FACULTEIT ECONOMIE
EN BEDRIJFSKUNDE

EVALUATING THE IMPACT OF DIFFERENT BUS LANES: CASE STUDY

FINDING PRIORITY RULES TO INCREASE THE EFFICIENCY OF BUSES

Word count: 28854

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Master's Dissertation submitted to obtain the degree of:

Master of Science in Business Engineering

Academic year: 2016 - 2017

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Abstract

This master thesis aims to acquire more understanding in the advantages of bus lanes. The paper is subdivided into two main parts. The first part of the research is a literature study, where one will investigate very briefly the evolution of traffic and the use of public transport. This will be followed by a closer look into the phenomenon of bus lanes. Here one will summarize the different types of bus lanes and their possible advantages in certain situations. The first part will be closed with the information one gained during the literature study concerning the methods of measurements to mathematize and visualize the possible relevant advantages. There are two common ways in capturing the details of the underlying system, the first one is a method based on simulation (microscopic-cellular automata). The second one is based on an analytical approach (the queuing theory).

In the second part one will couple the gained knowledge regarding the literature study with a case study in Ghent. For this research one has chosen the Rooigemlaan, in particular the area of the intersection between the Rooigemlaan and the Drongensesteenweg in Ghent. The goal of this case study will be to scale the advantages of an ordinary lane, a dedicated bus lane with and without set back and a lane with intermitted priority for buses. These advantages will be linked with the advantages offered by the use of transit signal priority. To end this thesis one will evaluate the previous described bus lane types and their influences on traffic, this will be done by sensitivity analysis where one will change the input values. To finalize the research, a conclusion will be formed based on the a cost-benefit analysis.

Acknowledgements

The first reason why one has chosen this subject to be the subject of the master thesis is because it is a day-to-day problem that has a huge impact on the environment and economy. By making the public transport more attractive one could solve a big part of the congestion and environmental problems. Another reason is because it seems to be a good exercise to end a five year education of business engineering - operations with.

The first person one would like to thank is my supervisor, Broos Maenhout. He helped me through the entire thesis, taught me some basics aspects of how to write a thesis, helped me with the structure, the model and has read and corrected every part. Without him this thesis would have been impossible.

Next, one needs to thank the people that helped with gathering the needed information. These people were Rik Hemelaer, Managing Director at the VAB, and Peter Behaeghe. They helped to get in contact with the right people, like Dirk Vanderbauwede, Bart de Mey and Frank Desloover, mobility experts at De Lijn. Also Pieter Morlion of Traffic Control Centre was of great help in collecting the data.

The last people that need to be thanked are the people who helped with the set-up of the model. For the mathematical part one needs to thank Professor Herwig Bruneel, he has taught me the basics of the queuing theory. Further Sabine Wittevrongel and Joris Walraevens helped me with modelling my specific problem. As for the simulation and visualization of the model one needs to thank Bart Wolput, traffic engineer at Tractebel and Raf Venken, senior project leader at Sweco.

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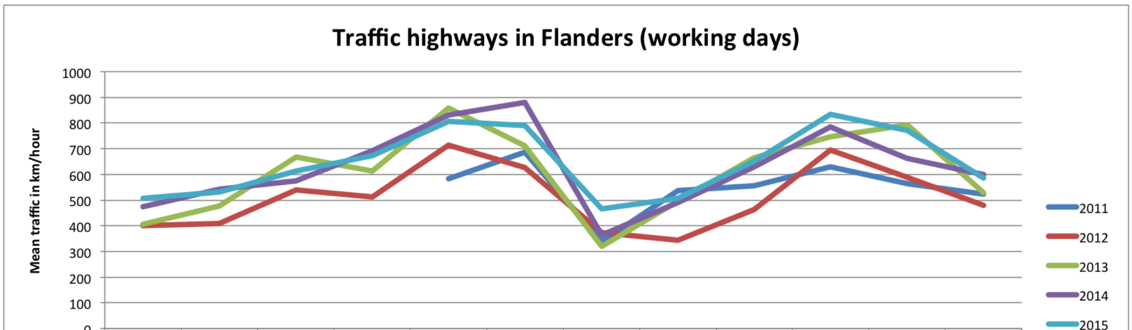
PART I

1 Introduction

The need to reduce congestion forms the objective of this paper. Here, one will search for solutions based on the possibilities offered by the public transport. The most compelling argument for congestion in this dissertation will be linked with the incremental use of technology and the increased availability of alternative modes of transport. The general idea behind the research is to recognize different ways to improve the attractiveness of public transport in order to convince people to consider public transport more often. To that end, people could opt out the use of cars and move to public transport. With this in mind a decrease in congestion could be made possible. In what follows there will be a short description of the problem, that is the evolution of congestion and the use of public transport. Afterwards, this evolution will be explained based on the insights of a paper written by David Banister. This explanation is based on the development of technology that forms a root cause of the shrinkage of the use of public transport. To end this part, one will explore the potential solutions in the area of public transport. This search will lead to the topic of the paper, bus lanes.

An explorative search has revealed two transformations in traffic. The first transformation is the increase in congestion over time. According to a study the loss of hours per vehicle from 2007 to 2020 will increase with 35% due to congestion (Federale Overheidsdienst Mobiliteit en verkeer, 2008). Also “Verkeerscentrum” has visualized the total increase in congestion over the years, one can easily notice an average increase in congestion (from 2011 until 2015) of hundred kilometres per hour on high roads (see fig 1.1).



