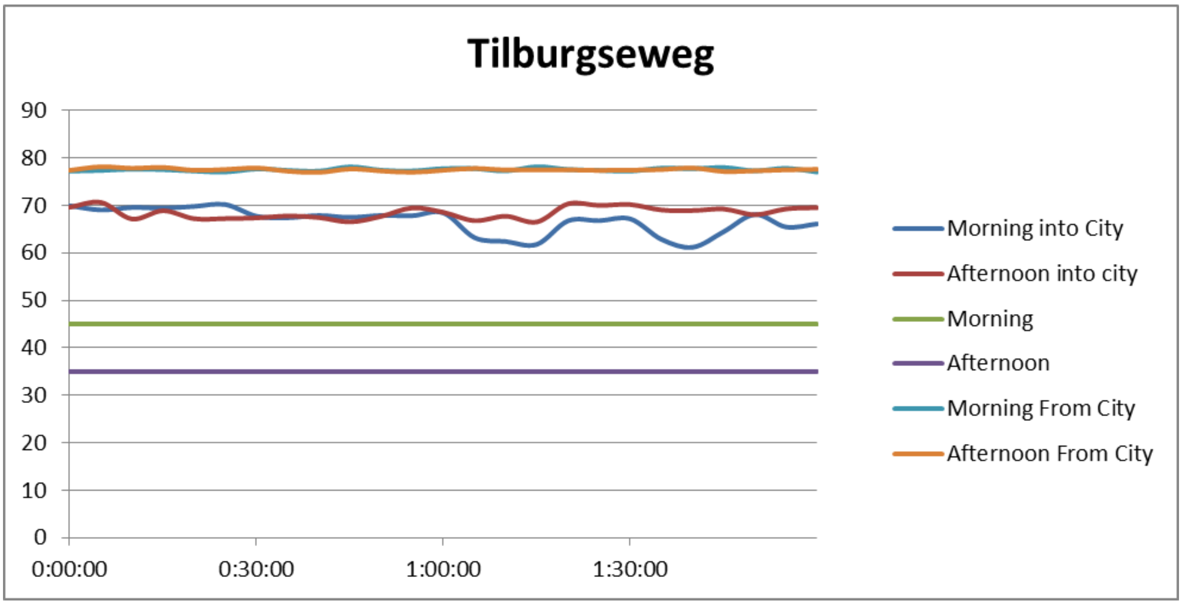

Figure 13: Three run average speed time diagram for the Tilburgseweg in both directions and in both morning and afternoon rush. Speeds on this road are constantly high.

