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Network Effects of Target Group Prioritisation by iTLC's

Bachelor Thesis

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Preface

This is the final report on my Bachelor Thesis as part of my Bachelor's program Civil Engineering & Management at the University of Twente. This thesis is the result of the research I conducted between April and July 2021 in cooperation with Goudappel. In this period, I learned a lot on doing individual research and got a glimpse of working within a consultancy firm in the working field of Civil Engineering. Despite that I executed this research from home, the online meetings and activities with the people of Goudappel still gave me an good idea of the company's activities.

I would like to thank my external supervisors of Goudappel Luc Wismans and Leon Suijs for making this research possible and guiding me throughout the process. The meetings gave me insight on a lot of topics that were important for my research and made it possible for me to achieve this result in the end. I would also like to thank my internal supervisor Tom Thomas for providing me feedback and insights on the set-up and the research itself.

In addition, I also want to thank Bastiaan Possel (Goudappel), who provided me with the model I used for this study and helped me out when something was unclear. Besides, I would like to thank Feike Brandt and Luuk Brederode (Dat.Mobility), who helped me understand the OmniTRANS software in more detail and gave me useful insights for my research.

Tom van Hal

Enschede, 7 July 2021

Abstract

This study assesses the effects of target group prioritisation on a network with multiple intersections controlled by intelligent traffic light control systems (iTLC's). When target group prioritisation is applied, a specific group gets (or keeps) a green light and can cross therefore (almost) unhindered the intersection. Current studies on target group prioritisation focus on the effects on a single intersection, but little knowledge is yet available on the effects of this measure when applying it on a specific route, corridor or city area. Since policy choices on implementing this measure are not limited to a single intersection and it is expected that target group prioritisation will influence the traffic distribution and flows in the network, it is important that policy makers can make well-founded decisions based on the effects of target group prioritisation on network level. Therefore, this study assesses the effects of target group prioritisation by granting priority to freight traffic on a route with 7 TLC-controlled intersections, using an already existing macroscopic dynamic transport model of the Voorne-Putten region.

To implement target group prioritisation in the macroscopic model, a trade-off is made between the different possibilities, which resulted in extending the green time for one direction on the chosen route. This does bring a limitation, since all the traffic on the route is prioritised instead of only one target group. However, the research still provide insight on the effects on all traffic, when one target group is prioritised. The effects of target group prioritisation are assessed for two different prioritisation scenarios. For the first scenario, the green times are extended with 30%, which should be feasible and realistic according to previous research. For the second scenario, the green times are extended with 60%, to see what the effects are in a more extreme case. For the assessment, both the travel time and number of vehicle kilometres are used as key performance indicators, to indicate if prioritised traffic benefits from the measure and if a shift in traffic distribution occurs. The KPI's are used to assess the route as a whole, the route in parts and for two non-prioritised routes (side streets). In this way, it can be assessed if the desired beneficial effects occurs, and if not where on the route possible bottlenecks occur, and in addition the impact on non-prioritised traffic can be analysed.

The analysis shows that applying target group prioritisation does not automatically result in travel time benefit for the prioritised direction as expected. Under normal traffic conditions (little/no congestion in the reference situation), the extension of green time results in a reduction of the travel time. However, an increase of traffic intensities resulted in bottlenecks on the prioritised route, mainly caused by the increase of turn delays for non-prioritised direc-

tions. Since for several junctions in the network the demand for a non-prioritised direction is high and capacity of this direction is reduced as a result of target group prioritisation, congestion and a blocking back effect occurs on the route.

In addition, the increase in travel time for non-prioritised traffic resulted in a shift of the traffic distribution, including a decrease of traffic on the prioritised route. This indicates that for many origin-destination pairs (OD-pairs) in the network, for which one of the route alternatives drives partly over the prioritised route, the travel time benefit does not outweigh the increase in turn delay when entering/exiting the route. Therefore, the traffic of these routes choose an alternative, competitive route. However, the route part analysis showed that some parts of the route are more attractive as a result of target group prioritisation.

This research shows that target group prioritisation does result in a shift of the traffic distribution and that it can be both beneficial or detrimental for prioritised and non-prioritised traffic, depending on the traffic conditions of the network. However, for a well-founded policy choice, more research on the network effects is needed. The results of this research only shows the effects of target group prioritisation on all traffic and does not distinguish between the different target groups. Besides, an extensive analysis on the traffic flows of the network is essential to identify a suitable trajectory to apply target group prioritisation on, so at least the prioritised target group does not experience detrimental effects.

Contents

Chapter 1

Introduction

Over the past years, the Dutch population living in urban areas increased from 70% in 1990 to 83% in 2017 and is expected to increase even more to over 90% in 2050 (Talking Traffic, 2017). The continuation of urbanisation results in an increasing lack of space in the Netherlands. At the same time, the use of mobile devices and technologies has an increasing impact on our society (Goudappel, 2021). New technologies enable people, devices and systems to share information and communicate, and therefore offers opportunities for organising mobility in a smarter way and making better use of limited space (Talking Traffic, 2017). The application of these new technologies within the mobility domain is what we also know as Smart Mobility.

Smart Mobility is a broad term that focuses on the potential of optimising existing infrastructure through the development and utilisation of digital networks (Papa and Lauwers, 2015). In general, Smart Mobility developments are related to the aspects Automation, Connectivity, Electrification and Sharing (ACES) (Weiss and Beiker, 2020). It includes developments on the 'technological site' of the spectrum, like smart roads that can generate solar energy. But also more 'consumer-centric' developments, like the travel application Flitsmeister or the Enschede Fietst app (Papa and Lauwers, 2015).

One of the major Smart Mobility projects in the Netherlands is the innovation partnership program Talking Traffic (TT), set-up by the Ministry of Infrastructure and Water Management. The goal of the project is to improve the flow of traffic in urban areas by stimulating and facilitating Smart Mobility innovations focusing on the element of Connectivity of Smart Mobility. Connectivity enables to gather real time data of the traffic situation as well as deploying C-ITS (connected/cooperative intelligent transport systems). The different applications developed within the TT program are focused on improving accessibility, safety and liveability and distinguishes three technical clusters (Be-Mobile, 2020):

- **Cluster 1** focuses on the development, roll out and deployment of traffic light data. This information can both be used to improve information provision towards the road user, as well as more efficient traffic control by the traffic light with data from the road user.
- **Cluster 2** has the goal to process, enrich and distribute a wide variety of data, for subsequent conversion into customised, real-time data sets and information.

- **Cluster 3** makes sure that the information will be available to a wide range of road users via their smartphones and navigation systems.

An overview of the three clusters is also shown in Figure 1.1.

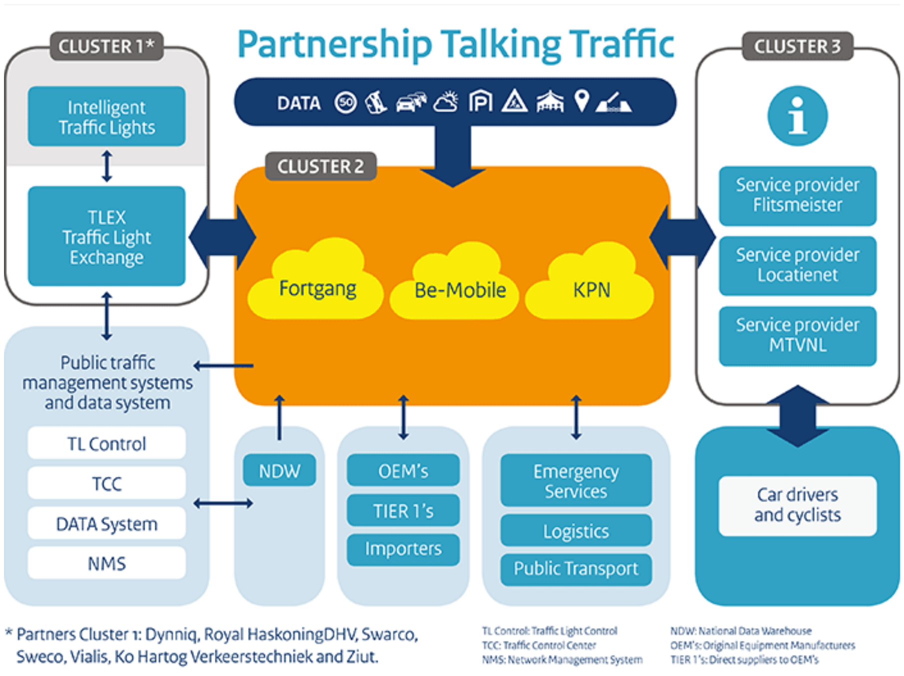


Figure 1.1: Overview clusters within Partnership Talking Traffic (CROW, 2019)

Partnership Talking Traffic has categorised the different applications in six use cases, based on their field of application (Be-Mobile, 2020):

1. In-vehicle signage and speed information;
2. In-car information about potential dangerous situations and road works;
3. Prioritisation of groups of road users at traffic lights;
4. In-car provision of actual traffic light information;
5. Optimisation of traffic flow by means of intelligent traffic light control systems (iTLC's);
6. In-car delivery of parking information.

In half of the use cases, the application of iTLC's, plays a key role. An iTLC contains hardware that can communicate with vehicles and navigation apps, and as a result offers opportunities for smart algorithms. Because of their flexible programmability, iTLC's can offer a good solution to many intersection problems related to traffic flow, safety, air quality or giving priority to specific target groups (e.g. public transport). It could improve traffic flow for both a single cross-section, as well as for a corridor with multiple TLC-controlled intersections (CROW, 2019).

One of the possibilities to control traffic flow is concerned by use case 3, which concerns the request for and assignment of priority at intersections with iTLC's. Giving priority means that a specific target group gets (or keeps) a green light and can therefore drive (almost) unhindered. Based on pre-determined traffic conditions, it is determined whether and how a vehicle is treated with priority. This is called conditioned priority. Besides, emergency vehicles get absolute priority when they arrive at an intersection controlled by iTLC's. An example of the application of target group prioritisation by iTLC's is green time extension for a specific direction (Be-Mobile, 2020).

Currently, controlling traffic flow while applying target group prioritisation at iTLC-controlled intersections is tested at a few locations in the Netherlands. Furthermore, several simulation model studies have been performed focusing on the local consequences of prioritisation of target groups (i.e. at the intersection at which a certain target group is prioritised). However, there is still limited knowledge available about the impact of this measure on network level.

1.1 Problem Context

To determine the quantitative impacts of target group prioritisation by iTLC's, Goudappel carried out a quick scan based on literature for the Province of Noord-Holland. At a particular intersection, a simulation study is conducted to see what the effects are on the waiting time by looking at different forms of target group prioritisation, different levels of demand and different proportions of prioritised users. The study shows that most of the applied prioritisation forms provide benefit for prioritised target groups, since it decreases the lost times. However, it also shows that prioritisation can increase lost times for non-prioritised target groups and if an intersection is already near saturation or oversaturated it can even be detrimental for the prioritised group (Visser, 2019).

Since not every road user can be prioritised, policy objectives determine the allocation of priority to specific target groups. Possible policies could be to lower emissions by prioritising freight traffic, or stimulating bicycle usage by prioritising cyclists. In most cases, these objectives are not limited to a single intersection, but involve a specific route, corridor or city area. It is likely that for a route with a lot of prioritised traffic, both prioritised and non-prioritised traffic experience improvements. However, it could also result in delays for non-prioritised road users. As a result of changing delays this could result in road users altering their route (i.e. more road users using the prioritised route and road users avoiding routes which encounter higher delays). These changes in route choice could result in both desired and undesired impacts at network level (e.g. more or less rat running).

Currently, little knowledge is available on the effects of target group prioritisation on a network level. What will be the consequences of prioritising a certain target group on a corridor of iTLC's? Are the travel times of the prioritised and non-prioritised user groups significantly influenced and could this result in, possible unwanted, changes in route choice? Would this for example result in more car traffic using the same route, or usage of alternative routes by non-prioritised traffic as a result of delay on their normal route? These are all questions related to this subject that one could ask, and why this research is conducted to provide answers.

Since the benefits of target group prioritisation are promising, it is important that policy makers can make well-founded decisions on implementing target group prioritisation. This research will focus on the possible network effects of prioritisation of target groups in a network by analysing various scenarios of target group prioritisation using a simulation model of an existing area. It is expected that the study shows the effect of target group prioritisation on the traffic distribution and travel times of parts of a network, for both prioritised and non-prioritised traffic, depending on the degree of prioritisation that is applied. A network is in this case assumed to be a reasonable sized area that exists of multiple intersections.

1.2 Research Dimensions

The aim of this research is to determine the effects of target group prioritisation on a network with multiple intersections controlled by intelligent traffic light control systems (iTLC's). The research focuses on a road network with motorised traffic and does not consider of pedestrians and cyclists. Given this aim, the following research question is posed:

What are the effects of target group prioritisation by Intelligent Traffic Light Control systems at network level for motorised traffic?

This question is split up into four smaller sub-questions, namely:

1. How can target group prioritisation at iTLC-controlled intersections be implemented in a transport model?
2. What are the performance criteria for assessing target group prioritisation at network level?
3. What are the route choice effects of applying target group prioritisation in a network?
4. What is the network performance of specific societal impacts when prioritising traffic?

1.3 Research Design

Central in determining the effects of a traffic measure is the use of a transport model. Depending on the scale of the research and the measure to be implemented, an appropriate model can be used. For this study, the effects of implementing target group prioritisation are investigated with the use of a macroscopic dynamic transport model. The choice for this type of model are explained in the next section.

The first sub-question studies how this traffic measure can be implemented in a transport model in order to assess the effects. It was decided on beforehand to assess the effects for two scenarios with both a different degree of prioritisation. For the configuration of these scenarios, literature research is conducted to find out the different possibilities to implement target group prioritisation. In addition, previous research on this topic is considered to draw expectations on the limits of target group prioritisation and to find out what the effects are on a microscopic scale. For the implementation in the transport model used, different possibilities were considered which resulted in an implementation method for which results of a previous study were used. Section 3.1 describes the process of the model configuration, which resulted in the two prioritisation scenarios used in the analysis.

The second sub-question identifies key performance indicators for assessing target group prioritisation at network level. Since the effects of the measure on network level is assessed, and not on intersection level as previous studies have done, different indicators are needed. The KPI's are chosen on their ability to assess the benefit for prioritised traffic, but also to measure the impact on non-prioritised parts of the network. The chosen KPI's are described in section 3.2.

The third sub-question analyses the route choice effects of applying target group prioritisation in the network. Each scenario, the reference scenario and the two priority scenarios, were configured separately in the model, so for each scenario the traffic flows could be simulated. To analyse target group prioritisation, three analyses are conducted that each assess the effect on the KPI's of sub-question 2. The complete method for analysing target group prioritisation is described in 3.3. The results of the analyses are discussed in Chapter 4.

The final sub-question describes the main impacts of applying target group prioritisation on a road network, given the results from sub-question 3. Given a certain policy objective for the application of target group prioritisation, several points of interest that should be considered before implementing are discussed. Also some possible advantages and disadvantages on target group prioritisation are discussed. This can be found in section 4.4

An overview of the steps that are conducted for this research is shown in Figure 1.2.

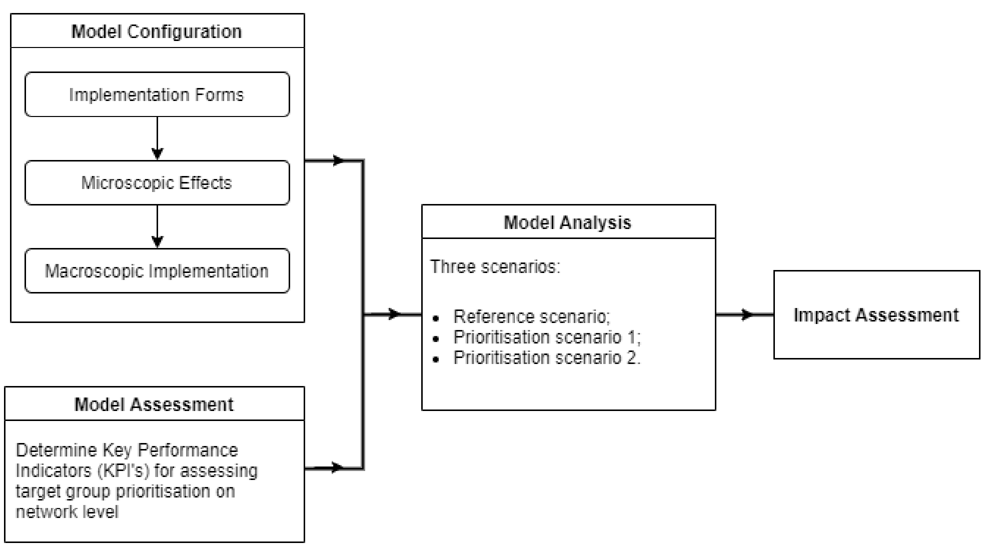


Figure 1.2: Overview of the steps conducted for this research

1.4 Scope

Since the research is conduced within a limited period of time, the following conditions are determined on beforehand.

To analyse the effects of target group prioritisation, a transport model can be used. These models are developed for the evaluation of infrastructural and traffic management measures aimed at the traffic flow and travelling times (Morsink and Wismans, 2008). There are roughly two types of transport models that can be distinguished: microscopic and macroscopic models. Microscopic transport models have the main advantage that they can provide traffic information from systems to individual level, which makes that the behaviour of an individual driver can be modelled. However, a disadvantage of a microscopic transport model is that the scale of networks that can be modelled is limited, since modelling the behaviour of each vehicle will take a big effort and resource in the required time, cost and high-level computational processes (Mardiati et al., 2014).

Since the goal of this research is to determine the effects of target group prioritisation on a city-sized network with multiple intersections, a macroscopic dynamic transport model is used. Despite the disadvantage that the individual behaviour of the vehicles is averaged and modelled implicitly by fundamental diagrams, this model type is suited to analyse the traffic behaviour in terms of aggregated variables like flows and the average speed of streams of traffic for the studied network. For a network of this scale, simulating with a microscopic transport model would take too much time and resources. A dynamic traffic assignment model is chosen, instead of a static traffic assignment model, since it provides more detailed information on the impact of changes made at intersections on for instance delays and queuing as well as dynamics over time, given the period simulated (Morsink and Wismans, 2008). An elaboration on the different transport models can be found in Appendix A.

For this analysis freight traffic is chosen to be the prioritised target group. It is important that for this study expectations and limitations on target group prioritisation can be drawn up, and besides results are needed as input for the implementation. Since multiple studies on prioritising freight traffic are available, this target group is chosen to consider for this study. Policy objectives for prioritising freight traffic could be to gain economic benefits and/or to reduce emission. In the past a pilot with prioritising freight traffic was conducted for this reason, known as the TOVERgroen pilot (Arane Adviseurs, 2004), and this form of providing priority is later also implemented at several other intersections in the Netherlands. Besides, a more recent study on the N279 shows that prioritising freight traffic is a justifiable policy choice (DTV Consultants, 2019).