	January	February	March	April	May	June	July	August	September	October	November	December
2011					584	686	337	538	555	630	565	523
2012	401	408	540	513	714	628	373	344	463	694	589	481
2013	405	476	668	614	859	711	320	495	665	747	794	530
2014	474	542	575	693	830	881	364	492	630	784	662	600
2015	508	531	613	673	807	790	465	506	651	835	772	587

Figure 3.1: Mean traffic on highways in Flanders (source: http://www.verkeerscentrum.be/pdf/rapport-verkeersindicatoren-2015-v1.pdf)

Another key point is the decrease in popularity of public transport. Five consecutive years in a row show a decrease in the number of bus and tram users. Furthermore, Mobiliteit Vlaanderen reported a loss of more than 20.000 bus and tram users over the five years (see fig 1.2)

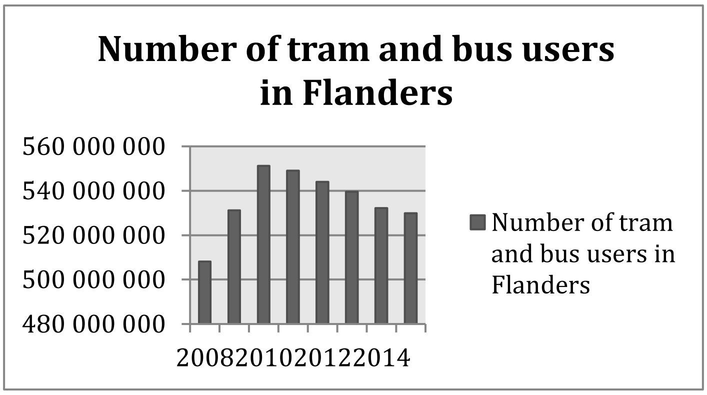


Figure 1.2: Evolution number tram and bus users (source: http://www.mobielvlaanderen.be/jaarboek-ovt/2015/de_lijn/2213netmanagement.pdf)

Technology is a root source problem of these two transformations (D. Banister, 2007). Most people would think of technology as a benefit for decreasing the congestion. Reasoning for this outcome is mainly the increasing flexibility (work at home, shop online etc.). The flexibility is a consequence of the huge substitution potential between transport and IT, and may lead to a reduction in the need for transport. However, the opposite has been proven. The possibilities offered by the IT influenced indirectly our leisure-based travel time in a increasing and flexible manner. To put it another way, people now have the opportunity to change their travel patterns and make them more flexible (D. Banister, 2007). Not only the technology created the increased flexibility but also the improvement of transport. With this growth in flexibility we are now able to use our increased leisure time to visit the things we want, when we want without any limitation in transport. This all changed our way of how we look at our travel time, which is now linked with positive emotions (D. Banister, 2007). Thus the substitution of transport into IT is more like a symbiotic substitution potential, some activities are substituted while other activities are generated or modification.

The increased flexibility in our travel patterns has created another consequence, namely a change in travel distance and travel speed. Because of the decentralisation of cities and the possibility for more random vacations and/or short breaks, people tend to travel further and with a higher speed (D. Banister, 2007). These two changes make people choose more often for their cars instead of substitution goods such as public transport, bicycles, etc. In other words public transport has become less attractive.

This trend is very unfortunate because public transport could offer us many advantages. With this in mind it will be clear that the main goal is to make public transport more attractive. One way in doing so is to free public transport from congestion. This brings us to the subject of the paper, namely bus lanes. One has chosen to focus its attention on buses because trams and trains are nearly as much affected by the congestion on the road network. As one can understand buses are often disturbed by queuing vehicles or congestion in general it is important to search for solutions that reduce or even eliminate the disruption. A solution for this problem is offered by bus lanes. Buses give rise to many opportunities and improvements for economical as well as social aspects in our society. Important to note it that these improvements can only be optimized if they access to bus lanes. The most important benefits of the use of buses are given below.

The concept of bus lanes, the different types and the applicability of each type will be explained next.