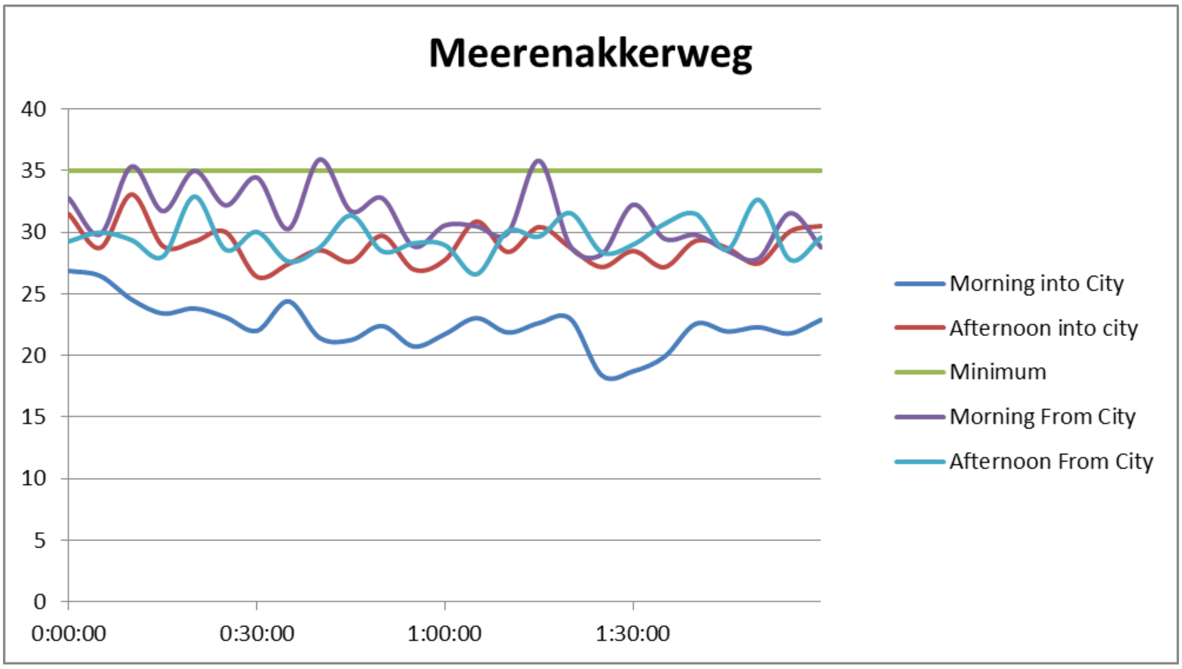

Figure 14: Three run average speed time diagram for the Meerenakkerweg in both directions and in both morning and afternoon rush. Speeds are below the 35 km/hr limit in all cases. Traffic into the City Centre during the morning rush is particularly slow.

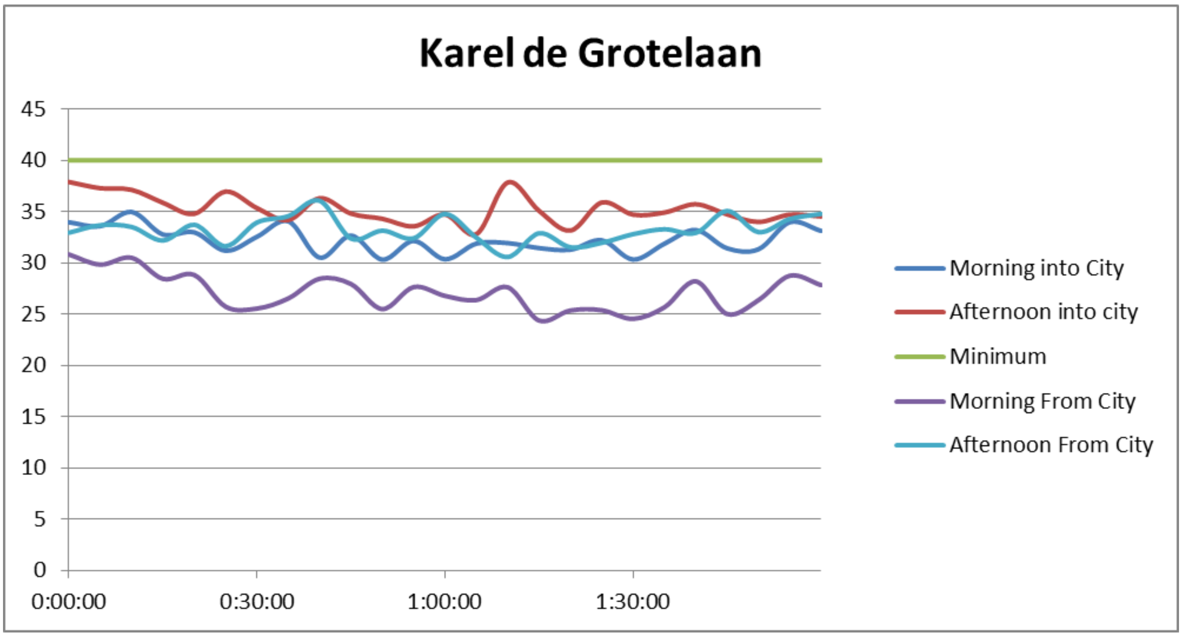

Figure 15: Three run average speed time diagram for the Karel de Grotelaan in both directions and in both morning and afternoon rush. On the Karel de Grotelaan multiple controlled intersections are present. The low speeds, in all cases below the 40 km/hr limit are stable and can probably be explained by the presence of multiple intersections. The morning rush traffic speed from the City Centre is remarkable low.