Chapter 2

Model Information

The scope of this study defines that a macroscopic dynamic transport model is used to analyse the effects of prioritising freight traffic. An already existing macroscopic model of the Voorne-Putten region is used to model the effects of target group prioritisation. This model will be introduced in section 2.1. The used software for this study is OmniTRANS, which is a transport planning software package and includes a dynamic macroscopic traffic assignment model known as StreamLine MaDAM. The model tries to calculate the expected traffic distribution in the network, which is defined as the situation where the route costs in an origin-destination pair (OD-pair) are equal. This is also known as an (user) equilibrium (Dijkhuis, 2012). Within OmniTRANS different modules are available to do simulation studies. The StreamLine module is used for the dynamic traffic assignment and will shortly be explained in section 2.2.

2.1 Voorne-Putten Transport Model

The problem context of this research mentions that for analysing the effects of target group prioritisation on a network scale "a reasonable sized area that exists of multiple TLC-controlled intersections" is needed. Therefore, Goudappel provided the transport model of the Voorne-Putten region for which they conducted several traffic analyses in the past years. The accessibility of the region is of great economic importance, since it covers a big part of the roads to the port area of Rotterdam. Besides, it is an important living area in the Rotterdam region with more than 160,000 inhabitants. For the most recent accessibility study conducted by Goudappel, the effects on the network with the realisation of the Blankenburg connection (Maasdeltatunnel) were analysed. The study area is shown in Figure 2.1.
The study area of the Voorne-Putten region consists of the main roads that connects Voorne-Putten and the Port of Rotterdam (Goudappel and DAT.Mobility, 2018). It includes:

- The A15 from the Maasvlakte to the Beneluxplein;
- The N218 Groene Kruisweg from A15 Stenen Baakplein via the Spijkenisserbrug and Aveling to the A15;
- The N57 from Hellevoetsluis via the Harmsenbrug to the A15;
- The Hartelweg between Groene Kruisweg and A15;
- The N494 Kanaaldijk-West from Hellevoetsluis to N218 Groene Kruisweg.

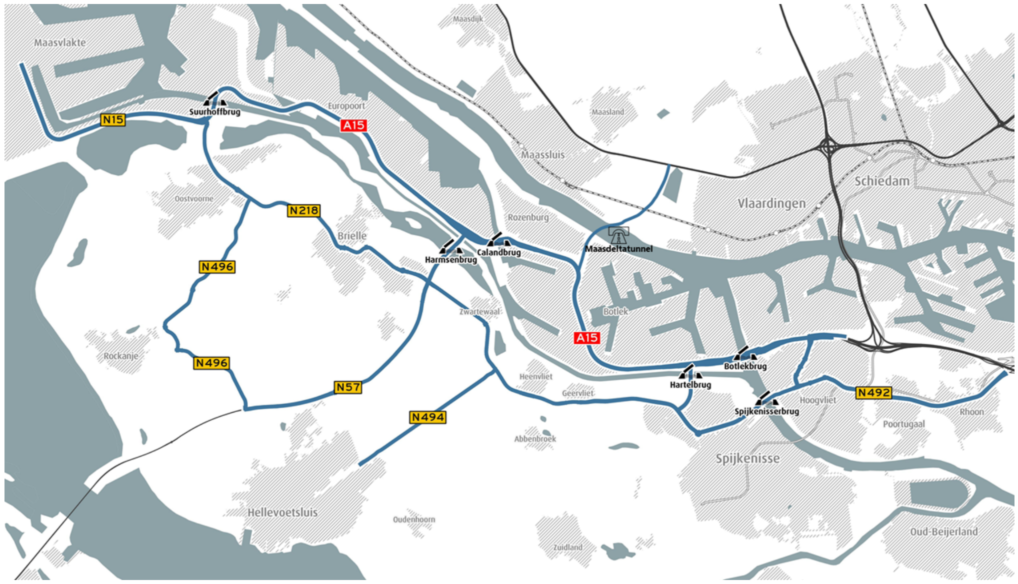


Figure 2.1: Voorne-Putten Study Area (Goudappel and DAT.Mobility, 2018)

For this research, the traffic conditions during the morning peak are simulated. To indicate current bottlenecks in the road network, the average speed per road segment is compared with the speed at free flow which can be seen in Figure 2.2. If a road section has an average speed that is half the speed during free flow (or even lower), the road section is considered to be a bottleneck since congestion occurs. This is marked with the red color in the figure. It can be seen that during the morning peak, the bottlenecks mainly occur at the roads towards the A15. Both the Harmsen connection and the Hartel connection with the A15 cause congestion on the connecting road (respectively the N57 and the Hartelweg). It can be seen that the latter one also affects the traffic flow on the N218. However, the congestion is not caused by bridge openings, since for both connections they are not included in the simulation of the morning peak.

A specific trajectory of the model that consists of multiple intersections is chosen to apply target group prioritisation on. For this selection, both the traffic intensities and car v.s. freight ratio of the network are analysed, to see if a reasonable proportion of all traffic are trucks. Besides, several OD-pairs are analysed to identify potential routes to apply target group prioritisation on with competing route alternatives. In case route fractions (fraction of total traffic on a route between OD-pair) and the travel times of the route alternatives are competitive, it is more likely a shift in traffic distribution occurs when one route is prioritised. This is important to be able to analyse the effect of the measure on the route choice.

This resulted in the selection of the route shown in Figure 2.3. The route covers a significant part of the road network and already contained TLC's. The route is approximately 11 kilometres long and consists of 11 intersections, of which 7 are TLC-controlled and adjusted to implement target group prioritisation. It is chosen to only prioritise the direction from west to east on this route and not both directions to be able to better interpret the effects of target group prioritisation. The more directions are prioritised, the more causes a certain effect can have which makes it difficult to analyse and explain. The route starts approximately 800 meters before the first TLC-controlled intersection with the N57 and ends 400 meters after the last intersection with the Hartelweg.

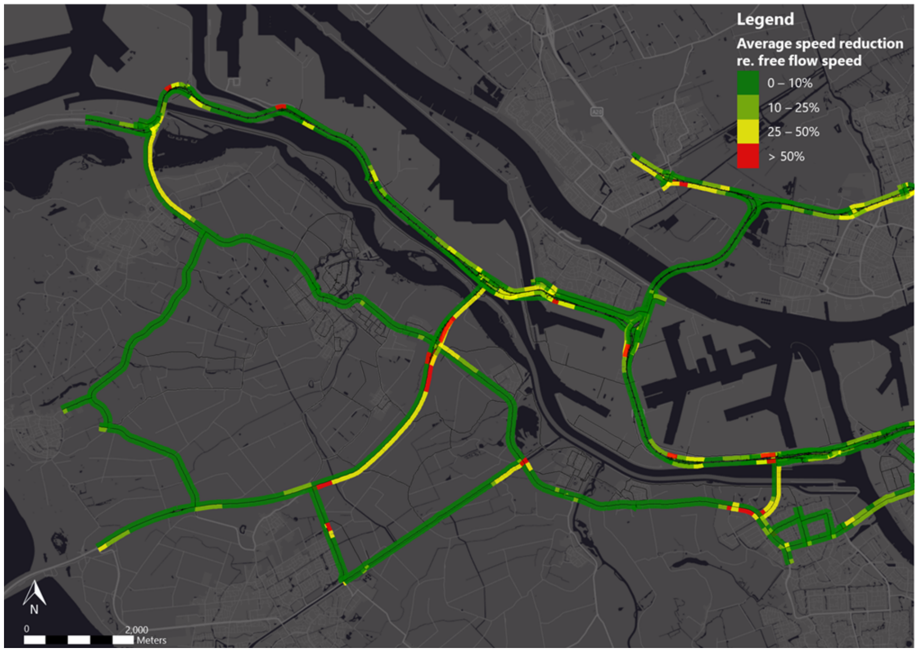


Figure 2.2: Average speed reduction re. free flow speed during the morning peak period

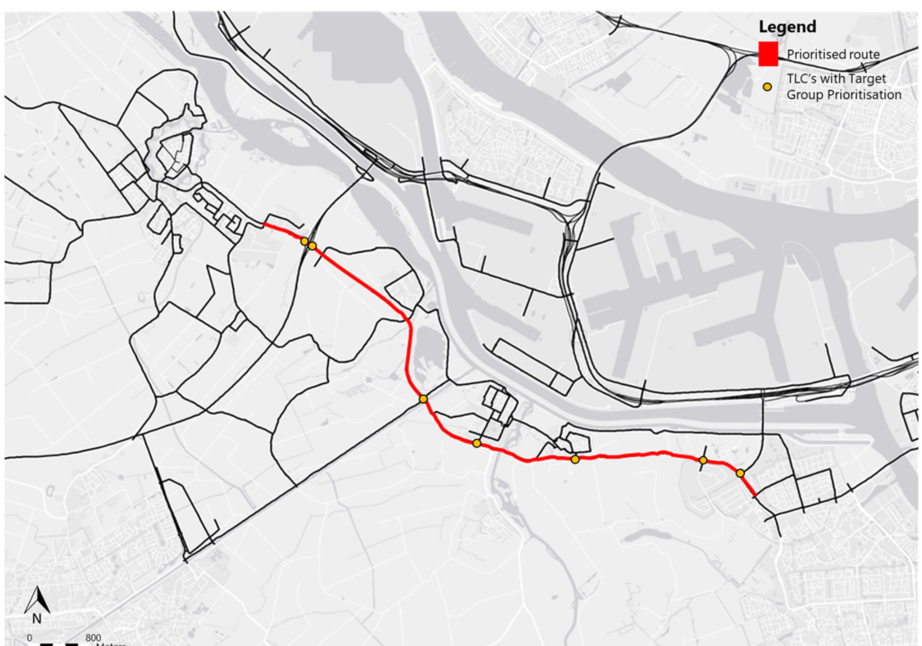


Figure 2.3: Prioritised route with adapted TLC's (West to East direction)

2.2 StreamLine MaDAM

Dynamic traffic assignment (DTA) is implemented in OmniTRANS by using the StreamLine module, which allows to assign traffic over time and analyse performance of the traffic flows in the network. The goal of DTA is to determine a dynamic user equilibrium (DUE), which simply means that at any time step, people cannot improve their situation by taking another route. Since it is assumed that travellers may have different perceptions about the network and their travel times, this is known as a stochastic model (Muijlwijk, 2012). The operation of StreamLine is visualised in Figure 2.4 and can roughly be split up in the following steps (Dijkhuis, 2012).

1. **Generation of routes:** for each OD-pair the most attractive routes are selected.
2. **Calculation of route costs:** for each route alternative generated in step 1 the route costs, which is often the travel time between origin and destination, are calculated.
3. **Calculation of the route fractions:** for each route choice moment the route costs of the generated route alternatives are compared and a proportion of traffic is assigned to each route.
4. **Propagation model (MaDAM):** the propagation model MaDAM, also called dynamic network loading (DNL) model, is a LWR (Lighthill-Whitham-Richards) model operationalised by a Cell Transmission Model combined with junction modelling. The propagation of traffic flow is computed (i.e. density, speed and flow) for each link segment within the network over time, given the (dynamic) demand.
5. **Calculation of route costs:** just as in step 2 the route costs are calculated for the generated route alternatives, taking into account the new traffic characteristics (i.e. intensities) calculated with the propagation model.
6. **Weighting of route fractions:** given the new route costs, the route fractions calculated in the current iteration are averaged with the fractions in the previous iteration by using the Method of Successive Averages (MSA).
7. **Convergence criterion:** the calculated route costs are compared with previous iteration, until a DUE is reached or a set maximum number of iterations is reached.

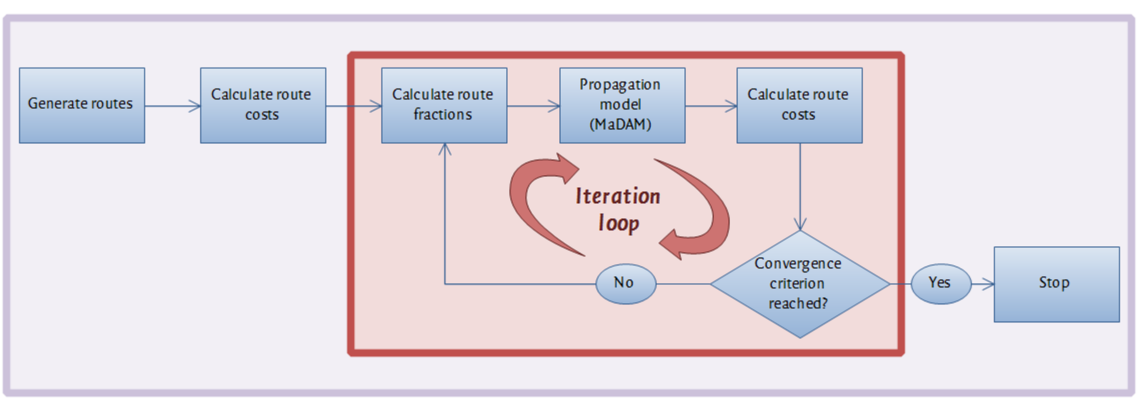


Figure 2.4: Overview of the operation of StreamLine in OmniTRANS (Dijkhuis, 2012)

The first step in the dynamic traffic assignment is the generation of routes for the included OD pairs. The route set generated is used in the entire simulation. In this process, first the shortest route of each OD pair is determined by using the Dijkstra algorithm. The alternative routes are generated with a Monte Carlo algorithm, until a stop criterion is set (maximum variance or maximum number of iterations). Afterwards, the routes are filtered on certain criteria which results in the final route set (Dijkhuis, 2012). It is also possible that an already existing route set is used, for example determined by a static assignment model.

During the simulation the route costs are calculated multiple times. In the second step of the DTA, the free flow (or instantaneous) travel times are calculated which are the travel times of the routes without delay. During the iteration loop, the route costs are calculated based on the time-varying link speeds of each link segment for every route choice interval (typically these are average travel times for every 15 minutes). These densities are each iteration updated by the MaDAM propagation model (Dijkhuis, 2012). The working of the propagation model is explained in more detail in Appendix B.

When for every route choice moment the route costs are determined, the traffic demand is divided among the route alternatives. In our model this is done with the Paired Combinatorial Logit (PCL) method. According to this method, all generated routes receive a proportion of traffic, but routes with low route costs receive a relatively higher proportion of traffic than routes with high route costs. Depending on the spread parameter, a travel time difference between the different routes has a large or low impact on the route fraction. A travel time difference of 1 minute has for example big impact when the spread factor is low, but has almost no impact when the spread factor is high. The spread parameter is directly related to the error term, taken into account in the utility function, and is associated with the perception, level of information of travellers as well as (other) not included parameters within the utility function. The route fractions that are calculated in the current iteration are averaged with the fractions in the previous iteration, also known as the method of successive averages (MSA). The following equation is used (Dijkhuis, 2012):

$$F_{i,r} = \frac{i-1}{i} \cdot F_{i-1,r} + \frac{1}{i} \cdot f_{i,r} \tag{2.1}$$

in which F is the total route fraction, weighted with previous iterations, f is the unweighted route fraction of the current iteration, i indicates the iteration and r the route for which the fraction is calculated.

The simulation stops when the stop criterion is reached, either a certain duality gap or a maximum number of iterations. The duality gap is the extent to which the route costs in the network change in comparison with the previous iteration and is set by the user. When the simulation is stopped because of the set duality gap, it means that the outcome of StreamLine is close to a DUE. However, it could take a lot of time before the model reaches a DUE so to save time the user can set a maximum number of iterations (Dijkhuis, 2012).

2.2.1 Junction Model XStream

In an urban network, relatively much of the time spent on a trip is incurred by queuing and turning at junctions. Deceleration, crossing and acceleration for a junction does involve an amount of delay. Therefore, the main objective of the junction modelling tool is to calculate the average delay per vehicle for each turning movement on the basis of the junction layout, turning flows and optionally signal settings (DAT.Mobility, 2016). The XStream model can be used in combination with the propagation model MaDAM, which is described in Appendix B.

Figure 2.5 shows a schematic visualisation of all possible turns on a four-way junction. The schematic view is always the same, regardless the junction type. The only difference is bottleneck bn_i, which has a given length, capacity and maximum speed depending on the intensities of the conflicting flows and the specifics of the junction. This layer of abstraction is introduced in XStream to be able to deal with all junctions in the same way, while still being able to mimic the junction specifics defined by its bottlenecks (Raadsen et al., 2010).

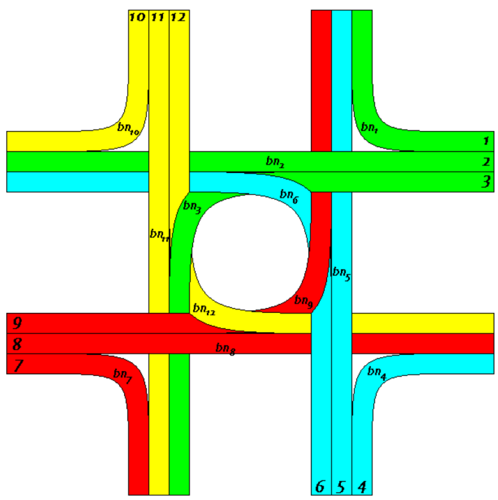


Figure 2.5: Schematic view of an XStream junction (Raadsen et al., 2010)

As mentioned before, StreamLine lets traffic flow through the network by splitting the links into small segments and recalculating the current stage for each segment every one to five seconds. For modelling junctions, MaDAM creates approach lanes for each junction arm as defined in the junction editor. This is also visualised in Figure 2.6. Each approach becomes part of the junction segment and is modelled as an individual segment. The traffic behaviour on an approach lane is based on the calculated delays determined by XStream. These delays are computed using junction models derived from the Highway Capacity Manual (HCM) (Bezembinder, 2018). Transforming the delay into a speed, each approach lane will have a traffic flow speed on its own. Besides, if an particular approach lane starts to get blocked and a queue is being formed, the other approach lane is not touched until the blocked approach lane blocks the entire approach, and therefore blocks also the inflow into the other approach lanes. The latter is also known as the blocking back effect (DAT.Mobility, 2016).

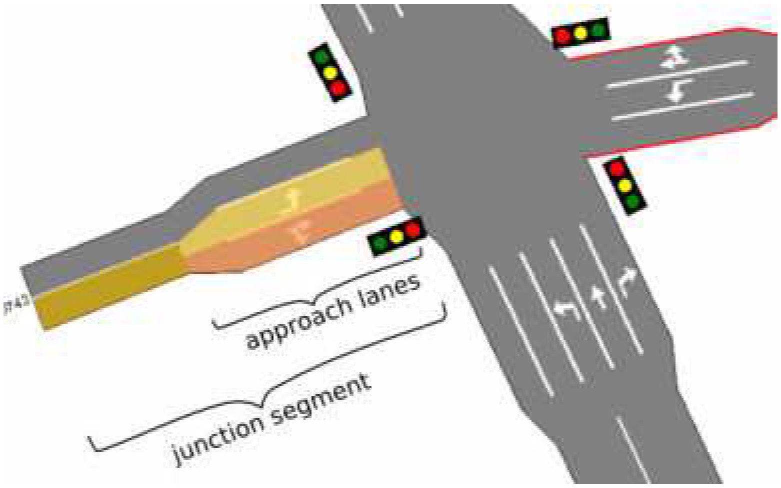


Figure 2.6: Visualisation of approach lane on junction segment (DAT.Mobility, 2016)

The above methodology entails the conversion of the junction input to a reduction of speed and capacity on turn basis resulting in “normal” propagation links with almost the same behaviour as all other links in the network (DAT.Mobility, 2016).