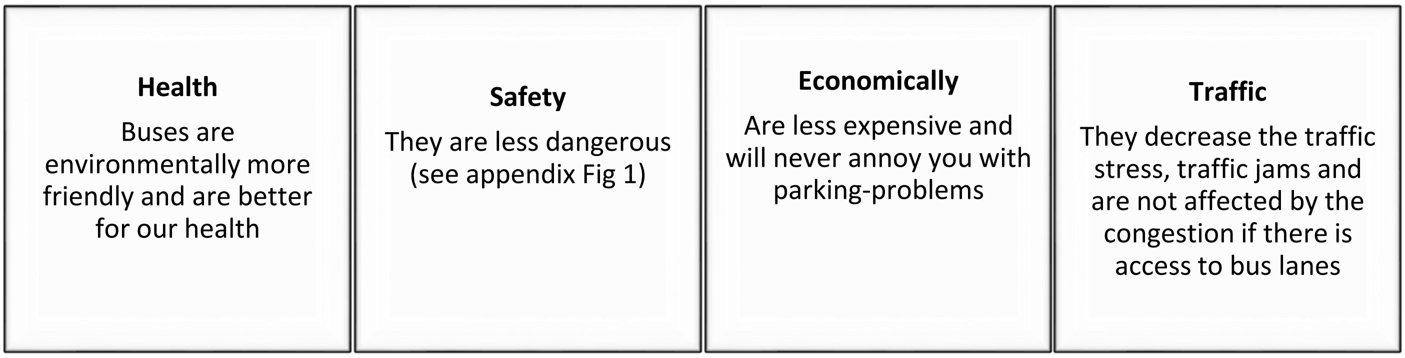


Figure 1.3: Advantages buses

2 The different types of bus lane systems

Bus lanes are lanes that are developed for buses, the use is mostly restricted to buses but sometimes there are certain rules (mostly determined by the time or date) that provide access to other vehicles. They are made to speed up the public transport because otherwise they will be held up by traffic. Below a short description will be given of three main bus lane types, this coupled with a well-known system that is often used in combination with these bus lanes (H.B. Zhu, 2010).

2.1 Dedicated bus lanes (DBLs)

The most famous bus lane type are the dedicated bus lanes (the abbreviation **DBL**), the DBLs are lanes that are completely dedicated to buses and as a consequence remove one lane from the general use, this will result in a decreased capacity for the other vehicles on the road.

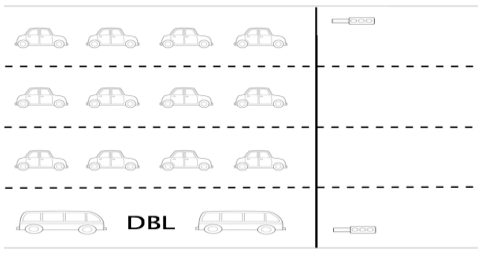


Figure 2.1: Solution 1 (Dedicated bus lanes)

2.1.1 Bus lane with set-back

In order to designate the influences of a dedicate bus lane, one will partition the latter into different cases. The first one will be a dedicated bus lane with set-back. The setback refers to the fact that a bus will loose its priority 30m before a traffic light. To that end, approximately six cars will now have the possibility to queue in front of the bus. An example is given below.

Figure 2.2: Solution 2 (Bus lane with set-back)

2.1.2 Ordinary lane with the last 30m as dedicated bus lane

This lane type can be seen as a merger between a dedicated bus lane and ordinary lanes. The concept of this method is to decrease the capacity loss incurred by dedicated bus lanes. Here, a dedicated bus lane will only be inserted thirty meter before the intersection.

2.2 Bus lanes with intermitted priority (BLIP)

By extending the use of DBLs with signals that regulate the use of the lane, one will get a bus lane with intermittent priority (**BLIP**) this lane will force traffic out of the lane and reserve it for buses. This is made possible by the use of variable message signs (VMS). Another explanation for a BLIP, is that it may also be seen as set of cocoons, these cocoons will be exclusively in use of buses. The length of cocoons begins at the rear bumper of a bus and extends their length until a fixed distance in front of the bus. This extension will be determined per block. A BLIP will often be used in situations where a bus approaches a traffic light. This is because buses loose plenty of time to pass the traffic light due to queuing vehicles. Below the process of a BLIP will be explained by the use of three situations:

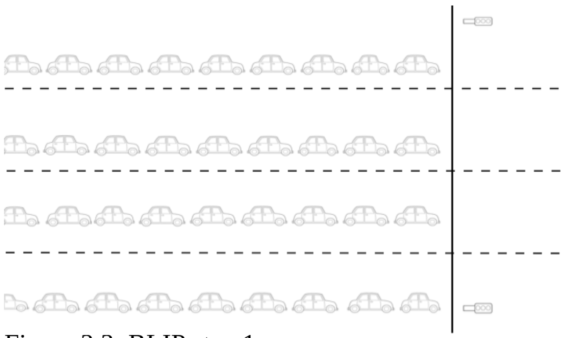


Figure 2.3: BLIP step 1

Situation one, there is no bus is in arrival. The lanes act like ordinary lanes without bus priority.

Situation two, a bus is in arrival, a variable message sign will provide a signal that pushes the cars to another lane. Some examples of a VMS are given below:

Figure 2.6: VMS example

Figure 2.7: VMS example 2

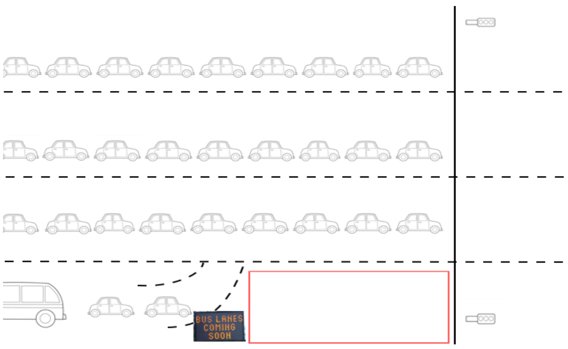


Figure 2.4: BLIP step 2

Situation three, the bus now has the ability to drive straight through the green light without any interruption of queuing cars. After this, situation one will take over again. In the case study one will notice that the third scenario, namely the ordinary lane with strict TSP on the Rooigemlaan, can be seen as a bus lane with an intermitted priority. This is based on the visual insights obtained in VISSIM, the program one will use to model the scenarios. In this program one will see that the green light will change a number of seconds before the arrival of the bus. This will make sure that the queue in front of the bus will be cleared at the moment the bus arrives. In other words the effect of the two will be similar.