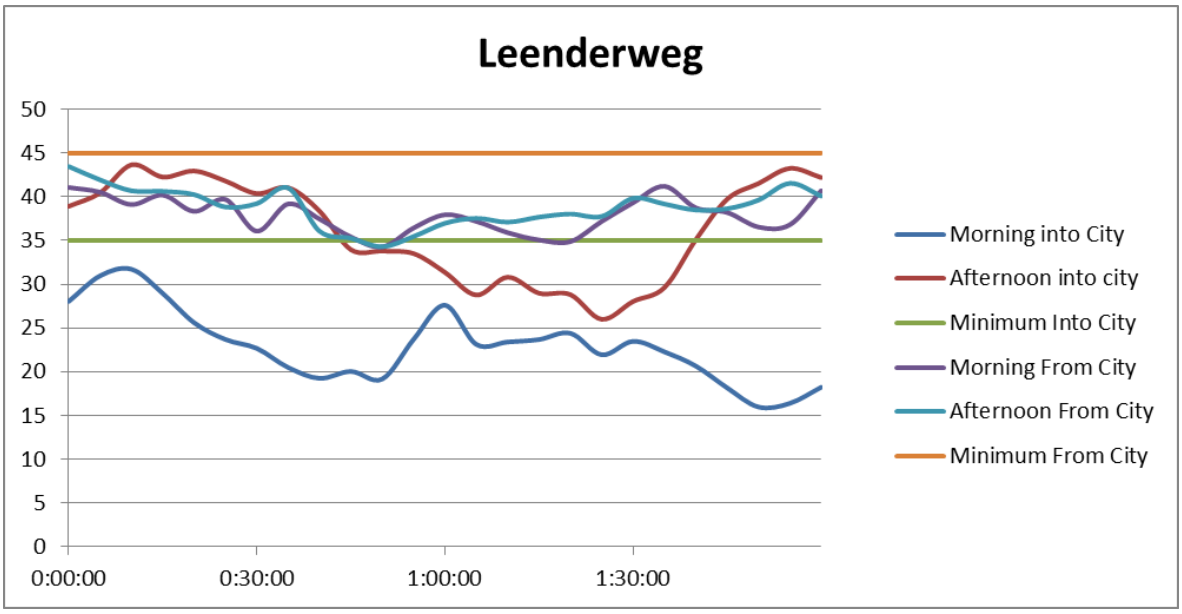

Figure 16: Three run average speed time diagram for the Leenderweg in both directions and in both morning and afternoon rush. Speeds on the Leenderweg are below the applicable speed limit. Particularly during the afternoon travel times are unstable.