The junction modelling module of OmniTRANS can define all types of junctions, namely: equal junctions, priority junctions, signalised junctions and (signalised) roundabouts. For this research, the signalised junction will be used to implement target group prioritisation in the model. In OmniTRANS there are three possibilities to specify a signalised junction, which are all based on two important traffic light control values: the cycle time and the green time. The cycle time is the time required for one sequence of signal displays (approximately the sum of the green times and intergreen times). The green time is the time in seconds a certain lane/turn is provided with a green light (Muijlwijk, 2012). The three different signalised intersection types in OmniTRANS are explained in Appendix C.1.

Next to the delay, as a result of crossing an intersection and queuing, while waiting for a red light, the junction also influences the capacity which could lead to additional delay if capacity does not match demand. Therefore, also the influence of the junction on the outflow capacity is needed and determined. For TLC’s, the settings will influence the capacity of a lane, which is the number of vehicles that can cross the intersection within an hour. The exact calculation of the capacity at a signalised junction is explained in Appendix C.2. It is important to realise that the lane capacity is dependent on the fraction of the lane green time and cycle time. For example, an increase in green time for a certain lane, increases the lane capacity. In contrast, an increase in cycle time decreases the lane capacity (assuming that the green time remains the same).

Chapter 3

Method

3.1 Model Configuration

The first part of this research is to investigate how target group prioritisation can be implemented in the macroscopic dynamic model that is provided. As mentioned in section 1.4, a macroscopic dynamic model is needed to assess the effects of target group prioritisation on a network level. However, a macroscopic dynamic model cannot exactly simulate the way target group prioritisation works. Therefore, previous studies on implementing target group prioritisation are used to get insight in the application possibilities and the effects of the measure on an intersection. The output of the microscopic studies is used to translate the effects into the macroscopic model in the form of an effect on the green time distribution of the selected intersections.

3.1.1 Implementation of Target Group Prioritisation

Currently, most TLC systems in the Netherlands are vehicle-based control systems. The presence or absence of vehicles on a certain direction is often determined with detection loops that are placed in the road surface. The use of iTLC's makes it possible to control traffic on an intersection by using data from single cars and communication with vehicles and navigation apps. It becomes possible to identify specific vehicles and prioritise target groups. For the implementation of target group prioritisation on an intersection or in a microscopic simulation model, roughly three implementation forms can be distinguished (Goudappel, 2019):

1. **Increasing green time:** when a particular direction already has a green light, this green time will be increased when a prioritised vehicle is approaching. The iTLC will continue its cycle when the maximum green time is reached. It is known that this scenario is the least intrusive way of prioritising, since no extra lost time of a phase change occurs because the number of phases in a cycle and the order of the phases remains the same (Agentschap Wegen en Verkeer, 2020).
2. **Deviation from cyclical traffic handling (shuffle/cut off):** traditionally, most traffic light control systems provide a green light to traffic participants in the same order every cycle. The order that directions get a green light is every cycle the same. A

direction where prioritised traffic is present can be provided with a green light sooner, by shuffling this sequence or by cutting off a phase (Goudappel, 2019).

3. **Extra green phase:** in this scenario, a direction is provided with green time multiple times within a cycle, by adding a new phase in the phase design when prioritised traffic is present. Within the fixed phase design, a new phase will be added (Goudappel, 2019). This is for example already applied for public transport, since they are equipped with short-range radio communication systems. When they arrive at an intersection, they are almost immediately provided with a green light (Nautikaris, 2021).

It is also possible to combine the three scenarios for the application of target group prioritisation. This shows that there are multiple ways to implement target group prioritisation on an intersection, varying from a limited to high degree of priority. The next section focuses on the results of applying these priority forms and for which conditions it is feasible.

3.1.2 Microscopic Studies on Target Group Prioritisation

Various simulation studies are already conducted to analyse the effects of prioritising target groups, mainly focused on prioritising transit and freight traffic. The effects could help to make predictions to what extent prioritising traffic is possible and under what conditions, so some expectations can be drawn up. Besides, the results of the simulation studies are needed to implement target group prioritisation in a macroscopic dynamic model. For this research the study of Visser (2019) is used.

Limits on Target Group Prioritisation

The studies of Manta (2019) and Mahmud (2014) have investigated which implementation forms of target group prioritisation (as discussed in section 3.1.1) are most feasible to apply on a TLC-controlled intersection. Both argue that the green time extension scenario and the early green strategy are most commonly applied. The increasing green time scenario is the most preferred one, since it reduces delay of the prioritised direction without the occurrence of extra clearance intervals that are needed more often in the early green strategy. In that scenario green time periods of other phases are cut off to provide green to the prioritised direction, which results in more phase transitions, and therefore more clearance intervals. The extra green phase scenario also causes more phase transitions and has more impact on the cycle time. Therefore, these studies conclude that the effects of this scenario are too detrimental for the overall traffic handling.

The research of Ahn et al. (2016) indicates that there is a limit on prioritising vehicles. This study applied target group prioritisation on two cases with freight composition rates of respectively 20% and 80%. Both cases show a reduction in travel time for trucks on the prioritised corridor. However, the case with a proportion of 80% prioritised freight traffic resulted in heavy congestion on the side streets since green time periods where largely shortened. To check the feasibility of target group prioritisation both the effects of prioritised traffic, as for the other modalities should be considered.

In addition, Ahn et al. (2016) examined the effects of target group prioritisation for different volume-to-capacity (V/C) ratios, which is a commonly used index for conveying congestion levels. The V/C ratio of the studied corridor in the morning peak is 0.85, which indicates a nearly congested traffic state. To also represent an uncongested situation, a scenario was tested with a V/C ratio of 0.5. The study shows that for a composition rate of 20% with a V/C ratio of 0.85, the effects are more beneficial compared to the uncongested situation with a V/C ratio of 0.5. This indicates that when almost no congestion occurs at a road, the benefits for prioritised traffic are limited compared to the reference situation without prioritising. This does not outweigh the congestion that occurs at the side streets. So, the benefit of target group prioritisation depends on the traffic conditions of the network.

Furthermore, the research of Visser (2019) shows that when the saturation rate of an intersection is high, prioritising vehicles can result in increasing lost times for all vehicles including the prioritised target groups. This also shows that the degree to which prioritisation can be applied is dependent on the traffic conditions, i.e. saturation levels should not be too low as well as too high.

In conclusion, previous research shows that there is a limit on prioritising vehicles and therefore not all application scenarios are feasible. Besides, applying target group prioritisation could have a high beneficial effect on the prioritised traffic, but be detrimental for the overall traffic handling of a road.

Microscopic Effects of Target Group Prioritisation

Previous paragraph shows that research is conducted on the effects of target group prioritisation on intersection level. Different studies were taken into consideration to use for the translation of the microscopic output into input for our macroscopic dynamic model. The study of Visser (2019) seemed to be the most suitable for this research as it discusses the effects of different implementation forms, which gives insight to what extent prioritisation is possible. Moreover, the study measures the effect for different proportions of prioritised traffic, which again gives an indication to what extent granting priority is possible. Besides, the study location is a Dutch TLC-controlled intersection, that is designed according to the Dutch regulations and represents Dutch traffic conditions. Our study also considers a Dutch case study, so it can be assumed that TLC characteristics are comparable. Foreign study locations might have non-comparable traffic conditions and TLC-settings regarding cycle time and green time distribution are often also different, which could give different results compared to a Dutch situation. Lastly, this study provide the details to put the effects into perspective, like information about the current traffic light control design. This is needed to make deliberate assumptions for the translation to a macroscopic level.

The study of Visser (2019) applied several scenarios of target group prioritisation on the intersection on the N196 with the connection to the Fokkerweg and Pudongweg in Amsterdam. This intersection fits for this study, since it is currently controlled by TLC's and a plausible amount of freight traffic travels via this intersection. Figure 3.1 shows a satellite image of the intersection.

Figure 3.1: Studied intersection on the N196 Fokkerweg/Pudongweg (Visser, 2019)

As discussed earlier, several implementation forms of target group prioritisation are known. The research of Visser (2019) distinguishes four scenarios for studying the effects of target group prioritisation at an intersection. The used priority application scenarios are explained in Table 3.1. For each scenario, the effects are measured for different proportions of prioritised traffic relative to the total number of vehicles. Besides, the scenarios are simulated for two variants: one variant with target group prioritisation applied on all directions and one variant where target group prioritisation is only applied on the directions of the normative conflict group. The normative conflict group (NL: maatgevende conflictgroep) is the group of lanes which has the highest signal cycle time of all conflict groups. A conflict group is a group of lanes that cannot get green at the same time, since the directions cross each other.

To see what the effects are of target group prioritisation, the lost time is taken as indicator: the extra travel time a vehicle has to cross the intersection compared to free flow conditions, so a combination of waiting time and lost time due to accelerating/decelerating. For each scenario, the lost times are measured for different proportions of prioritised traffic relative to the total number of vehicles. For each scenario, the average lost time of the lane groups considered are indicated for prioritised traffic, non-prioritised traffic and both groups together.

The lost time indirectly represents an effect on the green time distribution. When a certain direction is prioritised, a reduction in lost time is likely caused by an increase in green time. Assuming this, the results of this study could be used to translate the effect into the macroscopic dynamic model.

Table 3.1: Priority application scenarios simulation study (Visser, 2019)

	Priority application scenario	**Explanation**
1	Increasing green time	When a particular direction already has a green light, this green time will be increased when a prioritised vehicle is approaching. The traffic light control system will continue its cycle when the maximum green time is reached. When a prioritised vehicle arrives just after the maximum green time is reached, the TLC will continue its cycle.
2	Cut off + increasing green time	The phase in working will be cut off when a prioritised vehicle arrives from a different direction. If there are phases in between the phase of the prioritised vehicle, they are handled with minimum green time. The phase with prioritised traffic keeps green time as long as prioritised vehicles are arriving, until the maximum green time is reached.
3	Extra green phase + increasing green time	A direction is provided with green time multiple times within a cycle when prioritised traffic is present. Within the fixed phase design, a new phase can be added. The green time will be extended as long as prioritising vehicles are arriving on this direction, until the maximum green time is reached. Afterwards, the iTLC continues with the cycle.
4	Cut off + extra green phase + increasing green time	The phase in working will be cut off when a prioritised vehicle arrives from a different direction. This direction is directly provided with an extra phase and gets green time as long as prioritised vehicles are arriving, until the maximum green time is reached. Afterwards, the iTLC continues with the cycle.

As mentioned before, Visser (2019) studies the effects for a variant where priority is granted on all directions and a variant where the target group is only prioritised on the lane groups of the normative conflict group. Since a macroscopic dynamic model does not simulate individual vehicles, it is not feasible to implement target group prioritisation on all directions. Therefore, one direction of a route is chosen to apply target group prioritisation on, as also mentioned in section 2.1. The results of the variant where target group prioritisation is only applied on the normative conflict group (consisting of 4 lane groups) is therefore assumed to be the most suitable to take into account for our study, despite the plausible difference in lost times when it is only applied on 1 lane group.

Section 1.3 describes that the effect of target group prioritisation should be analysed for two prioritisation scenarios with both a different degree of prioritisation. To substantiate the degree of prioritisation that will be applied, the results of the study of Visser (2019) are used to translate the effect on the lost time to an effect that can be implemented in the macroscopic model. Each scenario implies a different degree of prioritisation: scenario 1 implies a relative low degree of prioritisation, scenario 4 a relative high degree of prioritisation. The results of two scenarios from the study of Visser (2019) are used to draw up two prioritisation scenarios. Since the study of Manta (2019) and Mahmud (2014) describe that scenario 1 and 2 are the most feasible to implement, these results are used to draw up the two prioritisation scenarios needed for this research.

Before discussing the possibilities to implement target group prioritisation in our model, first the results as described in the study of Visser (2019) are discussed to understand what the effect of target group prioritisation is on the average lost time of the normative conflict group.

The results of the application of the increasing green time scenario are shown in Table 3.2. It shows that increasing the green time for prioritised traffic has a relative limited impact on all the traffic present. Since the phase order of the cycle is preserved, no extra lost time caused by clearance intervals occurs. Up to a proportion of 25% there is a reduction of lost time for all road users. It is assumed that this reduction is the result of non-prioritised traffic that also profits from the green time extension on the prioritised direction. The non-prioritised traffic that profits from the green time extension is probably larger than the smaller non-prioritised traffic flows that have more lost time. The increase in lost times for a proportion of 50% is probably caused by an increased cycle time together with vehicles that have to wait an extra cycle, or even vehicles that cannot get in the right lane because they are blocked. This shows that there is a limit on prioritising vehicles, and confirms results from previous research.

Table 3.2: Lost times [s] of prioritised, non-prioritised and all traffic for scenario 1 (increasing green time) (Visser, 2019)

Scenario 1:	**Priority proportion**				
Increasing green time [s]	**0%**	**5%**	**10%**	**25%**	**50%**
Prioritised	35	31	30.5	32	35.5
Non-prioritised	35	34.5	32.5	33.5	35
All	35	33.5	32.5	33.5	35

In Table 3.3, the lost times of priority application scenario 2 are shown. In this scenario, the lost time of the prioritised traffic reduces with respectively 7.5 and 4 seconds for proportions of 5% and 10%. In contrast to scenario 1, the lost time for all the traffic and non-prioritised traffic will increase, which can be detrimental for the complete traffic handling. The high lost times when a proportion of 50% is prioritised are probably caused by shorter green time periods and cycle times. For each phase transition, the lost time increases also with clearance time, and when green time periods are often cut off this will quickly add up.

Table 3.3: Lost times [s] of prioritised, non-prioritised and all traffic for scenario 2 (cut off + increasing green time) (Visser, 2019)

Scenario 2:	**Priority proportion**				
Cut off + increasing green time [s]	**0%**	**5%**	**10%**	**25%**	**50%**
Prioritised	35	27.5	31	38	93
Non-prioritised	35	37	38	41	93
All	35	37	37.5	40	93

All in all, the results of both scenarios confirm the results of other research, namely that there is a limit on prioritising traffic since for a high proportion of prioritised traffic the lost time increases compared to the reference situation. Scenario 1 shows a relatively small profit for prioritised traffic on one intersection. However, the results show also positive effects for the non-prioritised traffic and when applying it on multiple intersections on a corridor it could show a reduction in travel time. The application of scenario 2 shows large benefits for prioritised traffic, but is detrimental for the non-prioritised traffic. Depending on policy choices, one could choose to implement this scenario.

Given the lost times of both scenarios, it is assumed that a reduction in lost time is an increase in green time for prioritised traffic. Since it is not possible to simulate individual vehicles in a macroscopic dynamic transport model, target group prioritisation is only applied on one direction. In addition, the simulation study of Visser (2019) calculated the average lost times for the normative conflict group, which includes 4 lane groups. It is assumed that these averages are a good estimation of the lost time of one lane group at an intersection which is prioritised in the model that is used in this study. The next paragraph will discuss the possibilities to implement target group prioritisation in our macroscopic traffic model and how it is done for this study.

3.1.3 Macroscopic Implementation of Target Group Prioritisation

Section 2.2.1 discusses the junction model XStream of OmniTRANS that is used to calculate the turn delay at intersections. Based on the junction settings, MaDAM converts the input to a speed and capacity on the turns of the intersection. From the microscopic research conducted, it is known that target group prioritisation will affect the traffic flow on a certain turn. There are four possibilities to mimic the effect of target group prioritisation in OmniTRANS, namely by modifying (one of) the three turn attributes or adjusting the green time distribution:

- **Impedance:** time value in seconds that represents the average control delay on the turn for a particular mode and time. The impedance value overrules the delay value that is calculated by the junction modelling module.
- **Saturation Flow:** value in vehicles/hour that overrules the saturation flow value that is used by the junction modelling module. The saturation flow is the maximum traffic intensity that can be handled by a lane, assuming that there is a continuous flow of road users without delay.

- **Coordinated:** factor that could decrease/increase the turn delay calculated by the junction modelling module for a certain lane and for a certain mode.
- **Adjust green time distribution**: change the signal settings by adjusting the cycle time and/or the green times for a turn.

Instead of changing the TLC settings, the turn attributes (impedance, saturation flow, coordinated) change the turn characteristics that are calculated by XStream. The main advantage of using the turn attributes, is that it is possible to change turn characteristics for each target group separately. Since only freight traffic should be prioritised, the turn attributes for this modality could be adapted to mimic the effect of target group prioritisation.

Despite the fact that using the turn attributes make it possible to distinguish between the two target groups in our macroscopic model (car and freight), it is chosen to adjust the green time distribution to mimic the effect of target group prioritisation for this research. This choice has several reasons. First of all, changing the impedance or saturation flow would result in manually overruling the model computing the effects of the interaction between demand and supply. Because this research is interested in the network effects, demand is expected to be influenced and therefore delays or saturation flows, which would be locally neglected when overruling the junction delay. Secondly, changing the coordinated for one target group, would neglect the effect that a non-prioritised target group can also profit from the priority granted to the prioritised target group. Thirdly, coordinated only changes the turn delay of a certain lane, but not the capacity. Therefore, it would only affect the other directions if for these turns additional turn delays are estimated and included via separate parameters. As explained in section 2.2.1, an increase in green time also means that the capacity of a certain lane increases. This effect might become important when demand on certain directions increase, to see what the effect of target group prioritisation is on the route choice.

Implementing target group prioritisation by adjusting the green time distribution involves a limitation, since no distinction between modalities can be made. Extending the green time for a certain lane, means that all traffic on that lane benefit from this equally, instead of a specific profit for one target group.

It is assumed that a reduction in lost time is caused by an increase in green time for a certain direction. The study of Visser (2019) shows the effect of prioritising one target group on the lost time. By translating the change in lost time to a change in green time, the green time extension implies the needed change in green time to mimic the effect of target group prioritisation on one direction. So, in this case all traffic on the chosen route is prioritised, but the degree of prioritisation is based on prioritising only one target group.

As mentioned before, two prioritisation scenarios are drawn up to assess the effect of target group prioritisation. To determine the needed green time extension to mimic target group prioritisation, the lost times of scenario 1 and 2 of the study of Visser (2019) are used. More specifically, the lost times of the first row of Table 3.2 and 3.3 are used to determine the needed green time extension to mimic the effect on the prioritised route.

To be able to translate the lost times to green times, an assumption should be made. As mentioned before, the lost time is the extra travel time a vehicle has to cross the intersection compared to free flow conditions. Given the lost time of the reference situation and the lost time of the situations where prioritisation is applied, the change in green time can be calculated with the following equation:

$$\Delta t_{green,i} = 2 \cdot (t_{lost,0} - t_{lost,i}) \tag{3.1}$$

in which $t_{green,i}$ and $t_{lost,i}$ are respectively the green time and lost time when a proportion i of vehicles is prioritised, and $t_{lost,0}$ is the lost time of the reference situation.