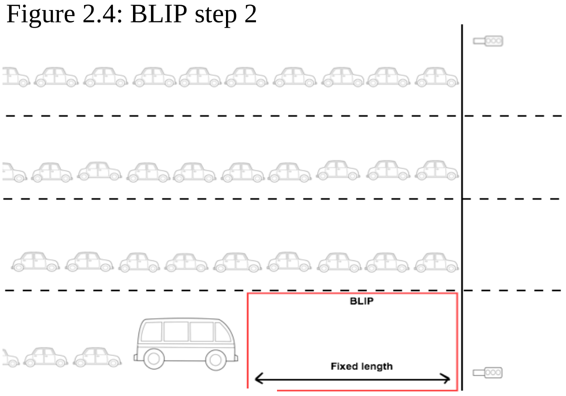


Figure 2.5: BLIP step 3

2.2.1 Bus lanes with intermitted priority (Rolling cocoons)

It is also possible to interpret a cocoon as a rolling/moving cocoon. In other words, a cocoon acts here as a moving surface (with a fixed length) in front of a bus and is completely free from non-bus vehicles. These cocoons will now moves along with the bus. The two figures below show the movements of a BLIP in front of a traffic light. In these figures the red rectangles serve as cocoons. As this method is more of a theoretical method and is almost impossible to convert into reality, one will leave this method as theoretical knowledge and there will be no further investigated on this part.

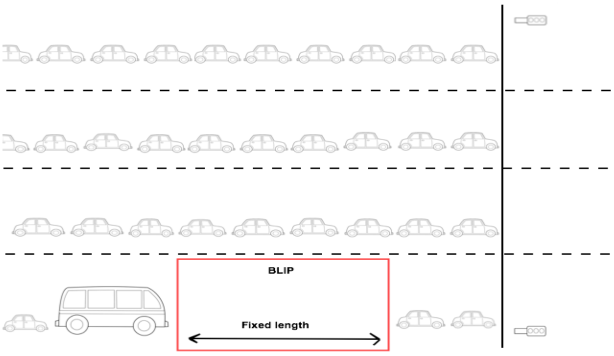


Figure 2.8: BLIP (Rolling cocoon), step 1

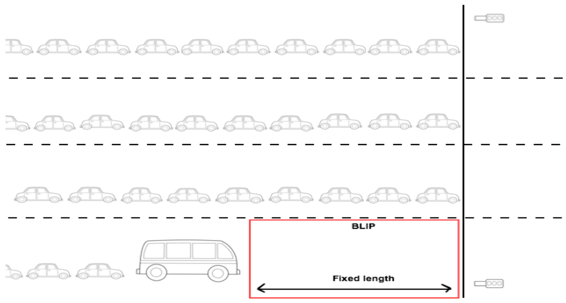


Figure 2.9: BLIP (Rollin cocoon), step 2

2.3 Bus-rapid-transit (BRT)

A third possibility is the bus-rapid-transit (**BRT**) and may be seen as a "surface subway". These lanes are specially designed to make sure a bus can drive without being disturbed. This is less suitable for a city like Ghent because of the costs and the infrastructural restrictions that may arise. For these reasons one will again choose to not execute this, thus there will be no further investigations on this part.

3 Other types of bus priority

3.1 Transit signal priority (TSP)

By now it should be clear that the purpose of the paper is to improve the efficiency of buses. In this paper one will try to achieve the goal by decreasing the waiting times for buses in front of traffic lights. For this reason it is not unimportant to include the transit signal priority into the discussion of this paper. Transit signal priority is a collection of techniques that make improvements to the vehicle flow and that decrease the delay of vehicles. These signals are mainly known as the capability of buses to extend the green light signal to claim the right to pass and proceed undisturbed through an intersection. In this paper one will combine this signal priority with the bus lanes discussed earlier. A combination of these two priorities should maximize the efficiently of buses at any intersection.

4 Road conditions and Bus priority

Another key point concerning the improvement of the bus flow is the specific situation on the road. For instance, if one is dealing with a very busy road it might not be smart to choose to reduce the capacity by introducing a dedicated bus lane. This could create problems for both cars and buses. One will now try to assign these problems based on studies developed by M. Eichler and H.B. Zhu. In these studies one can separate three scenarios. The first scenario, A, is designated to a dedicated bus lane. The second scenario, B, is linked to an intermittent bus lane and the last scenario, C, is an ordinary two-lane. In what follows one will discuss two factors that have a significant effect on the chance of a bus lane type to succeed in certain road conditions.