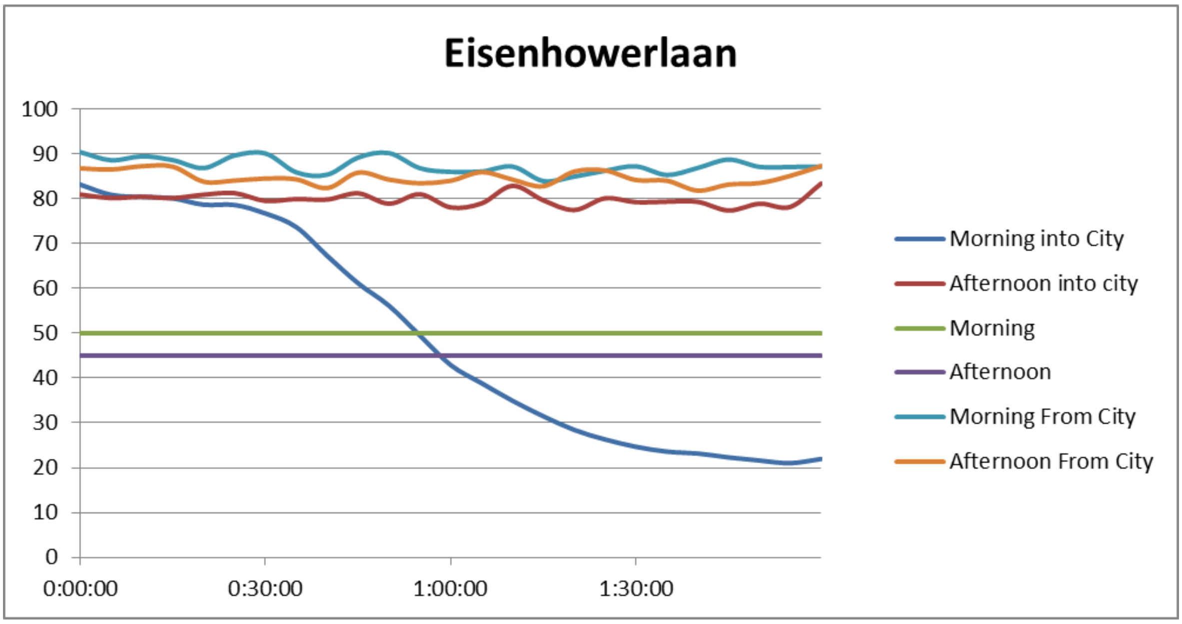

Figure 17: Three run average speed time diagram for the Eisenhowerlaan in both directions and in both morning and afternoon rush. In most cases the speeds are acceptable. Only during the Morning rush traffic speeds of traffic towards the City Centre Collapses Completely.

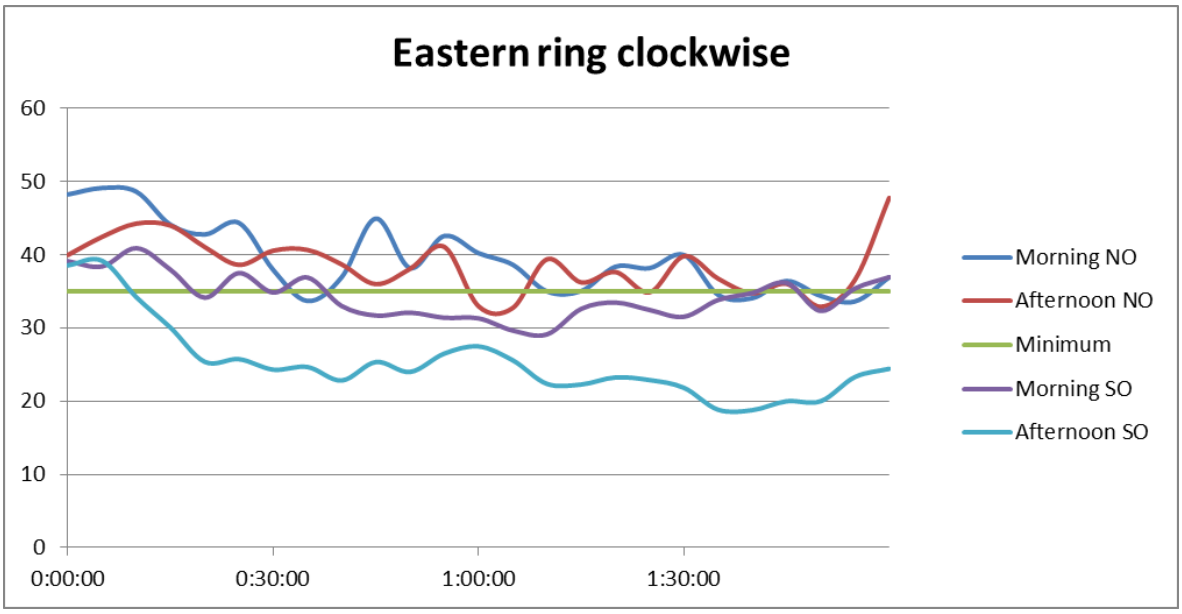

Figure 18: Three run average speed time diagram for the Eastern part of the Ring in clockwise direction in both morning and afternoon rush. The biggest problem occurs in the South Eastern part during both rushes.