It is assumed that the green times for the other signal groups remain the same, and therefore the cycle time increases with the amount of extra green time calculated. However, it should be mentioned that this translation from lost time to green time is a simplification and probably an underestimation of the change that is needed in reality. Since the cycle time will also increase, the lost time will increase and probably more green time is needed to have a reduction lost time. In fact, this is not possible without the reduction of green time for the other directions.

First, the equations are applied on the lost times of scenario 1, to see what the effects are on the green time distribution for a single signal group. The results are shown in Table 3.4.

Table 3.4: Effects priority application scenario 1 on green time distribution

Scenario 1:	**Priority Proportion**			
Increasing green time	**0% (ref.)**	**5%**	**10%**	**25%**
Lost time [s]	35	31	30.5	32
Green time [s]	27	35	36	33
Extra green time re. ref [s]	-	8	9	6
Extra green time re. ref [%]	-	29.6	33.3	22.2

The results show that for this scenario the green time is extended with 9 seconds at most compared to the reference green time distribution when the proportion of prioritised vehicles is 10%. It can be seen that for a proportion of 25% prioritised traffic, the green time extension is less compared to the 10% proportion case. This is probably because the number of prioritised vehicles is bigger than the number that can be handled within one green time period with maximum extension. To apply the effects also on intersections with different green time distributions and cycle times, the relative extra green time compared to the reference situation is calculated. In both the 5% and 10% case, this is approximately a green time extension of 30%.

The second scenario is a more extreme variant of applying target group prioritisation. The effects on the green time distribution are shown in Table 3.5.

Table 3.5: Effects priority application scenario 2 on green time distribution

Scenario 2:	**Priority Proportion**			
Cut off+ increasing green time	**0% (ref.)**	**5%**	**10%**	**25%**
Lost time [s]	35	27.5	31	38
Green time [s]	27	42	35	
Extra green time re. ref [s]	-	15	8	
Extra green time re. ref [%]	-	55.6	29.6	

From this table is immediately noticeable that the lost time for a proportion of 25% prioritised vehicles is higher compared to the reference situation. This indicates that there is a limit on applying target group prioritisation. The effect of the increasing lost time on the green time distribution is difficult to determine, so that is why the cells are empty. To indicate what the effect of this scenario on the green time is, the case with 5% and 10% proportion could be considered. This shows an absolute increase of 8 to 15 seconds compared to the reference case, which is a relative increase between approximately 30% and 55%.

Manta (2019) also applied the cut-off + green time extension scenario in her research on prioritising freight traffic. One of the indicators used in this research is the change in green time for the prioritised direction. The green time extension found in this research can be used to check whether or not the calculated values of Table 3.5 are a good estimation. It is known that the traffic conditions of this study are different compared to the study of Visser (2019), regarding the TLC-settings and traffic intensities. Nevertheless, Manta (2019) measured a green time extension of approximately 8 to 9 seconds, which is in the same order of magnitude as the calculated values in Table 3.5. In absence of a microscopic study that directly shows the effect of target group prioritisation on the green time distribution, it is assumed that the method applied to calculate the green times is a good estimation.

For our study, the relative change in green time for the prioritised corridor is needed to implement it in the macroscopic simulation model. To represent scenario 1 (green time extension) a relative increase of 30% is applied on the selected intersections. It is expected that this scenario is the most feasible and shows predominantly positive effects, based on previous research. The second scenario (cut off + green time extension) is also represented by a scenario, since it could be interesting to see what the effects are on the network if a more extreme variant is applied. Because this scenario showed a relative increase between the 30% and 55%, it is chosen to double the relative green time extension to 60%.

It is important to mention that the green time is extended for all traffic on the route. Since no distinction between the different modalities is made, it is not possible to say if this measure attracts one specific target group as desired when applying target group prioritisation. However, since the degree of prioritisation is based on prioritising one target group it is likely that an increase of vehicles in this study on the prioritised route, will also show an increase in a case when modalities are separated.

To summarize, the two scenarios that will be tested are:

1. Target group prioritisation with +30% green time for the prioritised corridor (30% prioritisation scenario).
2. Target group prioritisation with +60% green time for the prioritised corridor (60% prioritisation scenario).

As mentioned before, the application of equation 3.1 for the translation of lost time to a change in green time is in fact not completely right. Because the impact of prioritising is simplified, in which an average relative increase of green times is used and the green times of the other directions remain the same, the impact on the green times is probably underestimated. However, it is expected that the used scenarios of 30% and 60% of green time extension result in a green time extension that is of a realistic order of magnitude. Therefore, it will give a valid indication on the effect of target group prioritisation on a network.

3.2 Model Assessment

The aim of this research is to assess the effects of target group prioritisation on a network level. Therefore, key performance indicators (KPI's) that can assess the effects on this scale should be determined. Previous research mainly focused on the effect of target group prioritisation on intersection level, using for example lost time as KPI. However, for an analysis on network scale other KPI's are needed and are associated with policy objectives regarding target group prioritisation.

Policy makers probably want to know if prioritising a route results in the desired effect and if it not causes undesirable side effects. So, on the one hand a KPI should indicate whether or not travel time benefit is achieved. On the other hand, it is also important to know to what extent this measure influences the traffic distribution, so if the prioritised route is more attractive or not. Given this, two KPI's are chosen to analyse the effects on trajectory level: travel time and vehicle kilometres.

The first KPI for this analysis is the travel time. In section 2.1 is described that for this study, a route in the region of Voorne-Putten will be prioritised by extending green times. By taking an origin and destination the travel time between those two points can be measured for both the reference scenario and the scenarios with target group prioritisation. This KPI can be used to evaluate if the target group travelling via the route gains benefit from the implemented measure, or that side effects play a role and result in extra travel time. Also, the travel time can indicate what the effect of target group prioritisation is on non-prioritised routes. The travel time is calculated by summing up the link travel time and the turn delays of the intersections on a route. The turn delays are calculated with the junction model XStream, as discussed in section 2.2.1. The travel time can be calculated with the mean speed that is calculated by the propagation model MaDAM and length of each link.

Summing up for each link it results in the following equation:

$$\text{traveltime(t)} = \sum_{m=1}^{m} \frac{l_m}{v_m(t)} + t_{turn} \tag{3.2}$$

where l_m is the length of link m in kilometres, $v_m(t)$ is the calculated speed of link m for time step t in km/h and t_{turn} are the turn delays on the route.

The second KPI for this assessment framework is the number of vehicle kilometres (NL: voertuigkilometers), which are the number of kilometres travelled by the number of vehicles on a stretch of road within a time period. For example, if on a road section of 5 kilometres, 500 vehicles travel within an hour, the number of vehicle kilometres travelled is equal to 2500 vehicle kilometres. This KPI can indicate if the prioritised route also attracts extra traffic, or that traffic is repelled to other roads in the network that therefore face a traffic increase. So, it is assumed that this indicator implies a decrease or increase in traffic. For each link, the model determines the traffic intensity (or load) in vehicles per hour. However, this value is calculated every 5 minutes during the morning peak period. To calculate the vehicle kilometres for the prioritised route, the intensity was converted to values in vehicles per 5 minutes. For a link adjacent to an intersection, the total intensity of all directions is given. Summing up the values for each link, it results in the following equation:

$$\text{voertuigkm(t)} = \sum_{m=1}^{m} \frac{q_m(t)}{12} \cdot l_m \tag{3.3}$$

where $q_m(t)$ is the traffic intensity of link m at time step t in vehicles/hour and l_m is the length of link m in kilometres.

The number of vehicle kilometres is a good KPI to indicate the amount of traffic on a road. However, this indicator may give a distorted picture when congestion pattern changes and small time steps are used in the analysis. For example, when congestion occurs, the number of vehicle kilometres on a road section during a short time step can be low, since a smaller number of vehicles drive over the same length of road. Despite the high number of vehicles in this case, the number of vehicle kilometers decreases. Therefore, it should be taken into account that this phenomenon could occur when analysing the results.

To assess the effect of target group prioritisation on network level with the selected KPI's, three analyses are conducted. First, the total route for which target group prioritisation is assessed to see if this measure results in the desired beneficial effects for the prioritised vehicles. In addition, the route is split up in four parts to analyse the effects for each part separately. As described in section 2.1, the current traffic conditions in the morning peak result at congestion at some points. To see if this measure resolves the bottlenecks or that additional bottlenecks occur, an analysis on route parts is needed. Lastly, this research is also interested in the effects of target group prioritisation on non-prioritised traffic. Therefore, two non-prioritised routes are analysed to assess the expected detrimental effects for side streets.

The next section will describe the different analyses in more detail. For the interpretation of the results, it should be kept in mind that the results show the effect of target group prioritisation on all traffic of one direction, in case one target group is prioritised. Therefore, this study cannot present results of the KPI's for the prioritised and non-prioritised target groups separately.

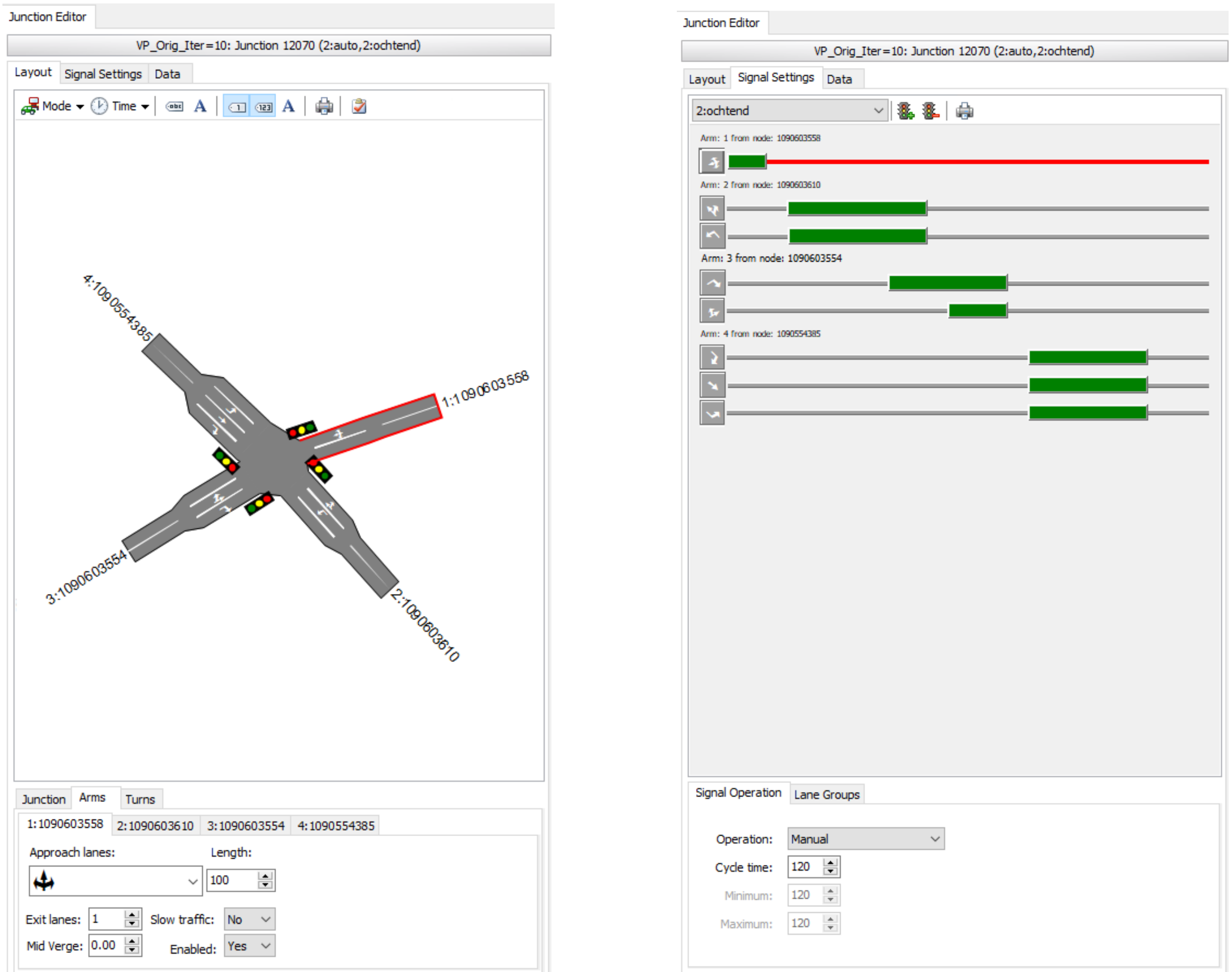
3.3 Model Analysis

To assess target group prioritisation on the selected KPI's, three analyses are conducted that together provide insight in the effects of this measure on the network. Before elaborating on these analyses, first the configuration of the two prioritisation scenarios in the model will be explained.

As described in section 2.1, target group prioritisation is applied on a route of approximately 11 kilometres. The route consists of 7 TLC-controlled intersections. For both prioritisation scenarios, the green time in the through direction and the cycle time of each signalised junction is adapted. The adaptation of the signal settings is done by using the junction editor tool in OmniTRANS. This tool can be used to view and adapt the intersection characteristics. It shows the lay-out of the intersection and which junction type is applied (Figure 3.2a). Besides, for each arm of the junction the lane characteristics are defined, that includes the number of lanes and the lane direction. For signalised junctions, a signal scheme can be defined which indicates the green times for each turn and the cycle time of the TLC installation (Figure 3.2b). This can be done manually, but can also be set on automated or actuated as described in Appendix C.1. It is possible to apply different signal settings for different time periods.

For this research, the signal settings of the TLC's are set manually, by using the signal settings as implemented in the original model. This means that for the whole morning peak the signal settings are fixed (NL: starre regeling). Next, the junction editor tool is used to adapt the green time distribution. Two separate variants of the model next to the reference variant are created for which the green time of the through direction on the prioritised route is adapted: one variant with a green time extension of 30% and one variant with a green time extension of 60%.

For example, the green time of the through direction and cycle time of the intersection with the N494 are respectively 30 and 120 seconds. For the 30% prioritisation scenario the green time is extended with 30% which results in a new green time of 39 seconds. As mentioned in section 3.1.3, the cycle time increases with the calculated green time extension which results in a cycle time of 129 seconds for this intersection. The green times of the other lane groups remain unchanged. The exact signal settings of each TLC considered for both the reference scenario, as for the prioritisation scenarios can be found in Appendix D.



(a) Junction lay-out

(b) Signal settings

Figure 3.2: Junction editor in OmniTRANS

For all three scenarios, the traffic flows of the network are simulated for the morning peak period, which is a period of 2 hours between 07.00h and 09.00h. For every time step of 5 minutes, the model saves the traffic data in a PMTURI route database. The data is stored for each Purpose (P), Mode (M), Time (T), User (U), Result (R) and Iteration (I), that is defined in the model. The route choice moment of the model is set on every 15 minutes, which means that every 15 minutes the route choice for the new generated trips is reconsidered based on the traffic conditions in the network of that time step. As mentioned before, the model is used for previous accessibility studies conducted by Goudappel and was therefore iterated 5 times. For this study, 10 iterations were conducted to have a more reliable result. Although the model is better converged after 10 iterations (instead of 5 iterations), there is reason to believe that the equilibrium (DUE) is not yet reached. Since running one variant of the model takes approximately 28 hours, it is chosen to set the limit on a maximum of 10 iterations.

With the generated data of each scenario, the following analyses are conducted to assess target group prioritisation on the set KPI's.

3.3.1 Route Analysis

The first analysis considers the whole prioritised route as indicated in section 2.1. It provides insight in the effects of target group prioritisation on the travel time and number of vehicle kilometres for all traffic on this route. For both KPI's, the results of the different scenarios are compared with each other.

3.3.2 Route Part Analysis

The second analysis focuses on specific parts of the prioritised route. Figure 3.3 shows the division of the prioritised route in four parts. Part 1 covers the two intersections at the N57, part 2 covers the intersection with the N494, part 3 covers the next two junctions of the N218 and part 4 the remaining 2 junctions on the route. Analysing the route in parts, gives the opportunity to see if the effect resulted from the complete route analysis occurs at each route part, and if not possible causes that result in a different effect can be identified.

3.3.3 Non-Prioritised Route Analysis

It is assumed that target group prioritisation will affect the traffic flow at the streets that are not prioritised. Therefore, the effect of target group prioritisation on the travel time and number of vehicle kilometres is analysed for two small routes that are not prioritised. Both routes are indicated in Figure 3.3. Route 1 is approximately 600 meters and travels from the N494 to the prioritised route. Route 2 is approximately 900 meters and goes from the Hartelweg to the prioritised N218. Both routes are chosen, since a reasonable number of vehicles travel via these routes which makes the results more reliable, in contrast to a route that is used by only a small number of vehicles. It is therefore assumed that this analysis will provide an rough indication for the effect of target group prioritisation on non-prioritised traffic.

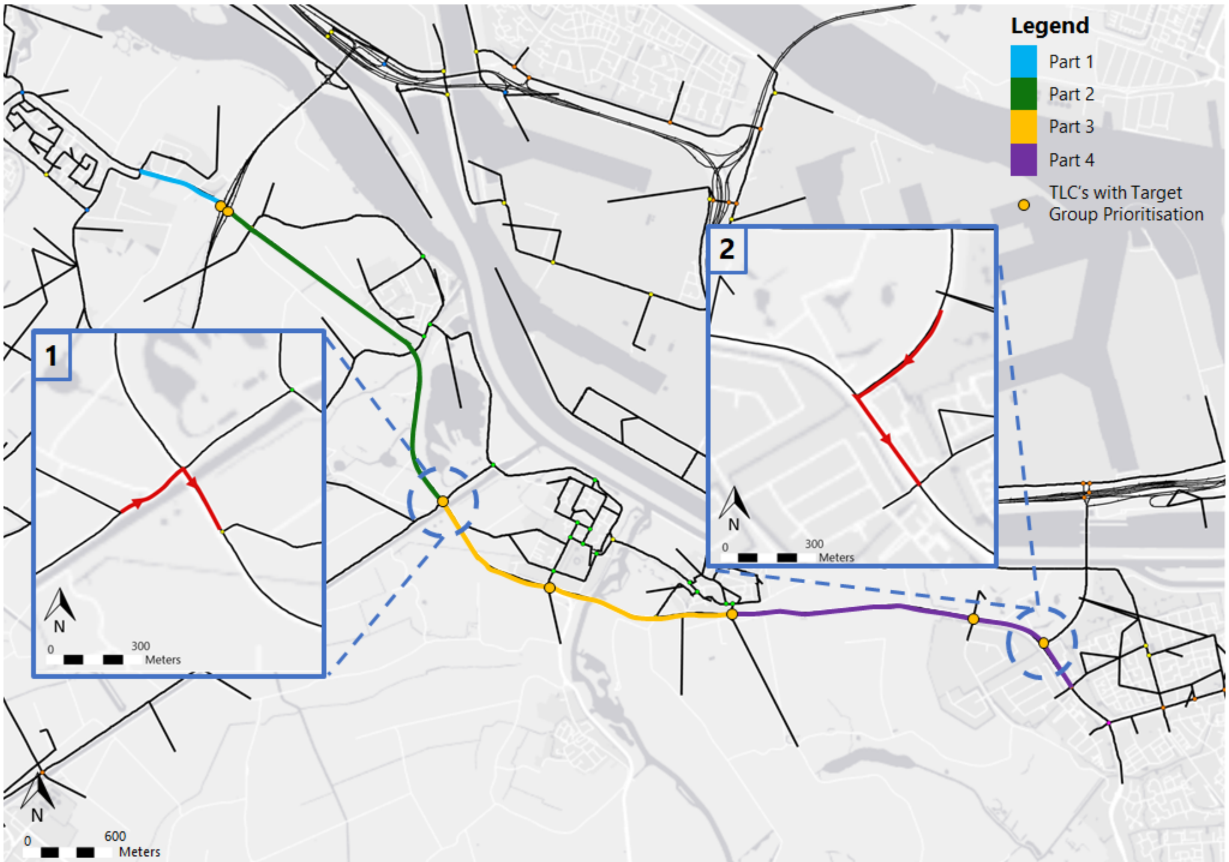


Figure 3.3: Prioritised route in parts and non-prioritised routes

3.3.4 Model Analysis: Overview

An overview the complete model analysis for this research can be found in Table 3.6.