4.1 The relationship between the demand and the bottleneck capacity

A first manner for analysing the implementability of bus lane types is the relationship between the demand and the bottleneck capacity. Based on literature one can decide that not all bus lane types are applicable in every situation and that some types are more suitable than others at certain situations. With this in mind, one can separate the bus lane types based on some rules/findings. For instance, take the problem discussed in the previous paragraph, it has indeed been indicated (M. Eichler and C.F. Daganzo, 2006) that pure pre-emption (DBLs and DBLs/TSP) should be used when the demand is less than 80% or 90% of the q_D [1]. As for a BLIP, by virtue of the reduction in the needed capacity, these conditions will be relaxed. This system can be used in situations where the capacity is near the bottleneck capacity of the road. Moreover, if the capacity reaches a percentage that is higher than 120% there will be no place to introduce priority lanes without seriously increasing the delays of other road users, the only tool that can be used to increase the bus flow is a TSP.
The use of TSP in combination with the different types of bus lanes is another important aspect that needs to be considered. As mentioned earlier the only priority in situations where the capacity exceeds the bottleneck capacity by more than 20% is the TSP. It is easy to understand that the advantages for a bus of a pure TSP will be extremely small compared to the use of TSP in combination with a BLIP, not to mention the advantages of a combination with a DBL. This is because a pure TSP strategy makes use of the priority signal without reserving a lane, in this case when the capacity is near its maximum, a bus would be interrupted too much in order to take advantage of the benefits from the signals (M. Eichler and C.F. Daganzo, 2006). The combination of the BLIP and TSP creates a synergy effect. A BLIP will reduce or even eliminate the "signal queue delay", while a TSP will reduce the "signal stop delay". To put it in another way, pairing a BLIP and TSP can eliminate a significant amount of the delay. The result will be a bus travel time being only a function of the distance, bus speed, the time it needs to change all other traffic lights and the time it looses for stopping, boarding and alighting passengers (M.D. Eichler, 2005). In other words the BLIP and TSP are perfect and complementary partners.

[1] With q_D = The flow at the bottleneck capacity = The capacity of the reduced system.

4.2 The ratio of the number of buses to the total number of vehicles

A second aspect is the ratio of the number of buses to the total number of vehicles, and is symbolized by the letter R. This section and the next section are mainly based on a study done by H.B. Zhu, 2010. This study is an examination of the reactions of the bus flow related to the density on a road (number of cars per hour) with a R-value equal to 0,1. One obtained the following findings. When increasing the density (fig 4.1) it is noticed that for a dedicated bus lanes buses keep on moving in a free flow phase even when the total density is larger than or equal to 0,17, while at that point the bus flow begins to decrease in case of a BLIP and an ordinary two-lane. Of course, the bus flow will remain higher for the BLIP compared to the ordinary two-lane traffic. Now looking at the car flow (fig 4.2) a decrease is already noticed at a density of 0,07 for the DBLs. To conclude, an increasing density will make the lane jammed when lane changing is forbidden. The car flow is maximized by the use of an ordinary lane without bus priority, in this situation a BLIP will be the second best option. These findings can be found in the figures below.

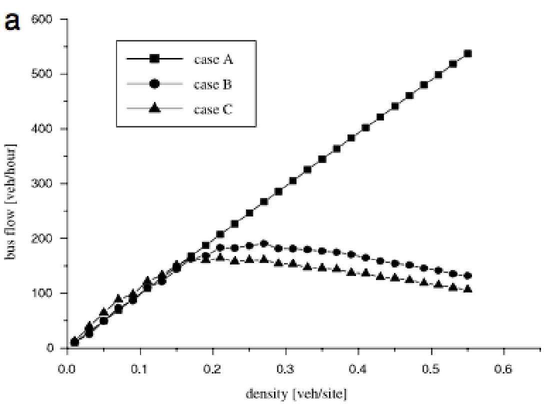


Figure 4.1: Bus flow in relation to the density (veh/site) for the three scenarios (source: H.B. Zhu, 2010)

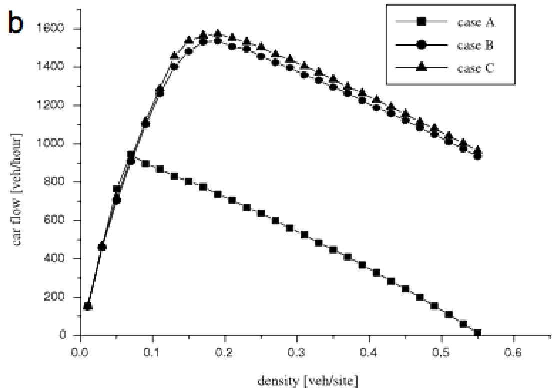


Figure 4.2: Car flow in relation to the density (veh/site) for the three scenarios (source: H.B. Zhu, 2010)

The same study is done for the relationship between the velocity and the density (H.B. Zhu, 2010). The velocity of the bus flow will remain constant over the increasing density when using a DBL system while the velocity of the bus flow will highly decrease when using a BLIP or ordinary two-lane. By increasing the R ratio to 0,2 it is noticed that the velocity in a DBL system would also decrease. For the BLIP strategy it is proven that the bus flow increases and the car flow decreases with the higher R when the total density is getting larger. A possible explanation is the decrease in the opportunity for cars to insert in the bus lane with the increase of value R. In a DBL system the car flow is bigger compared to the bus flow until the density has reached 0,39 vehicles/site, while the flow of people/hour will always be optimal when making use of a bus. In a BLIP system the car flow always remains bigger compared to the bus flow the same can be said for the flow of peoples per hour. The table on the next page summarizes some traffic conditions and links them with the bus lane type that best handles these conditions.