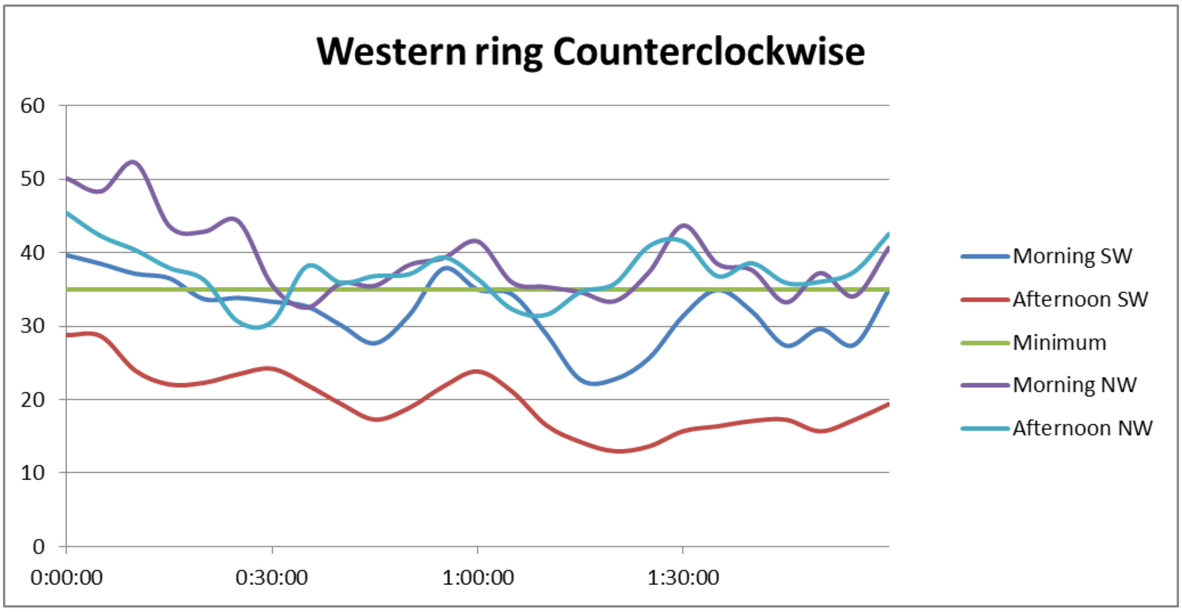

Figure 19: Three run average speed time diagram for the Western part of the Ring in clockwise direction in both morning and afternoon rush. During the afternoon the speeds drop below 35km/hr.