Table 3.6: Overview of the model analysis

Analysis	Scenarios
Route Analysis	Reference
	30% Prioritisation
	60% Prioritisation
Route Part Analysis	Reference
	30% Prioritisation
	60% Prioritisation
Non-Prioritised Route Analysis	Reference
	30% Prioritisation
	60% Prioritisation

Chapter 4

Results

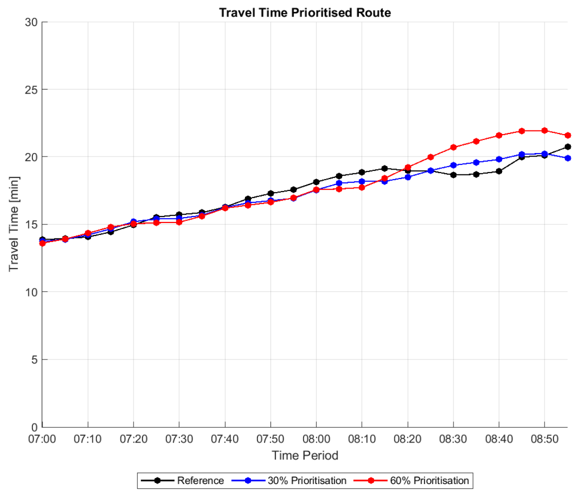
This section discusses the results of the model analysis by assessing the effects of target group prioritisation on the selected KPI's travel time and number of vehicle kilometres. For the interpretation of the results, it is important to keep in mind that all traffic on the selected route is prioritised. Therefore, the KPI's only indicate what the effect is of prioritising one target group on all traffic. Despite the fact that the model saves data for car and freight traffic separately, the results presented are only based on the data for car traffic. Since both modalities experience the same traffic conditions, the results for both modalities are almost the same. Because the network consists of more car traffic than freight traffic, these results are expected to be the most reliable and therefore chosen to assess the effects of target group prioritisation. The results of the three analyses discussed in section 3.3 are presented over the time for the morning peak, which is the period between 07.00h and 09.00h.

4.1 Route Analysis

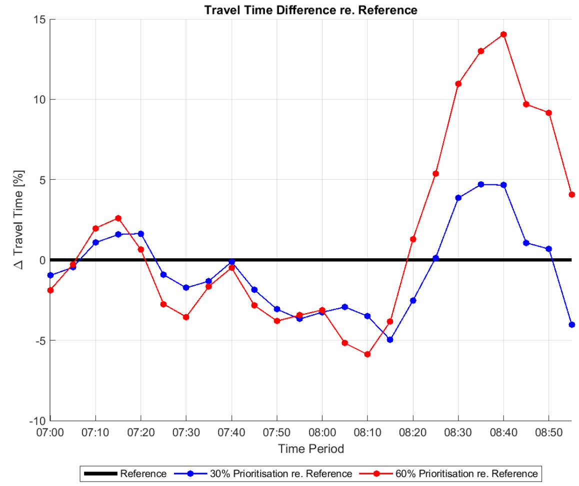
For the route analysis, the effect of target group prioritisation is assessed over the whole prioritised route on the chosen KPI's. The expectation of applying target group prioritisation on a route is that the travel time will decrease and/or the number of vehicles taking this route will increase, since the route becomes more attractive. The results of this analysis can confirm or contradict this expectation.

The travel time and the number of vehicle kilometres of the prioritised route for the three scenarios is shown are shown in Figure 4.1 and Figure 4.2 respectively. Besides, the relative differences [%] of the prioritisation scenarios relative to the reference scenario are also visualised.

The results of the reference scenario (black line) are first discussed, to understand the traffic conditions of the prioritised route without application of target group prioritisation. Figure 4.1a shows that the travel time increases as the morning peak proceeds. This is partly caused by an increasing traffic demand on the complete road network as the morning peak proceeds. This increase is also visible in Figure 4.2a, where the number of vehicle kilometres is shown.

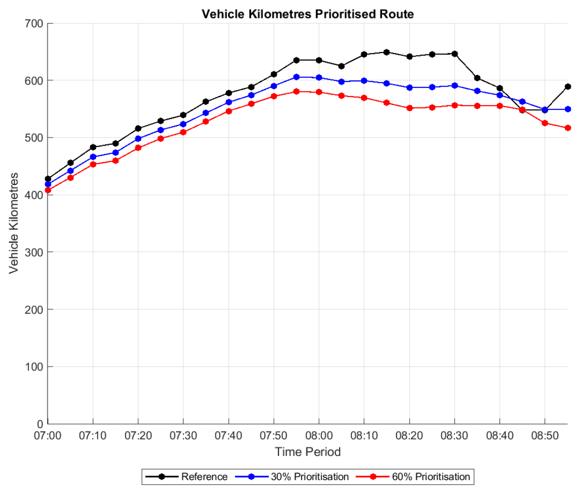


(a) Travel time [min]

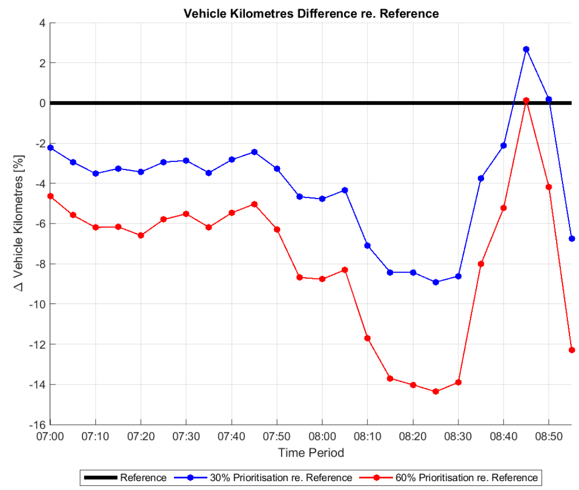


(b) Relative difference travel time [%]

Figure 4.1: Travel time prioritised route for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation



(a) Vehicle kilometres



(b) Relative difference vehicle kilometres [%]

Figure 4.2: Vehicle kilometres prioritised route for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation

However, from 08.15h till the end of the morning peak the traffic demand on the network decreases. This pattern is visible in Figure 4.2a, but the travel time of the reference scenario increases for the last 15 minutes after a small reduction. Figure 4.3 shows that at 08.45h not all queues on the prioritised route are resolved, which therefore results in a travel time increase because of congestion.

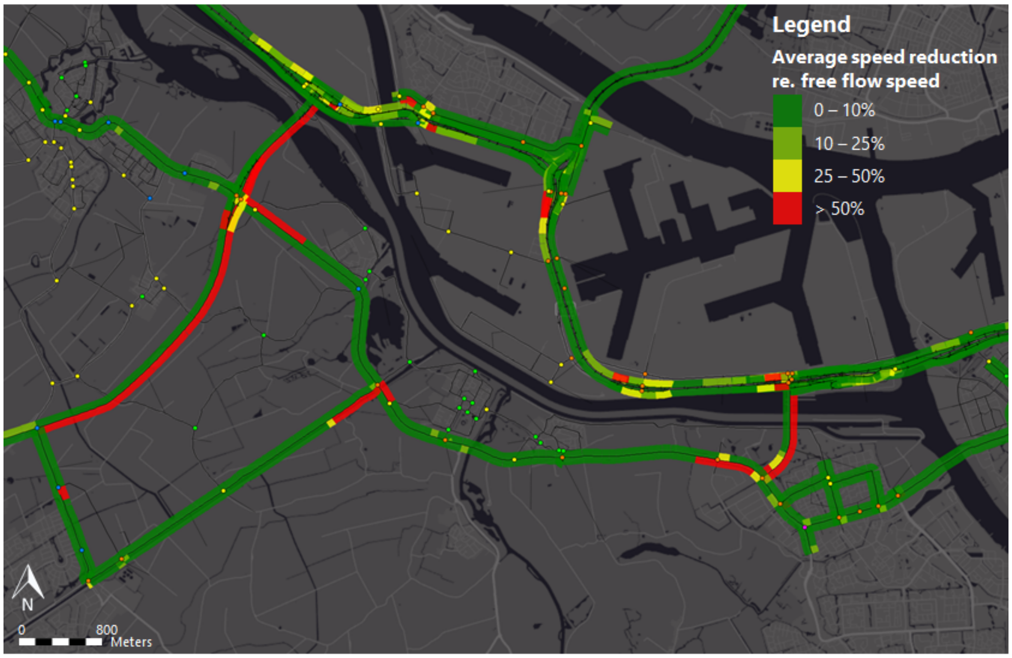


Figure 4.3: Average speed reduction re. free flow speed at 08.45h in the reference scenario

Both prioritisation scenarios (blue and red line) show more or less the same pattern on the travel time and number of vehicle kilometres. Remarkably, both travel time and vehicle kilometres show a different effect than expected. It can be seen that prioritisation does not result in a decrease in travel time during the entire morning peak, and besides the number of vehicle kilometres decreases. The latter effect indicates that target group prioritisation does not attract extra vehicles, but even repel vehicles on the whole route during the morning peak. This implies that for multiple OD-pairs in the network, an alternative route is more attractive in the case target group prioritisation is applied on the selected route.

The cause of this phenomenon are probably the turn delays of the different directions. For the prioritised direction, the turn delay decreases since green time is extended. However, since the cycle time of the junction increases and the green time of the other directions remains the same as in the reference situation, the turn delays of the non-prioritised directions increase. An increase in turn delay directly results in travel time increase for routes that travel via the prioritised route partly and enter/exit the route via a non-prioritised turn at one of the TLC-controlled junctions. A secondary effect that could occur is that this also results in queues, which increases the travel time even more. This can cause a shift in the traffic distribution, since an competitive alternative route is for multiple OD-pairs now more attractive. It can be seen that the difference in number of vehicle kilometres increases when the traffic demand on the network is at its maximum, which indicates that for the first hour only the effect of the extra turn delay is visible and later secondary effects decreases the number of vehicles on the prioritised route.

However, it should be mentioned that a decrease in vehicle kilometres does not necessarily imply that there is actually a decrease of vehicles on the prioritised route. The intensity of all directions on a link at an intersection is summed, so it could also be that the decrease seen is mainly due to a decrease in turning traffic. Nevertheless, since we do see a decrease over the whole trajectory, it is plausible that target group prioritisation causes less traffic to use the selected route.

Regarding the travel time, it can be seen that target group prioritisation results in a travel time decrease for the first hour of the morning peak. However, the opposite effect can also be seen during the last half an hour, namely a clear travel time increase. It is known that this cannot be caused by an increase in traffic on the route, since the number of vehicle kilometres decreases when target group prioritisation is applied relative to the reference situation. The cause of this phenomenon is probably the same as for the reduction in vehicle kilometres, namely the increase in turn delay for the non-prioritised directions. As described in section 2.2, the turn delay increases since the capacity of the non-prioritised directions decreases. This can result in a blocking back effect, which makes that traffic driving on the prioritised route are blocked by vehicles that want to exit the route via a non-prioritised direction. The difference between the 30% and the 60% prioritisation variant might imply that the latter variant causes blocking back at more junctions, compared to the 30% prioritisation variant.

4.1.1 Conclusion Route Analysis

The results of the route analysis contradict the expectations on the effects of target group prioritisation on the prioritised route. It can be seen that the travel time for the prioritisation scenarios relative to the reference scenario does not show a reduction during the whole morning peak. However, separating the results of roughly the first and second hour of the morning peak, applying target group prioritisation shows a reduction in travel time for the first hour. Besides, for the 30% prioritisation scenario the travel time benefit gained during the first part of the morning peak does outweigh the increase in the end. Assuming that over the whole day, most of the time the traffic intensities are equal or lower than the first hour of the morning peak, it results in predominantly travel time benefit. Next to the travel time decrease, it was also expected that applying target group prioritisation would increase the number of vehicles travelling via the prioritised route. However, during the whole morning peak the opposite effect can be seen for both prioritisation scenarios.

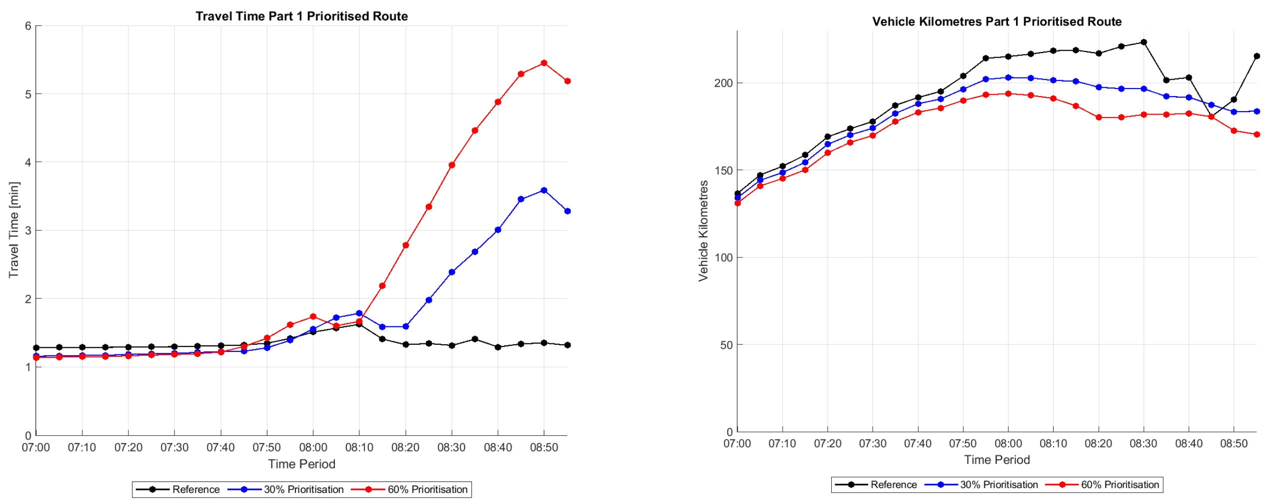
To see whether the effects shown in the route analysis apply for the whole prioritised route, or that different effects can be seen on specific parts of the route, the route part analysis is conducted. The results of this analysis will be discussed in the next section.

4.2 Route Part Analysis

For the route part analysis, the prioritised route is subdivided into four parts, as shown in Figure 3.3 of section 3.3.2. It is likely that the effects of target group prioritisation on the whole prioritised route can be traced back to a certain part of the route. Therefore, it is expected that some parts of the route will show the desired effect, namely a travel time reduction and/or an increase in vehicle kilometers when target group prioritisation is applied. Each part will be discussed separately.

4.2.1 Part 1

Figure 4.4 shows the effects of target group prioritisation on the travel time and number of vehicle kilometres for part 1 of the prioritised route. It can be seen that the number of vehicle kilometres shows more or less the same pattern as for the whole prioritised route. The increase in turn delay on the directions that exit and enter the N57, result in a decrease of vehicles that travel via this route segment.



(a) Travel time [min]

(b) Vehicle kilometers

Figure 4.4: KPI's for part 1 of the prioritised route for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation

The travel time of both prioritisation scenarios relative to the reference situation shows a more interesting pattern. For the first part of the morning peak, a decrease in travel time for the prioritisation scenarios relative to the reference situation can be seen. The reduction is in the same order of magnitude as the green time extension at the intersections, which is the primary effect of target group prioritisation. The second part of the morning peak shows a completely different pattern, namely a large increase in travel time for both prioritisation scenarios. The increase in travel time starts from the moment the peak in traffic demand on the whole road network is reached (08.00h/08.15h). From this moment in time, a blocking back reaction seems to occur on this part. This reaction can be illustrated with Figure 4.5.

The dominant traffic flow, arriving at the junction, turns left or right when arriving (blue and yellow lanes), instead of driving straight via the prioritised direction (green lane). When the number of vehicles is more than the blue and or yellow lanes can store, vehicles for these directions have to wait in the red part which blocks vehicles that want to continue driving on the prioritised (green) lane.

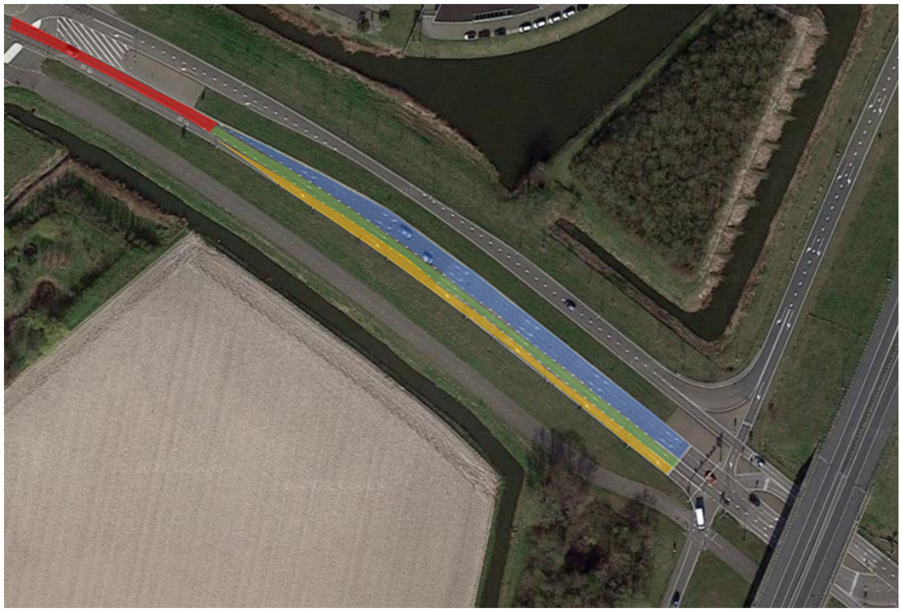
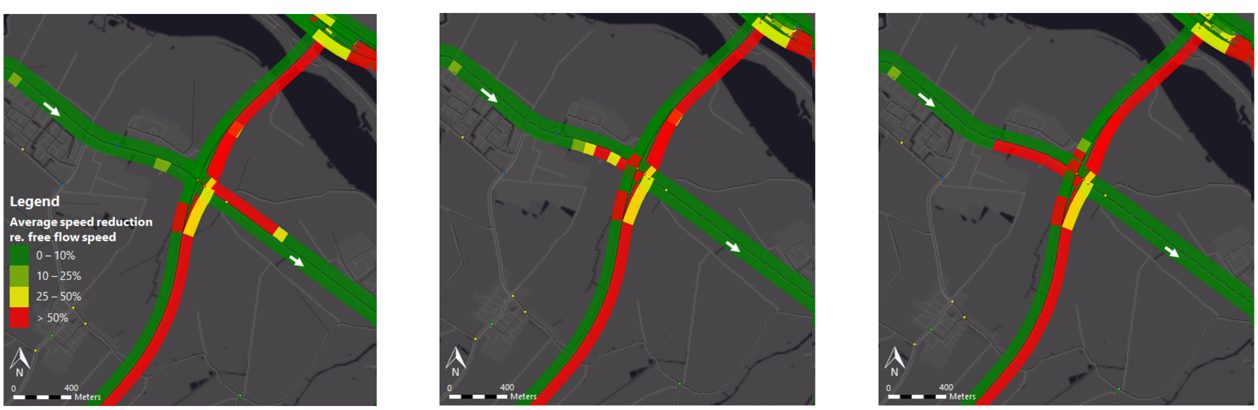


Figure 4.5: Satellite view of the intersection with the N218 and the N57

This assumption is confirmed when looking at the average speed relative to the free-flow speed for all three scenarios in Figure 4.6. It can be seen that for both prioritisation scenarios at time 08.30h, the average speed is half of the free-flow speed which implies congestion. The prioritised direction is indicated with the white arrows.