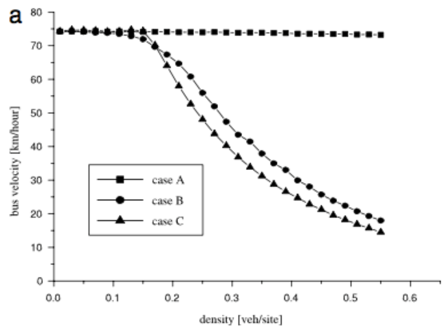


Figure 4.3: Bus velocity in relation to the density (veh/site) for the three scenarios (source: H.B. Zhu, 2010)

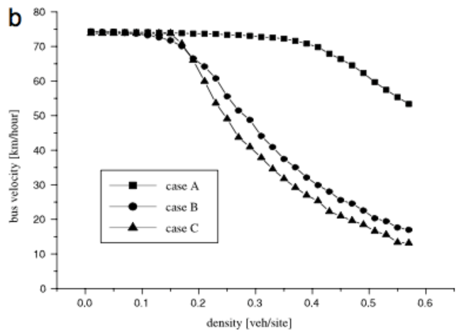


Figure 4.4: Car velocity in relation to the density (veh/site) for the three scenarios (source: H.B. Zhu, 2010)

	TSP	DBLs/TSP	BLIP/TSP	Ordinary two-lane
The demand is less than 80% or 90% of the q_D		X		
The demand gets near the bottleneck capacity			X	
The demand exceeds 120% of the capacity	X			X
High density while the bus flow is important		X		
High density while the car flow is important				X
Constant velocity of buses		X		
Highest flow of people per hour		X		

Table 4.1: Desired type of bus lane systems in different situations

To end this paragraph one would like to highlight the importance of implementing good rules and clear systems when using bus lanes. This because bus lanes are often shared with other vehicles, we call this a shared-use bus priority lane. Not only are the rules for these shared spaces allocated per time class but also an allocation based on the specific classes of vehicles may exist. This is very important because bicycles, taxis, vehicles turning into a property etc. all have different rules and all have the possibility to interfere with buses. (A. Weinstein Agrawal etal., 2013)

This introduction provides answers to the increasing need for bus lanes, it also gives a short overview of the existing types of bus lanes and it couples them with specific traffic conditions. In the next paragraph one will formulate the problem setting, this followed by a detailed study of all the variables and parameters of importance in the problem. Next there will be a short introduction of the possible technics to solve this problem. The final part of the paper is called the case study, here one will investigate the probabilities of introducing different types of bus lanes and their consequences on both buses and cars. In this way the gained knowledge as a result of the literature study can be applicated on a real life example. This case study will first give a short description of the situation on the selected road. Afterwards an investigation of the four scenario's will take place. This will be followed by a description of all the obtained values. To end the case study there will be a short discussion about our findings based on a cost-and-value analyse.

5 Problem setting

The main problem in this paper is the decrease in the attractiveness of buses, this while cars gain in popularity. A solution for this problem is the improvement of the efficiency of buses. In other words one will try to decrease the travel time of a bus, which could hopefully lead to a positive effect on the attractiveness of buses. This is made possible by the use of bus lanes. Bus lanes will free a bus from traffic, such that a bus could derives its benefit from jumping over the queuing vehicle. It is obvious that this will only be possible if we are dealing with a street with two or more lanes. The main parameters of the problem are stated below.

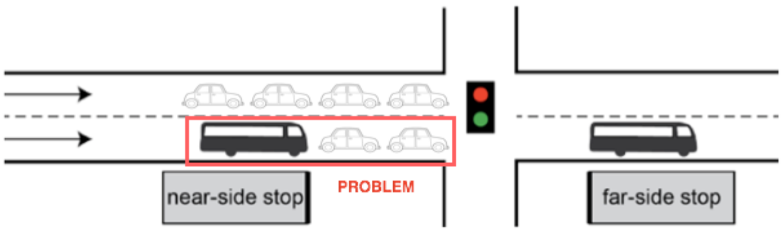


Figure 5.1: The problem

The road characteristics are the first aspects of importance. The numbers of lanes for instance, determines the service rate and capacity of a road. It is shown that, on roads with three or more lanes, a BLIP does increase the delay of traffic but it does not significantly decrease the capacity of the roadway (Eichler and Daganzo, 2005). Another road characteristic, is the infrastructure of the road. The traffic flow for example, will change dramatically if the road contains intersections, roundabouts, traffic lights etc. One would definitely choose to include traffic lights in the case study in order to investigate the possibilities of the different bus lane types in combination with TSP.

A second aspect that needs to be included are the agents on the road. For the case study one needs to fabricate a model that could represent the situation in real life. For this reason it is evident to incorporate all the agents that interfere on the selected road. The type of agents and with how many they are depends on many aspects, and is very volatile. A first aspect that determines the interactions between the agents is of course the type of lane, for a DBL the only agents are buses. In a BLIP system the type of agents would alternate in periods, some moments the lane will be restricted only for the use of buses while other moments non-bus vehicles may also use the lane. For a pure TSP system and the ordinary lanes it is clear that the agents remain a combination of cars and buses. The third aspect is linked with the policies over the shared-use of the bus priority lanes and is determined by a higher institution. Some cities for example give access to bus lanes on peak periods only, and permit taxis, bicycles, motorcycles, etc. to use the lane at any time. The bicycles, pedestrians and motorcycles are also of great importance certainly for the turning movements of other vehicles. These aspects will be all included into the case study.