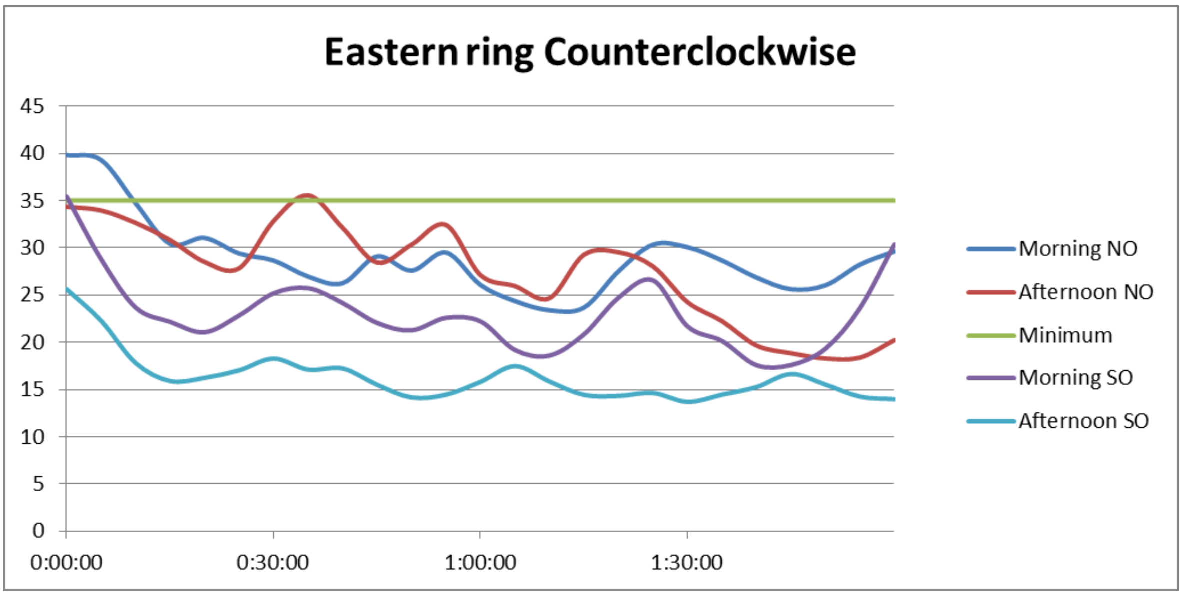

Figure 20: Three run average speed time diagram for the Eastern part of the Ring in Counterclockwise direction in both morning and afternoon rush. All averages are below 35km/h. At the South eastern ring, speeds are especially low.

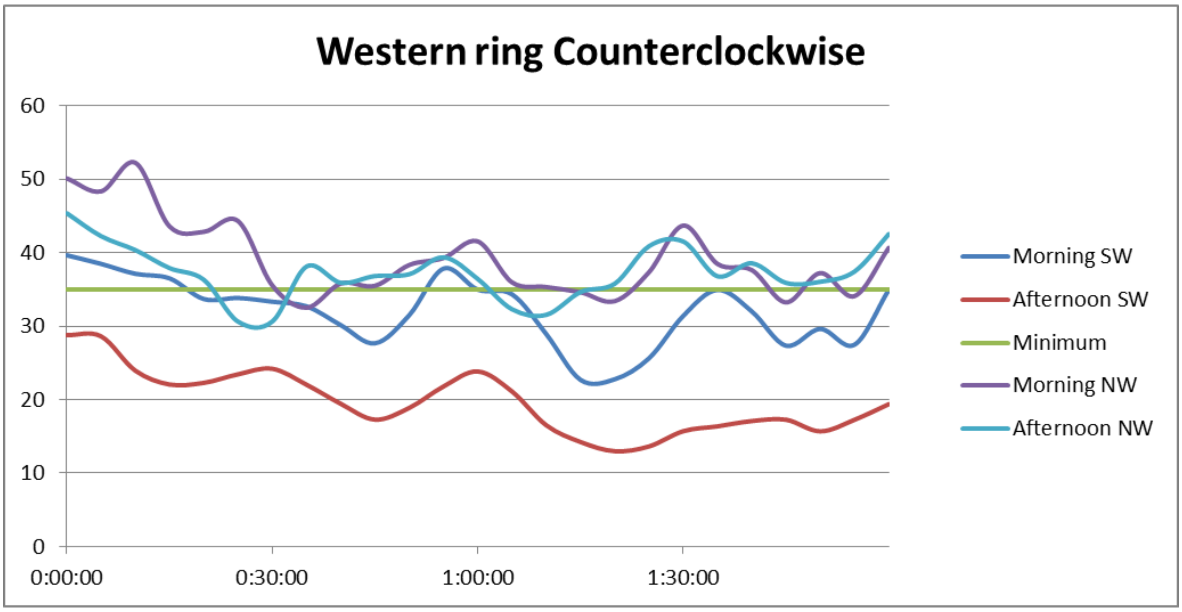

Figure 21: Three run average speed time diagram for the Eastern part of the Ring in Counterclockwise direction in both morning and afternoon rush. All averages are below 35km/h. At the South eastern ring, speeds are especially low.