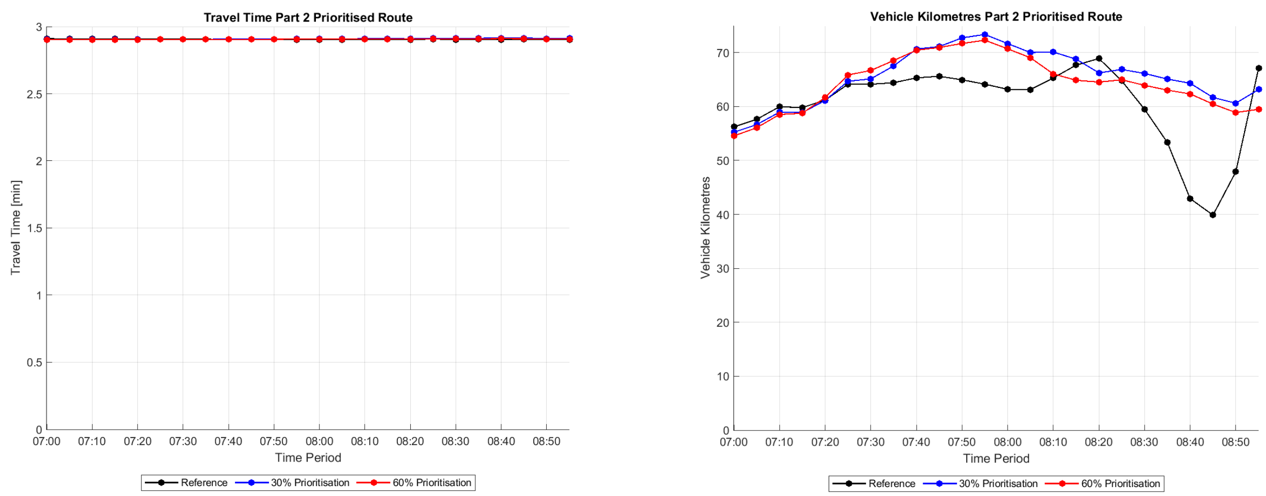
(a) Reference scenario (b) 30% prioritisation scenario (c) 60% prioritisation scenario

Figure 4.6: Average speed reduction re. free flow speed at 08.30h for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation

4.2.2 Part 2

Figure 4.7 shows the effects of target group prioritisation on the travel time and number of vehicle kilometres for part 2 of the prioritised route. Only a small reduction in travel time compared to the reference situation as can be seen in the figure. This indicates that target group prioritisation works as expected on this TLC-controlled intersection and has apparently no secondary effects on the traffic flow for this part.

Apparently, this attracts extra vehicles on this part since target group prioritisation results on average in more number of vehicle kilometres on this part compared to the reference situation. This indicates that there are OD-pairs in the network that now send a larger proportion of traffic over this part of the prioritised route instead of another route alternative. It is plausible that traffic that used to travel via the N494, now travels via the N57 and the prioritised N218.



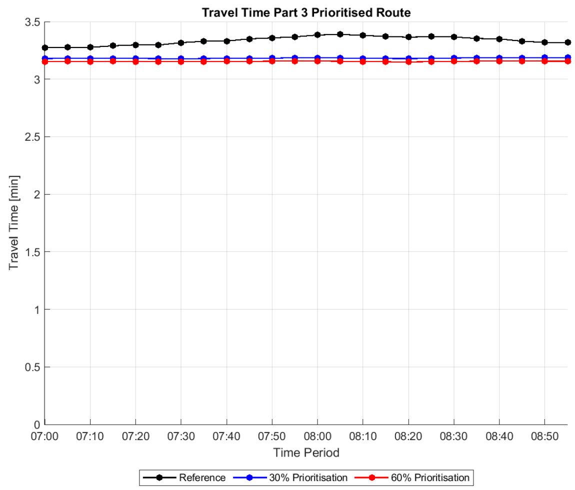
(a) Travel time [min]

(b) Vehicle kilometers

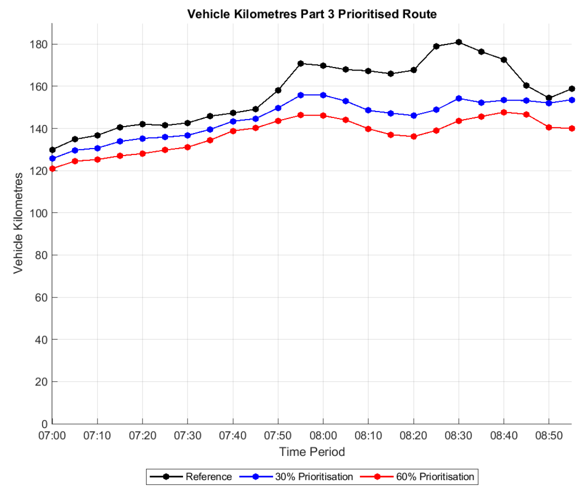
Figure 4.7: KPI's for part 2 of the prioritised route for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation

4.2.3 Part 3

Figure 4.8 shows the effects of target group prioritisation on the travel time and number of vehicle kilometres for part 3 of the prioritised route. It can be seen that the number of vehicle kilometres shows more or less the same pattern as for the whole prioritised route. The increase in turn delay on the directions that exit and enter the prioritised route, result in a decrease of vehicles that travel via this route segment. The travel time shows a reduction when target group prioritisation is applied, which is the desired effect. The travel time benefit of both scenarios relative to the reference scenario is in the same order of magnitude as the green time extension applied on the two TLC-controlled intersections that are covered by this part.



(a) Travel time [min]



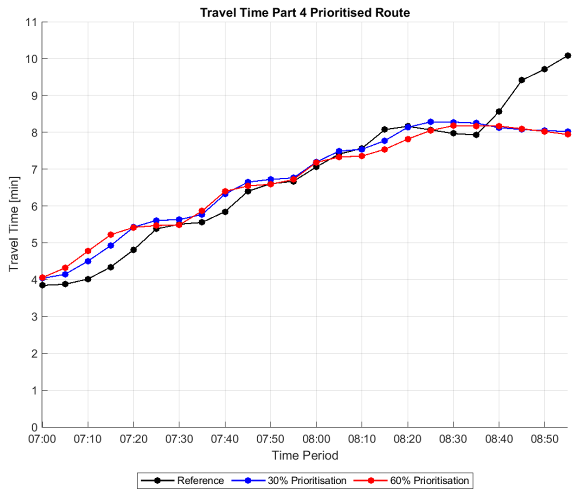
(b) Vehicle kilometers

Figure 4.8: KPI's for part 3 of the prioritised route for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation

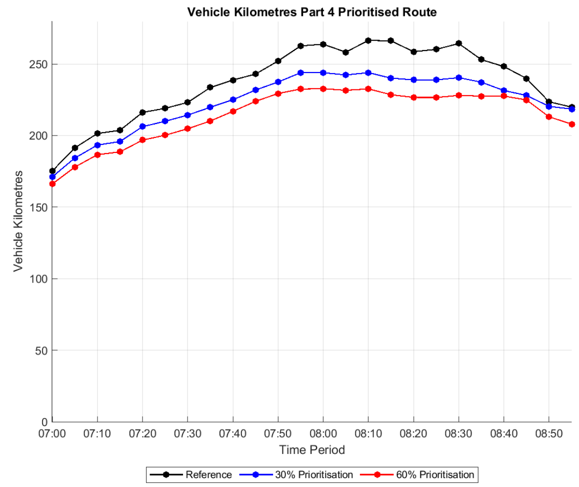
4.2.4 Part 4

Figure 4.9 shows the effects of target group prioritisation on the travel time and number of vehicle kilometres for part 4 of the prioritised route. Again, the number of vehicle kilometers show the same pattern as for the whole prioritised route. The increase in turn delay on the directions that enter or exit the prioritised route, result in a decrease of vehicles that travel via part 4 of the prioritised route.

The travel time of part 4 shows during a big part of the morning peak period a comparable travel time for both reference and prioritisation scenarios. The largest travel time benefit is gained at the end of the morning rush hour from 08.40h till 09.00h. Here, a travel time benefit of approximately 2 minutes is gained for both scenarios, which is significant. This travel time benefit cannot be the primary effect of green time extension, since the difference is not in the same order of magnitude as the extension. Therefore, it is assumed that this benefit is a secondary effect of the application of target group prioritisation. It is known that the traffic demand at the end of the morning peak reduces. Besides, the increase in travel time in the reference situation indicates a blocking back effect, which result in a queue. Assuming that a blocking back reaction does not occur in prioritisation scenarios, because a shift in traffic distribution caused a reduction in vehicles travelling via this part, a travel time difference of 2 minutes is plausible. However, it is likely that this leads to more congestion on the side streets of these intersections.



(a) Travel time [min]



(b) Vehicle kilometers

Figure 4.9: KPI's for part 4 of the prioritised route for reference scenario, scenario with 30% prioritisation and scenario with 60% prioritisation

4.2.5 Conclusion Route Part Analysis

The route part analysis shows that only a small part of the traffic travels via the whole prioritised route. The number of vehicle kilometers showed that for almost all parts, target group prioritisation reduced the amount of traffic on the route. This indicates that when the travel time for the prioritised scenarios increases relative to the reference scenario, this has to be a blocking back effect. At some junctions on the route the dominant traffic flow does not take the prioritised route. Since the green time of the other directions is decreased, it reduces the capacity of the other lane groups. Therefore, queues occur and blocking back makes that travel time on the prioritised route increases. Besides, the increased turn delay possibly also makes other competitive routes more attractive when travel time of travelling via the prioritised route increases by entering/exiting the route.

4.3 Non-Prioritised Route Analysis

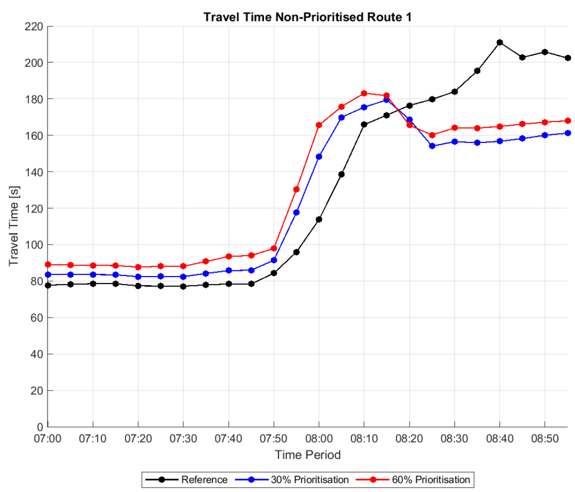
For the last model analysis, the KPI's are measured for two routes that are not prioritised. This analysis will give an indication of the effect of target group prioritisation on side streets.

Both routes cross an intersection that has to cope with a lot of traffic in one of the directions in the reference situation. Figure 4.3 in section 4.1 shows that at time 08.45h congestion occurs at non-prioritised route 1. It is expected that both prioritisation scenarios will worsen this effect. Besides, the junction that is included in route 2 shows congestion on the N218, which is the prioritised route. As mentioned in section 4.2 it is expected that, as a result of target group prioritisation, congestion occurs on the side streets. Therefore, it is expected target group prioritisation results also in an increase in travel time and/or a decrease in vehicle kilometres for route 2.

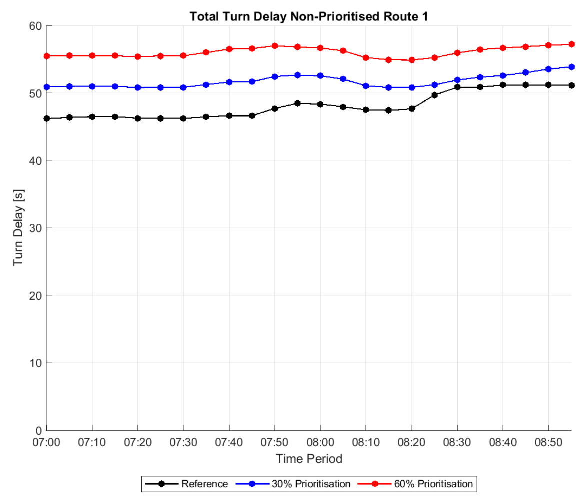
The results will be discussed for both routes separately. Since only small routes are analysed, the travel time is indicated in seconds. Next to the travel times and the number of vehicle kilometres, also the total turn delay on the route is shown. This indicates what the effect of a change in turn delay by prioritisation is on the travel time of a route.

4.3.1 Route 1

Figure 4.10 shows the travel time and total turn delay for the three scenarios and in figure 4.11 the number of vehicle kilometres for this route is visualised. The congestion on route 1 that was visible in Figure 4.3, can also be seen in the results of the travel time for the reference scenario. Besides, the number of vehicle kilometres of the reference scenario show an increase of traffic as the morning peak proceeds. Therefore, congestion and possibly also blocking back for this turn occurs on the route in the reference situation.



(a) Travel time [s]



(b) Total turn delay [s]

Figure 4.10: Travel time and total turn delay of non-prioritised route 1 for reference scenario, 30% prioritisation scenario and the 60% prioritisation scenario

Both prioritisation scenarios show a different effect than expected in the second hour of the morning peak. It can be seen that for the first hour the travel are increase by the primary effect of target group prioritisation, namely an increased turn delay. This increase in turn delay for this direction is also visualised in Figure 4.10b. At the start of the second hour, the travel times of the prioritisation scenarios increase, just as in the reference situation since the number of vehicle kilometres increase at this moment in time.

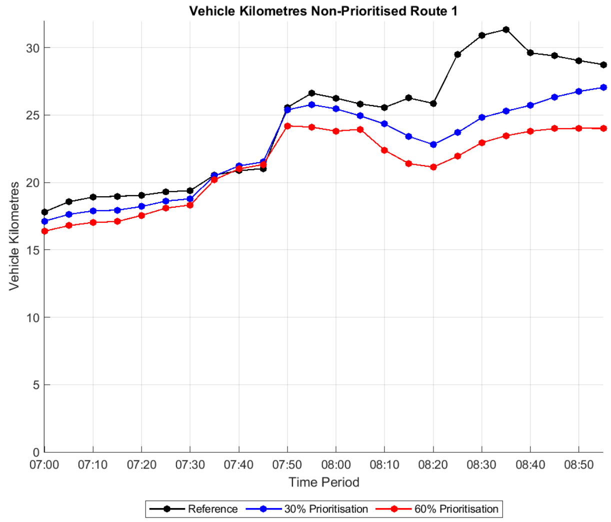


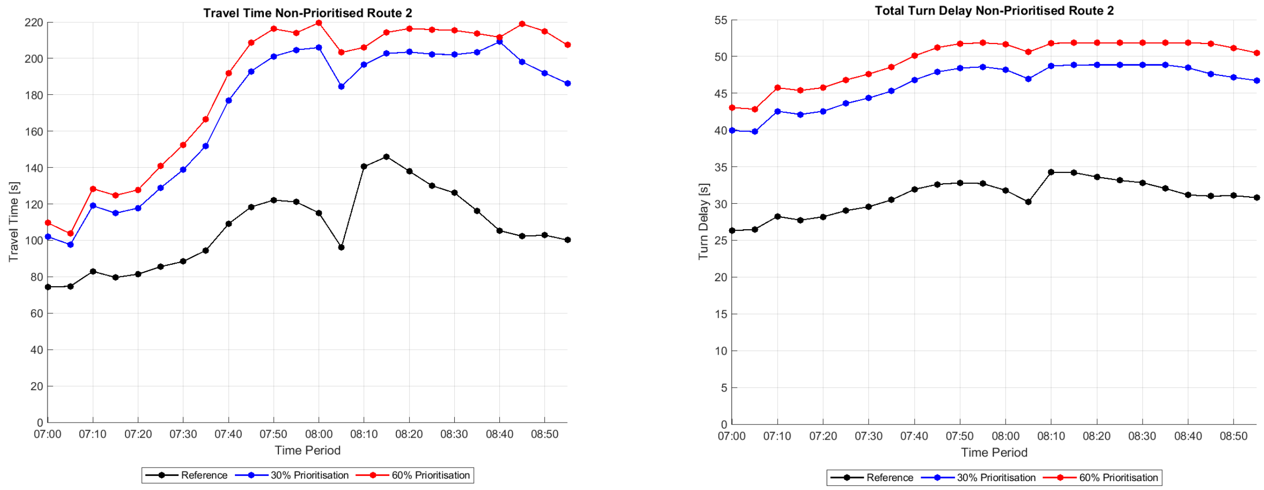
Figure 4.11: Vehicle kilometres of non-prioritised route 1 for reference scenario, 30% prioritisation scenario and the 60% prioritisation scenario

From 08.15h till the end of the morning peak period the difference between the prioritisation scenarios and the reference scenario increases and applying prioritisation reduces the travel time relative to the reference situation. Despite the increase in turn delay as a result of target group prioritisation on a different direction, both the travel time and number of vehicle kilometres decreases. It is assumed that this effect represents a "turning point" in the route choice of multiple OD-pairs. As a result of the high travel times, other competitive alternative routes become more attractive and therefore the number of vehicles on this route decreases. Since the overall traffic intensities in the network also reduce from this time step till the end, the increase in vehicle kilometres as a result of vehicles that again start to use this route does not result in congestion.

4.3.2 Route 2

Figure 4.12 shows the travel time and total turn delay for the three scenarios and in figure 4.13 the number of vehicle kilometres for this route is visualised. This route shows a pattern that is more in line with the expectations for a non-prioritised route. It is assumed that in comparison with route 1, the junction in the route is less saturated in the reference situation, since no big travel time increase as in route 1 is seen. Besides, the number of vehicle kilometres shows a pattern that is in line with the total traffic demand in the network over time.