Also the road conditions discussed in section four have a prior influence on the selection of the bus lane type. These factors will for instance influence the arrival times and the queue behaviour. The queue discipline in the case is of type FIFO (first in first out). Because the first vehicles that arrive at a traffic light will be served first. It will be very important to consider all the possible interactions between the queuing vehicles. The side-streets and the possible turning behaviour will also need some attention.

The most difficult aspect in the case study will definitely be the distribution and development of an appropriate system for the traffic lights, these need to merge the demand of all agents in the system. It is of huge importance to get this right because it determines the service rates for all parties.

With this basic description in mind it is time to go more into detail and subdivide the problem into parameters.

6 The objective function

To keep the travellers happy and to avoid an overload of complaints the most important aspect in a bus system is the punctuality of the arrival time of the buses, when buses arrive too late it would lead to displeasure on behalf of the travellers side because they could arrive late on their appointments or even miss them. Else if the bus would depart too early it would also lead to displeasure on behalf of the travellers because they could miss their bus. Constraining the bus drivers to not depart earlier than the departure-hour has already solved the latter problem. The former problem will be the subject handled in our case study. By setting our objective to minimize the expected travel time summed up with the travel time variability, we could deal with this problem. Mathematically this would give us the next formula (C. Carrion and D. Levinson, 2012):

$$U = \gamma_1 \mu_T + \gamma_2 \sigma_T \qquad (1)$$

With:

U = The objective function (minimizing the sum)

μ_T = Expected travel time (e.g. mean travel time distribution)

σ_T = Travel time variability (e.g. standard deviation of the travel time distribution)

The γ coefficients are weights for the mean travel time and standard deviation.

A factor that normally needs to be incorporated into the objective function is the degree of risk aversion of the traveller, in this case the "traveller" may be seen as the bus driver, and the bus driver its responsibility is to bring the people at a specific place in time. One will choose not to include the risk aversion here, because multiple authorized people have defined the hours of arrival. These people will choose the hours in a way where they have already incorporated the risk.

This is the theoretical side of the objective but because one can do it easier based on a monetary approach this will be the preferred method. In this method one will use the cost values from WLO to obtain the best bus lane type with a minimized travel time for both buses and cars. The method will convert the lost time caused by congestion into a monetary value.

As for the constraints one uses a method elucidated by the Highway Capacity Manual 2000. This method is called the LOS criteria and links the delay per vehicle with the Level of Service for a signalized intersection. This criteria fits perfectly in the case study because one attends to obtain the optimal bus lane type based on the average delay per vehicle. In that way one will automatically see the level of service provided by the lanes. The table on the next page represents the value LOS criteria.

Level of Service	Average Control Delay (sec/veh)	General Description (Signalized Intersections)
A	≤10	Free Flow
B	>10 - 20	Stable Flow (slight delays)
C	>20 - 35	Stable flow (acceptable delays)
D	>35 - 55	Approaching unstable flow (tolerable delay, occasionally wait through more than one signal cycle before proceeding)
E	>55 - 80	Unstable flow (intolerable delay)
F	>80	Forced flow (jammed)

Figure 6.1: LOS criteria (Source: 2000 HCM, Exhibit 16-2, Level of Service Criteria for Signalized Intersections)

For the case study one will use this criteria in the search for the most appropriate bus lane type, in a manner that the level of service (LOS) per vehicle type (buses or cars) will stay at the same level or will jump to a level with a better performance. This means that for the case study one will aim to find a bus lane type that improves the LOS for buses without hurting the LOS of cars by more than one level.

The next paragraph, is assigned to a detailed study concerning the factors that influence our objective function discussed earlier. The goal in the next paragraph will be to get into the mind of a bus driver and discuss all the possible elements that may affect the arrival time of a bus.

7 Introduction of the scenarios

Now that a clear objective function has been stated and the basic idea behind bus lanes is also clear, it is time to determine the factors that may influence the objective function. First, one will describe the road network and its possible scenarios. This will be followed by a mathematical discussion about the main parameters per scenario. The mathematical disquisition is kept very theoretically and will serve as the fundamentals for the understandings and expectations in the case study. To end this literature study one will discuss two common methods to solve this problem.

One will now discuss the three most important scenarios (The ordinary lane, The dedicates bus lane and the bus lane with intermitted priority) and combine this with the road conditions, this will form a total of eight scenarios. In the case study one uses this theoretical overview to model its own scenarios. The scenarios are described below:

1. A one-lane road, without bus priority, with this one refers to an ordinary lane.
2. A one-lane road, with bus priority and where buses make use of TSP systems.
3. A two-lane road, without bus priority, so the road will be equally shared, this will be an ordinary two-lane.
4. A two-lane road, with bus priority and where buses make use of TSP systems.
5. A two-lane road, where one lane will be exclusively dedicated to buses, this will be the DBL system.
6. A two-lane road, where one lane will be exclusively dedicated to buses combined with the use of TSP, this will be the DBL with TSP.
7. A two-lane road, where one lane will be exclusively dedicated to buses in some conditions, this will be the BLIP system.
8. A two-lane road, where one lane will be exclusively dedicated to buses in some conditions combined with the use of TSP, this will be the BLIP & TSP system.