An interesting phenomenon that is clearly visible for this route is how the change in turn delay when prioritisation is applied, influences the total travel time on the route. Looking at the change of turn delay for the 30% prioritisation scenario, an average increase of 15 seconds can be measured which in the end results in an travel time increase of more than 1 minute. Also for the 60% prioritisation scenario an increase with approximately a factor 4.3 is measured, which is significant. This shows that applying target group prioritisation on this junction result also in secondary effects, namely queue forming.



(a) Travel time [s] (b) Total turn delay [s]

Figure 4.12: Travel time and total turn delay of non-prioritised route 2 for reference scenario, 30% prioritisation scenario and the 60% prioritisation scenario

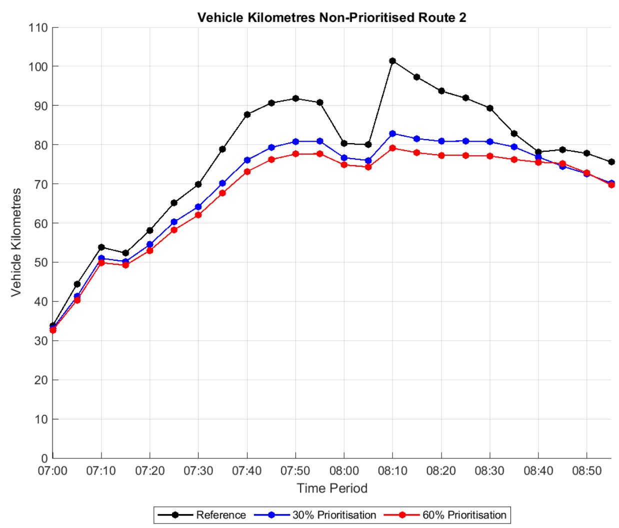


Figure 4.13: Vehicle kilometres of non-prioritised route 2 for reference scenario, 30% prioritisation scenario and the 60% prioritisation scenario

4.3.3 Conclusion Non-Prioritised Route Analysis

The analysis of the non-prioritised routes show that target group prioritisation can have varying effects on the side streets that are not prioritised. In general, the increase in turn delays for the prioritisation scenarios relative to the reference scenario results in an even higher increase in the travel time, which is caused by queues before the intersection. However, route 1 shows that when demand reaches a certain point, it can change the route choice of multiple OD-pairs which in the end results in a positive effect on the travel time for the side street. Apparently, increasing the turn delay for a non-prioritised direction has a positive effect on the traffic flow, which in this case can for example be beneficial to destination traffic, assuming that through traffic takes a different route.

4.4 Impact Assessment

Applying target group prioritisation on a network will have societal impact on the network, not only for the prioritised target group, but also for the non-prioritised modalities. For our study, it was decided to take freight traffic as prioritised target group, since previous studies indicate that this can be a justifiable policy choice. This section will focus on the impact of prioritising freight traffic and based on the results from this study, get insight in what is important for taking such a policy decision.

The main objective for prioritising freight traffic based on previous studies from DTV Consultants (2019) and Arane Adviseurs (2004) is that it can gain economic benefits. On the one hand, a reduction in travel time for freight traffic over a year can save a lot of costs (see for an example of the cost calculation the study of Arane Adviseurs (2004)), and on the other hand, as a region you are more attractive for industry to establish itself there.

The desired effect of target group prioritisation is a reduction in travel time. For most parts of the analysed route, the study showed this reduction for the first hour of the morning peak. It is therefore assumed that most of time on a day, the measure works as intended and therefore result in travel time benefit. Nevertheless, it is important that a major adverse effect of target group prioritisation for both prioritised and non-prioritised traffic is excluded, as in the second hour of our simulation period. In addition, the decrease in travel time for the prioritised route does not directly makes the route also more attractive. In fact, the opposite effect was seen in this analysis.

The main cause for the reduction in traffic on the prioritised route is the increase in turn delay for all non-prioritised directions, both on the prioritised route itself as on side streets. The increased turn delay for side streets results in a change in route choice, since competitive route alternatives that avoid the prioritised route are more attractive. In addition, the analysis showed that for junctions with a dominant traffic flow different than the prioritised direction can cause blocking back. Both effects could result in traffic travelling via routes that are not suitable to cope with extra traffic (rat-run traffic).

This indicates that, regardless of the number of intersections where this measure is applied, the network effect is extremely important to consider in order to avoid undesirable effects. This study showed that the measure can influence the route choice of traffic that you might not have taken into account in the first place. Therefore, a good analysis of the traffic flows within the network is important to avoid detrimental effects for both prioritised and non-prioritised traffic. In addition, it might be beneficial in some cases to prioritise certain additional directions to prevent blocking back.

Microscopic studies have indicated more advantages of prioritising freight traffic. It mentions that it reduces the number of stops at an intersections for this target group. Especially for this target group this can result in a positive effect, since the acceleration and deceleration of freight traffic takes more time in comparison to car traffic. Reducing the number of stops for freight traffic, will result in a higher proportion of vehicles that can cross the intersection within one green time period. In addition, the acceleration and deceleration of cause also more emission relative to car traffic, so also for sustainability purposes this policy choice could be made. Since our study focused on the macroscopic aspects of target group prioritisation, it is not possible if based on the results of this research these benefits are actually reached. However, based on this study, it can be concluded that these advantages are only reached when no congestion occurs as a result of prioritising traffic (blocking back).

In the end, this research indicates, just as previous, microscopic studies, that there is a limit on prioritising target groups. Changing the green time for a certain target group (or direction in this study) increases the capacity for one direction, but this goes hand in hand with a reduction for another direction. Depending on the traffic intensity on the particular direction, this may or may not cause traffic handling problems. It is therefore also difficult to prioritise multiple target groups, also since traffic flows of target groups might be different. In conclusion, as a policy maker, you cannot avoid the fact that certain target groups will experience negative effects. Therefore, it is important to check whether these effects are limited, so that a policy choice can be made on that basis.

Chapter 5

Discussion

The results of this research should be interpreted with some caution for a number of reasons. To start with macroscopic transport model used for this analysis. It should be mentioned that the model presents a prediction of the real-life traffic behaviour, so it cannot be a 100% reproduction of real-life traffic. Besides, the simulation has iterated 10 times, but still has not reached a Dynamic User Equilibrium (DUE). This means that the traffic distribution still varies when more iterations are done, and therefore also results could differ. Nevertheless, the model provides sufficient insight in the effects of prioritising traffic on road sections and it is assumed that further research can also improve the settings in the model to implement this measure.

Regarding the implementation of target group prioritisation in the macroscopic dynamic model two prioritisation scenarios are determined. These scenarios are based on an effect on the green time distribution for that study. Therefore, an assumption is made to translate the change in lost time that is measured to a change in green time. In contrast to our study, the measured lost times of the microscopic study is are average values of all normative conflict directions for which target group prioritisation is applied. For our research, it is decided to prioritise only one direction. It could therefore be possible that the actual change in green time needed is higher or lower.

Besides, the translation from lost time to green times is presumably an underestimation of the real green time extension to reach the reduction in lost time measured. Since a green time extension for one direction is accompanied by an increase in cycle time for the TLC, it will in turn cause a small increase in the lost time for that direction. To compensate for that, again more green time is needed. Therefore, it is assumed that the extra green time derived from the lost time are in fact an underestimation.

In addition, it is assumed that to a certain degree non-prioritised modalities will also profit from target group prioritisation in practice, but not in the generic way as assumed in this research. To be more specific, in our research the whole direction is prioritised independent of the actual demand of the specific target group being prioritised. As a result, this study provides insights in which certain directions are prioritised, but can not be seen as the specific impact of prioritisation of a target group. In practise, the effect of this measure will be dependent on the ratio of prioritised v.s. non-prioritised traffic. When only a small fraction of the vehicles is prioritised, the profit for non-prioritised traffic will also be smaller.

The model analysis shows that prioritising all traffic on one direction could have a big, detrimental impact on both the prioritised route and the side streets. In this study, prioritising only one direction results at oversaturated junctions (intensity $>$ capacity) in a blocking back effect, when turn delays on directions of the dominant traffic flow increase. To profit from target group prioritisation it is therefore important that traffic flows are analysed, both on the proposed prioritised direction as on the exiting/entering directions. The blocking back reaction could for example be prevented by increasing also the other directions on the prioritised link.

In addition, previous microscopic research (as discussed in section 3.1.2) shows that the effects of target group prioritisation are dependent on the traffic demand in the network. When a network is oversaturated (V/C ratio $>$ 0.9), which means that on multiple places in the network structural congestion could occur, it is known that the effects of target group prioritisation are often detrimental for both prioritised and non-prioritised traffic. On the other hand, in an situation with a very low V/C ratio (V/C ratio = 0.5) it could happen that the signal settings without target group prioritisation result overall in a better traffic handling. For this research, the effects of target group prioritisation are only measured for the current traffic demand of the network. However, changing the overall traffic demand of the network, could show different effects and provide more insight in sensibility of target group prioritisation when traffic conditions change. This might for example be interesting, so you can draw better expectations for other networks with a lower/higher demand or to predict effects when demand increases in the future.

Furthermore, it is assumed that the results of target group prioritisation on the non-prioritised side streets are more detrimental in this analysis compared to a case when one target group is prioritised on all directions. In this case, it is plausible that the increase in turn delay is smaller since the target group can also be present on the side streets.

Overall, this study shows that it is important to map all traffic flows of the different target groups in order to achieve a positive effect of target group prioritisation. Not only for freight traffic, but also for a situation in which you prioritise bicycle traffic, it is important that the degree of prioritisation is in proportion to the amount of traffic of your prioritised target group. If not, it can result in a negative effect. In addition, a change of the traffic distribution will only occur in case there are multiple competing routes. For example, a travel time benefit of 30 seconds when applying target group prioritisation on a total travel time of half an hour will not result in a change in route choice. This is for example important to keep in mind in case you want discourage a certain target group to take a certain route.

5.1 Correction Reference Scenario

For this analysis the number of vehicle kilometres is calculated with the traffic intensity of each link, which is for the adjacent link of a junction the summed intensities of all directions. It was proposed to do an additional analysis to look at the effect for target group prioritisation per direction, to see if traffic intensities on the prioritised direction actually decrease and to better indicate the route choice effects. However, analysing these data showed unexpected values that could not be explained, especially the values for the reference scenario. No mistake could be found at this point in time in the model, so therefore the reference scenario was run again. This resulted in different values, that were more in line with the expectations.

Since the most of the analysis of the results was already conducted, this was discovered too late to change the whole analysis. However, a quick review of the new results for the reference scenario showed that this error has only a relatively small effect on the overall pattern and conclusions we have drawn from the analysis as it is now. The following can be deduced from the new data of the reference scenario:

- In comparison with the reference scenario used in this research, the new results show more traffic on the prioritised directions. However, as a result of target group prioritisation, the amount of traffic will still decrease but probably more significant than showed in the analysis.
- Part 1 of the route showed a big increase in travel time when target group prioritisation was applied in comparison to the reference scenario. This effect is still visible when the new results of the reference scenario are used. Just as for the original results of the reference scenario, the turn delay of prioritised direction of the first intersection increases when target group prioritisation is applied. So, despite the green time extension for this direction, the turn delay still increases. This implies a blocking back reaction caused by queues occurring for the second intersection in part 1.
- The analysis for non-prioritised route 2 would probably show different results when the new reference scenario would be applied. It can be seen that target group prioritisation increases the traffic intensity, instead of a decrease. Besides, also the turn delay decreases relative to the reference scenario, which is arbitrary since this direction is not prioritised. A complete analysis on the KPI's would probably result in an explanation for this phenomenon.

Chapter 6

Recommendations

As a result of this study and the discussion of the previous section, some recommendations for future research can be made.

Firstly, the use of a macroscopic model makes it not possible to apply target group prioritisation for one target group on multiple directions. An microscopic dynamic model can model this, since the traffic behaviour of individual vehicles is simulated. An option might be to use a mesoscopic transport model for a future study that combines the possibility to distinguish traffic modalities, but can also model the effects for a network of this scale.

Secondly, for the implementation of target group prioritisation in a macroscopic dynamic model it would be interesting to do a microscopic study on beforehand, where directly the effects of target group prioritisation on the green time distribution are measured. This makes it possible to directly deviate the needed green time extension, instead of translating the lost times with some assumptions.

Thirdly, it would be interesting to see what the effect of target group prioritisation is on a prioritised route when the route fractions remain the same as in the reference situation. Originally, this was also part of this research, but because of some limitations in OmniTRANS it was not possible to model this. However, it could give a more 'clean' effect on target group prioritisation.

Fourthly, microscopic research indicates that the effect of target group prioritisation is sensitive for a change in traffic demand on an intersection. Based on the differences in effects for the first and second hour in our analysis, it is assumed that a change in traffic demand (less or more traffic) would also result in different network effects. Therefore, it would be interesting to assess the effects of target group prioritisation for two additional variants, one with a lower traffic demand and one with a higher traffic demand.

Finally, this research mainly focuses on the effects of target group prioritisation on specific parts of the network. For a complete network analysis it is also interesting to measure the effect on all main routes in the network, and also analyse more OD-pairs to get more insight in the shift in traffic distribution. To do so, it is likely that additional KPI's are needed.

Chapter 7

Conclusion

This research was conducted to answer the main research question:
What are the effects of target group prioritisation by Intelligent Traffic Light Control systems at network level for motorised traffic?

To answer this question, the research is subdivided into four sub-questions that will be answered first.

1. How can target group prioritisation at iTLC-controlled intersections be implemented in a transport model?

Using a macroscopic dynamic transport model, there are four possibilities to implement target group prioritisation. The turn attributes impedance, saturation flow and coordinated could be modified to change the turn characteristics calculated by the junction model, or the green time distribution could be adapted. It was assumed that changing the impedance or saturation flow results in overruling the effects of the interaction between demand and supply. Besides, coordinated would neglect the benefit non-prioritised groups would have from target group prioritisation, and it does not change capacity. Therefore, it was chosen to adapt the green time distribution to implement target group prioritisation by extending the green time for one direction, despite the limitation that all traffic on this route was prioritised instead of one target group. Two prioritisation scenarios were determined by translating the effect on lost times of a previous research to a change in green times: a scenario with 30% green time extension and a scenario with 60% green time extension. These scenarios are used to compare the effect of target group prioritisation with the reference scenario in the model analysis.

2. What are the performance criteria for assessing target group prioritisation at network level?

For this research, two key performance indicators were determined that could analyse the effects of target group prioritisation on a network level: travel time and number of vehicle kilometres. The travel time indicates whether or not travel time benefit is achieved on a certain route, and to see what the effect is for non-prioritised traffic. The number of vehicle kilometres indicates what the effect of target group prioritisation is on the traffic distribution, so if a route becomes more attractive or if traffic is repelled. To provide insight in the network effects of target group prioritisation, the KPI's are used in three analyses. First, the complete route is analysed to see if target group prioritisation results in the desired beneficial effects for prioritised vehicles. In addition, the route part analysis provide insight in possible bottlenecks that could occur. Lastly, the effect on non-prioritised traffic is assessed by analysing two non-prioritised routes.

3. What are the route choice effects of applying target in a network?
The analysis on the effects of target group prioritisation shows that it is not obvious that this measure result in a reduction of travel time or the attraction of more vehicles on the prioritised direction. It shows that under relatively normal traffic conditions, the primary effect of target group prioritisation is achieved regarding the travel time reduction. It can be seen that the extension of green time for multiple TLC-controlled intersections, can result in travel time benefit. However, when traffic intensities on the network increase, target group prioritisation causes secondary effects which results in bottlenecks on the network particularly at locations where in the reference situation also congestion occurred. On the selected route only the capacity of the prioritised direction has increased by extending the green time and the capacity of the turning directions decreased, since turn delays increased. At junctions where the dominant traffic flow takes a non-prioritised direction, a blocking back effect occurs which result in congestion on the prioritised route. An extreme example of this was seen in part 1 of the route, at the intersection with the N57.

In addition, the analysis shows that the increase in travel time for non-prioritised traffic results in a shift of the traffic distribution. Looking to the number of vehicle kilometres, target group prioritisation results in a decrease on the whole route relative to the reference situation. This indicates that for many OD-pairs in the network, for which one of the route alternatives drives partly over the prioritised route, the travel time benefit does not outweigh the increase in turn delay when entering/exiting the route. However, the analysis of non-prioritised route 1 shows that it can also result in an unexpected desired effect. The increase in turn delay for the non-prioritised direction, resulted in a increase of the total travel time which makes that for many OD-pairs a competitive alternative route is probably more attractive. Due to this route choice effect, it can be seen that the travel time decreases again. This effect could for example be beneficial in a case when you want to avoid through traffic to take a certain route, so the travel time for local traffic decreases.

4. What is the network performance of specific societal impacts when prioritising traffic?

The results of this study show that prioritising traffic has an impact on the road network for both prioritised and non-prioritised traffic. Some conclusions from previous studies and the results of this study can be combined to indicate what the societal impact is of target group prioritisation on the traffic network, and more specific what the impact is of prioritising freight traffic. Previous studies indicate that it prioritising freight traffic can result in cost saving and could also make a region more attractive. However, this study shows that this policy choice is only feasible under certain conditions. An increase in travel time for non-prioritised traffic could result in traffic distribution shift, with the potential for rat-run traffic in the area. In addition, when target group prioritisation causes detrimental effects (i.e. blocking back), the advantages mentioned in microscopic studies (reduction in stops and less emission) also not hold. Since both previous and this study indicate that there is a limit on prioritisation, policy makers can control the impact by basing the degree of prioritisation on the room available on the network for prioritising and, on that basis, selecting a target group that matches the interests in the area.

In summary, the research shows that target group prioritisation results in route choice effects in the network. The detrimental effect of the implementation of this measure on the non-prioritised traffic can have impact on the junctions in the network, which also could result in a network effect of target group prioritisation that is not beneficial for the prioritised target group. This shows that the effects of target group prioritisation are highly dependent on the traffic conditions and many other factors of the road network. Nevertheless, the analysis shows that it is possible to improve traffic conditions with target group prioritisation. By extending this research by analysing additional KPI's and conducting a comprehensive study of the traffic flows in the network, it should be possible to make a well-founded policy choice for target group prioritisation in the future.

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Appendix A

Transport Models

Transport models are developed for the evaluation of infrastructural and traffic management measures aimed at the traffic flow and travelling times. Policy makers use them to see the effects of specific traffic measures, but they can also help to predict the effect of autonomous developments on the traffic system. Think for example about changes in population structure. Transport models can be categorised based on the allocation technique used to assign traffic to the modelled road network (Morsink and Wismans, 2008).

In most cases, transport models are categorised based on the allocation technique used to assign traffic to the modelled road network. A distinction is made between static and dynamic transport models (Morsink and Wismans, 2008). Both model types are derived from the classic four-stage transport model, where the trip decision process of road users is described by four decisions people make during a trip from origin to destination (Dijkhuis, 2012).

1. The first stage is the **trip generation**, that determines the production and attraction of traffic;
2. Second is the **trip distribution**, that determines how many trips are made and from which origin to which destination;
3. The **model split** stage distributes the trips over the different modes of transport;
4. Lastly, the **assignment** of traffic determines the routes of the trips over the network.

The four-step model can be visualised as in Figure A.1.

Deploying measures can influence all choices which are described in transport models, but will depend on the level of impact. Realising for instance a new road to reduce the travel times between areas, can significantly change the distribution, modal split and route choice or even the trip generation. It is expected that prioritising target groups at signal-controlled intersections, given the local impacts, found in literature will mainly influence the route choice within a network. Therefore, this paragraph focuses on the assignment step.

As mentioned before, the assignment models can be divided in static and dynamic assignment models. Static models do not consider the variation over time and are often based on link travel time functions possibly in combination with (average) junction delays provided for a certain stationary demand. The travel times computed are averages and rough estimates,

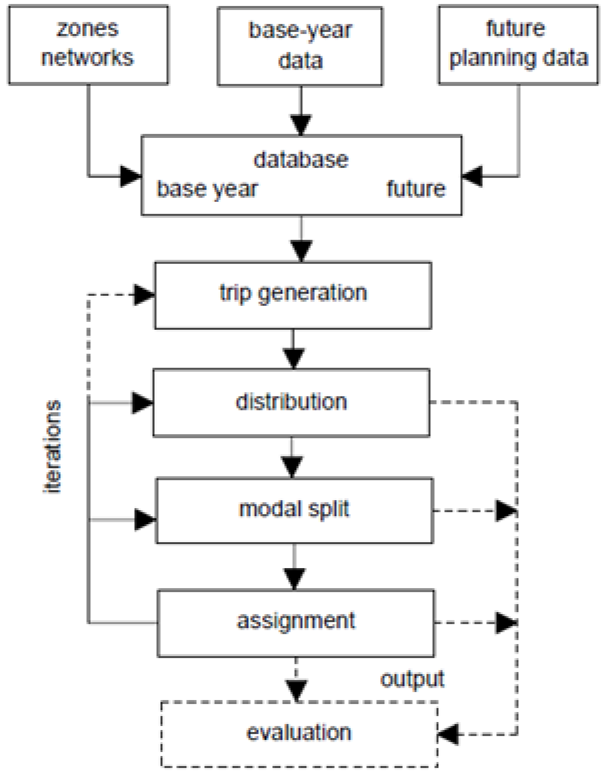

Figure A.1: The classic four-stage transport model (Ortúzar and Willumsen, 2011)

mainly used for the modelling of route choice or the other choices within the model, like the modal split and distribution. These travel times are rarely considered to be a main outcome of these models, while flows and Volume/Capacity ratios are.

Dynamic traffic assignment models can assign traffic over time, where changes in the demand for and supply of infrastructure in the resulting traffic flow are considered. These models provide more detailed information on the impact of changes made at intersections on for instance delays and queuing as well as the dynamics over time, given the period simulated. They are generally used when there is an interest to evaluate the impact of measures on the traffic dynamics, and especially when Dynamic Traffic Management measures like TLC's are considered. Dynamic traffic assignment models can be subdivided into microscopic, mesoscopic and macroscopic models (Morsink and Wismans, 2008).

A.1 Microscopic Assignment Models

Microscopic assignment models compile an overall picture of the traffic flow from movements of individual road users on road sections and junctions. Most models are based on both the mechanical and functional properties of vehicles, as on behavioural aspects of the driver. The behavioural aspects mainly concern the modelling of route choice behaviour, lane changing behaviour, gap acceptance and car following behaviour (Morsink and Wismans, 2008).

The main advantage of using a microscopic model is that it can provide traffic information from system to individual level, which makes that the behaviour of an individual driver can be modelled. One could for example see what the effect is of the users on the addition of an extra lane at an intersection or changes in green times, as well as explicitly model the communication between vehicles and TLC's. This makes that microscopic assignment models are ideally suited for modelling prioritisation at intersections. However, microscopic models have also their weaknesses. Modelling the behaviour of each vehicle and tracking in a traffic condition will take a big effort and resource in the required time, cost and high-level computational processes. This is because the simulation process will be done in real time, but also because such models are usually stochastic in nature which means repetitions are needed to derive the average results. The scale of microscopic models is therefore limited, and therefore unsuitable to determine the effects of traffic measures on large networks (Mardiati et al., 2014).

An example for which a microscopic assignment model is used, is the study conducted by Visser (2019) which is described in section **??**. For this study, an intersection in Amsterdam was modelled in the micro-simulation software VISSIM to analyse what the effects are of target group prioritisation on that intersection.

Another example described in the paper of Mardiati et al. (2014) that used a microscopic model is an analyses of incident-induced lane traffic manoeuvres. It was assumed that compared with incident-free cases, lane blocking incidents may result in anomalous increases in lane changes upstream from incident sites, thus creating unusual queue lengths and delays. Besides, lane changes can generate other traffic flow phenomena, such as secondary accidents and spillback events. In this case microscopic transport modelling is used, since it treats incident-induced traffic flow as a non-equilibrium system of particles with transitional jamming phases caused by unusual speed and lane-changing variations.

A.2 Macroscopic Assignment Models

Macroscopic assignment models represent traffic flow in terms of aggregated variables like intensities and the average speed of streams of traffic. The model exists of two parts, namely a route choice model and a dynamic network loading (DNL) model. The DNL is often based on traffic flow theory in which the behaviour of traffic on roads is modelled using the Fundamental Diagram, based on the LWR model using a numerical approach (i.e. dividing the network in segments in which traffic conditions are). This DNL can be single user class (i.e. only total flow is considered in which for example cars and trucks are combined using a passenger car unit factor) or multi-user class (i.e. flows are modelled by distinguishing classes represented by layers, e.g. separating cars and trucks). The outcome of a macroscopic assignment model are forecasts of traffic flows per road section per time interval (Morsink and Wismans, 2008). In contrast to microscopic assignment models, macroscopic models are suited for large scale, network wide applications where the macro-characteristics of traffic (speed, density & flow) are of prime interest with comparatively less computational cost (Mohan and Ramadurai, 2013).

Macroscopic dynamic assignment models combine the advantages of static models (e.g. higher computational speed and a larger modellable network) and some of the microscopic model aspects (e.g. time-varying traffic flow) (Morsink and Wismans, 2008). This makes them suitable to calculate the network effects of traffic measures.

However, the weakness of such models is that the microscopic behaviour of vehicles is not explicitly modelled. This means that car following and lane changing behaviour of vehicles is averaged and modelled implicitly by fundamental diagrams. As a result, the communication between vehicles and TLC's cannot be modelled and also the dynamics at intersections are simulated in a simplified manner by setting outflow capacities of links as an outcome of junction models, which use the time dependent flows. In case of TLC's, the outflow capacity depends on the green time distribution provided as an input or automatically determined by the junction model given the flows. This means that target group prioritisation cannot be explicitly modelled within such models.

One of the projects for which a macroscopic model is used is a study conducted by Weperen (2013). The study discusses the possibilities and effects of redistributing traffic with "route-oriented traffic management (ROTM)", which is a concept that distributed relations over routes in a network by providing road users with specific traffic information and by creating the required capacity on routes. Different distribution principles are worked out and implemented in a transport model of the city of Assen. The model provided answers on intensity/capacity ratios, travel times and the use of preferred routes.

A.3 Mesoscopic Assignment Models

Mesoscopic assignment models describe traffic flows at an aggregate level, like macroscopic assignment models, but also use a general description of individual behaviour as a function of macroscopic quantities. Unlike as in microscopic assignment models, the individual behaviour is not specified per vehicle, but in stochastic magnitudes that hold for a platoon of vehicles. However, these models are in practise hardly ever used.

A.4 Overview Transport Models

Table A.1 provides an overview of the main advantages and disadvantages of microscopic assessment models and macroscopic assessment models. Since mesoscopic assessment models are not often used, they are not included in the overview.

Table A.1: Overview microscopic and macroscopic assessment models

	Advantages	**Disadvantages**
Microscopic assessment models	The behaviour of an individual traffic user can be modelled, which includes route choice behaviour, lane change behaviour, gap acceptance and car following behaviour.	The scale of application is limited, since modelling the behaviour of each vehicle and tracking in a traffic condition will take a big effort and resource in the required time.
Macroscopic assessment models	They are suited for large scale, network wide applications and have comparatively less computational cost.	Individual behaviour of vehicles is not explicitly modelled, which means that traffic behaviour of vehicles is averaged and modelled implicitly by fundamental diagrams.

Appendix B

Propagation Model MaDAM

The propagation model that is used by StreamLine to determine several traffic conditions is called MaDAM. MaDAM is a cell based model, which means that a link is divided in several segments with equal lengths. Each segment contains information about traffic variables like speed, density and flow. Along the whole length of each segment, the value of these variables is assumed to be the same (i.e. within a segment stationary and homogeneous traffic conditions are assumed). However, every timestep (typically 1 to 3 seconds) the traffic conditions are updated based on the (changing) inflow and outflow of segments as well as changing conditions on the upstream and downstream segment. A motorway link with its segments is illustrated in Figure B.1. It shows that in segment i, the traffic variables are based on the traffic flow on the subsequent and preliminary segments, which is also called a second order model (Dijkhuis, 2012). The three most important traffic variables of MaDAM are:

- **Traffic density,** $\rho_{m,i}(t)$ **[vehicles/km/lane]:** the number of vehicles in segment i of link m at time t, divided by the length of the segment L_m and the number of lanes of link m (λ_m).
- **Mean speed,** $v_{m,i}(t)$ **[kilometres/hour]:** the average speed on a segment i on link m at time t.
- **Traffic flow,** $q_{m,i}(t)$ **[vehicles/hour]:** the number of vehicles that leave segment i of link m during the time between time t and $t + 1$.

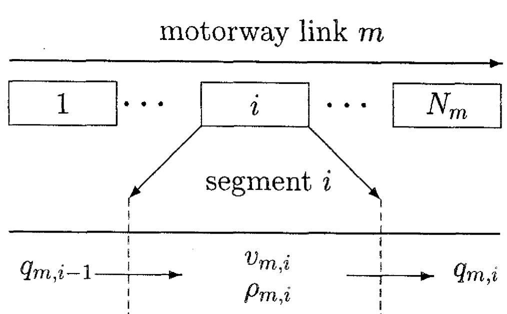

Figure B.1: Discretised motorway link (Kotsialos et al., 2002)

An overview of the working of the propagation model can be seen in Figure B.2.

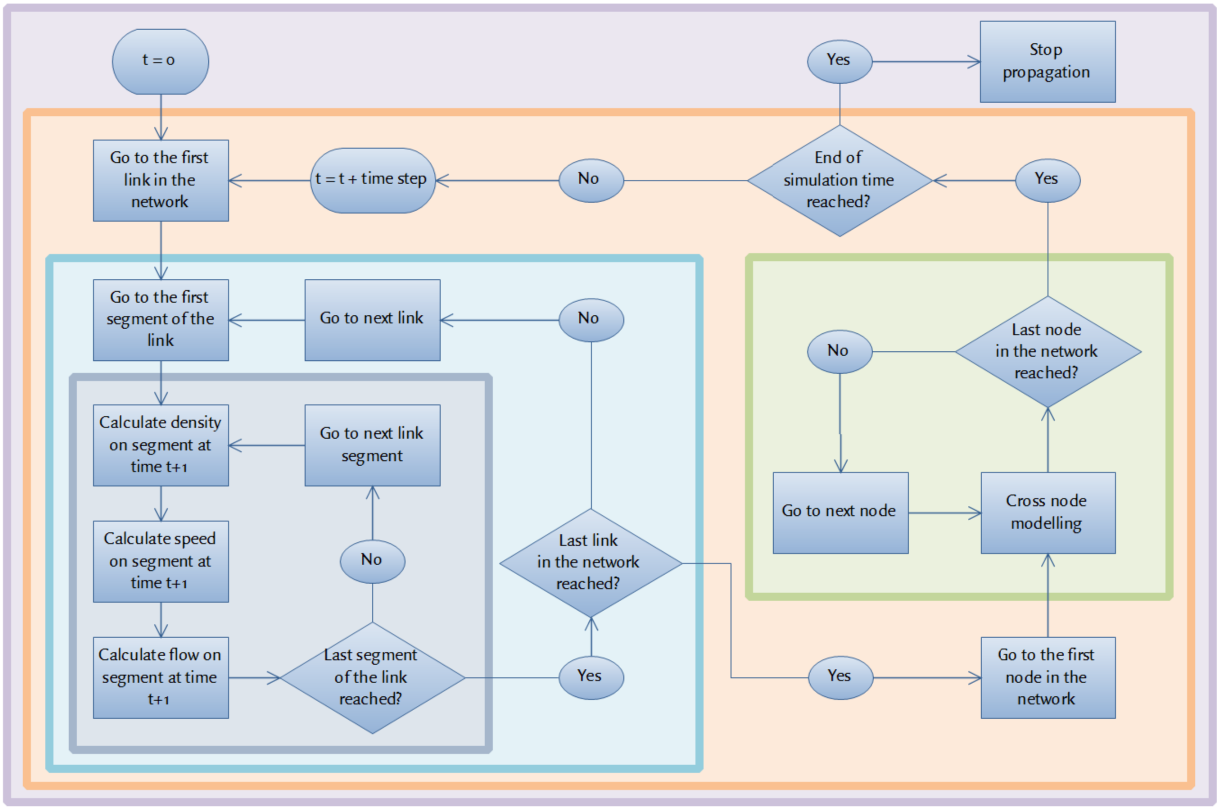

Figure B.2: Overview of the steps that are taken in StreamLine during propagation (Dijkhuis, 2012)

Appendix C

Junction Model XStream

C.1 Signalised Intersection Types

OmniTRANS has defined the following signalised intersection types:

- **Manual**, where the signal cycle time and the green times can be set by hand in the junction editor. The signalling scheme is fixed-time, which means that the cycle time and green times will never deviate from the scheme for the period for which it is defined (DAT.Mobility, 2016).
- **Automated**, where the junction modelling module will optimise the setting of the traffic lights during the assignment, such that given the demand at a junction the total travel time is minimised. So, no cycle or green times are coded on beforehand. This signal control type roughly corresponds to the real situation where the traffic lights interact with the demand, using induction loops in the roads (Muijlwijk, 2012).
- **Actuated**, which is basically a combination of the manual and automated signal control. One could set an average, minimum and/or maximum cycle time or green times and the junction modelling module changes the cycle time given the set boundaries, to minimise the average control delay (DAT.Mobility, 2016).

C.2 Lane Capacity Signalised Intersection

The calculation of the capacity at a signalised junction is done as follows. First, the capacity of a turn is set on the saturation flow: the capacity [veh/h] of a turn when there are no conflicting movements (so in a free-flow case). Because the junction model itself incorporates the existence of approach lanes, the combined capacity of all lanes for a turn is determined:

$$Q_{b,t} = s_t \tag{C.1}$$

where $Q_{b,t}$ is the base capacity of turn t and s_t is the saturation flow of turn t (DAT.Mobility, 2016).

Next, the capacity per lane is calculated from the capacity per turn with the following equation:

$$Q_{b,l} = \frac{\sum_{t,l} Q_{b,t}}{nr_{t,l}} \tag{C.2}$$

where $Q_{b,l}$ is the base capacity of lane l and $nr_{t,l}$ is the number of turns t on lane l (DAT.Mobility, 2016).

The final capacity of a lane depends on the green time. The green time is the same for all lanes in one lane group. For calculating the green time, information is needed about the conflicting lane groups. A conflict matrix is used to define conflict groups, which are lane groups that are in conflict with all other lane groups. For every conflict group, a cycle time is calculated, which is set on the minimum time period such that the junction can handle all traffic in the conflict group. In the end, the cycle time of the normative conflict group (NL: maatgevende conflictgroep) is applied on the junction. The normative conflict group is the lane group which has the highest signal cycle time of all conflict groups. Given this cycle time, the green times are calculated for all lane groups (Muijlwijk, 2012). The final capacity can be calculated with the following equation:

$$Q_l = \frac{gt_l}{Ct} \cdot Q_{b,l} \tag{C.3}$$

where Q_l is the capacity of lane l, $Q_{b,l}$ is the base capacity of lane l, gt_l is the green time of lane l and Ct is the cycle time (DAT.Mobility, 2016).

Appendix D

TLC-Settings Prioritised Route

Table D.1: TLC-settings prioritised route

Nr	Nodenr	Cycle Time			Lane	Offset			Green Time		
		Ref	30%	60%		Ref	30%	60%	Ref	30%	60%
1	1090604380	65	73.4	81.8	1	2	2	2	26	26	26
					2	46	54	63	6	6	6
					3	12	12	12	10	10	10
					4	11	11	11	28	36.4	44.8
					5	57	65	74	6	6	6
2	1090604381	65	69.8	74.6	1	54	54	54	32	32	32
					2	65	65	65	20	20	20
					3	54	54	54	24	24	24
					4	52	52	52	6	6	6
					5	16	16	16	16	20.8	25.6
3	12070	120	129	138	1	0	0	0	10	10	10
					2	15	15	15	35	35	35
					3	15	15	15	35	35	35
					4	40	40	40	30	30	35
					5	55	55	55	15	15	15
					6	75	75	75	30	30	30
					7	75	75	75	30	39	48
					8	75	75	75	30	30	30
4	13094	73	81.1	89.2	1	0	0	0	6	6	6
					2	0	0	0	13	13	13
					3	12	12	12	6	6	6
					4	0	0	0	12	12	12
					5	40	40	40	27	27	27
					6	40	40	40	27	27	27
					7	40	40	40	27	27	27
					8	40	40	40	27	35.1	43.2
					9	0	0	0	6	6	6
					10	0	0	0	6	6	6
					11	0	0	0	6	6	6
					12	0	0	0	6	6	6

Nr	Nodenr	Cycle Time			Lane	Offset			Green Time		
		Ref	30%	60%		Ref	30%	60%	Ref	30%	60%
5	13127	116	131.9	147.8	1	1	1	1	21	21	21
					2	1	1	1	21	21	21
					3	89	89	89	21	21	21
					4	89	89	89	21	21	21
					5	89	89	89	21	21	21
					6	1	1	1	21	21	21
					7	113	113	113	53	68.9	84.8
					8	26	26	26	26	26	26
					9	26	26	26	26	26	26
					10	70	70	70	16	16	16
					11	70	70	70	16	16	16
6	8208	170	192.8	215.6	1	0	0	0	35	35	35
					2	160	160	160	47	47	47
					3	100	100	100	43	43	43
					4	100	100	100	43	43	43
					5	100	100	100	43	43	43
					6	149	149	149	21	21	21
					7	166	166	166	76	98.8	121.6
					8	41	41	41	20	20	20
					9	42	42	42	40	40	40
					10	88	88	88	6	6	6
7	8205	120	126	132	1	105	105	117	80	80	80
					2	25	31	37	40	40	40
					3	25	31	37	95	95	95
					4	70	76	82	25	25	25
					5	0	0	0	20	26	32
					6	0	0	0	20	20	20