As stated before one will not include three or more lanes because it is shown that, on roads with three or more lanes, BLIP does increase the traffic delay but does not significantly decrease the capacity of the roadway. When defining the eight scenarios on a mathematical base one needs to incorporate and expand these scenarios by the possible interactions between these agents, possible intersections, signalization and their service system. This all with the goal to obtain a model that represents the obstacles a bus needs to overcome.

Because some scenarios will not differ a lot from one another one will first summarize the parameters per scenarios. An x will stand for the fact that there is a big difference between the factor of the previous scenario and the factor of the selected scenario.

	Parameters						
Scenario	Velocity	Capacity analyse	Service system	Interaction	Ratio of the number of buses to the total number of vehicles (R)	Density	Flow
(1) The ordinary one-lane, without bus priority	x	x	x	x	x	x	x
(2) The ordinary one-lane, with bus priority		x					
(3) The ordinary two-lane, without bus priority	x	x	x	x			
(4) The ordinary two-lane, with bus priority		x					
(5) The DBL system on a two-lane road	x	x	x	x			
(6) The DBL system on a two-lane road with bus priority		x					
(7) The BLIP system on a two-lane road	x	x	x	x			
(8) The BLIP system on a two-lane road with TSP		x					

Table 7.1: The change in parameters per scenario

The values of last three factors will change over the scenarios but their formulas will remain unchanged. The theoretical aspect of the service system will here be explained based on the queuing theory, this theory is explained in the further sections. To summarize it very quickly, one will look at congestion in a similar way as one looks at queuing people. The case study will be a road with two or more lanes, where cars and buses arrive in front of a traffic light, when doing this they will form a queue. For this reason one can compare the situation of the case study with the approach of the queuing theory. Here, the lanes may be seen as queues and the traffic lights may be seen as servers. Because every scenario is characterised by a number of lanes, it is obvious that the more lanes one has the more servers will be available. This will have a huge impact on the service system. Another key point that may influence the service system is the system of the traffic lights. The system of the traffic lights is segregated into cycles and stages. They will direct the green, amber and the red times based on the circumstances on the road. These circumstances will be spotted by a detector, this will count the arrivals of cars, buses, pedestrians, bicycles etc. and will determine the service system. Likewise, will the TSP have an impact on the service system. One assumes that this pre-emption of signals is done in the most efficient way and that the red phase will on average be reduced on the main road by 1/4 of its length (M.Eichler and C.F. Daganzo, 2006). This will affect the side streets, to leave them as unaffected as possible, one further assumes that the reduction in their green time due to the passage of a bus is dissolved in following cycles with an increase in green time of the same magnitude (M.Eichler and C.F. Daganzo, 2006). When implementing the TSP one will make use of this reasoning.

With this in mind one will now start by examining the parameters more carefully per scenario. The description of these parameters will be of use as a theoretical insight of the model that one will discuss in the case study. The case study will model the problem by the use of the program VISSIM. This is a traffic simulation program for the optimization of traffic design. In that way one could use the theoretical expectations and values as a comparison with the values obtained from a simulation technic.

7.1 Scenario 1: The ordinary one-lane, without bus priority

In an ordinary one-lane without bus priority it is safe to say that buses and cars will share the lane in a way in which no one has privileges. Cars behind a bus will have to reduce their velocity and adjust it to the velocity of the bus, they will also loose time caused by the bus stops. Passengers who have luck and are not driving behind a bus will maintain their maximum speed in case there is no congestion, otherwise their speed will be equal to the velocity of the congestion. So the first factor one would need to discuss is the velocity.

7.1.1 Velocity

The velocity can here be subdivided into three types, namely v_{max}^F, v_{max}^s and v corresponding with the fast, slow and mean vehicle velocity respectively. The former velocity[2] is for vehicles that are not bothered by a bus in front of them. As a consequence they will be able to maintain their original velocity. Velocity of slow vehicles, v_{max}^S, these vehicles include buses and cars driving behind a bus. This velocity can be seen as the mean speed of a bus including the lost time due to bus stops and the embarking and disembarking passengers. The sum of the velocity of all the vehicles divided by the number of cars (this summation is done over a certain sample time T), after dividing this summation by T, one will obtain the average velocity.
The mean velocity is given by the next formula (this formula remains accurate for every scenario) (H.B. Zhu, 2010):

$$v = \left(\frac{1}{T} \sum_{t=t_0}^{T+t_0-1} \frac{1}{N} \sum_{N}^{n=1} v_n\,(t) \right) \tag{2}$$

With:
- T: A selected sampling time interval
- $v_n(t)$**:** Velocity of the n^th^ vehicle at time t
- N: The number of vehicles

7.1.2 Capacity analysis

A traffic system can be compared with a demand-supply model in the economy, when the demand (flow) exceeds the supply (critical density) one can get in to trouble. In this case this will lead to congestion. Congestion can be subdivided in two types. The first one is slow traffic congestion, where the vehicles still have a minimal velocity. The second one is stationary traffic, where one will notice no more movements between cars. In the case study one will define a vehicle as queuing when its velocity is below a value of 5 kilometres per hour, this situation will end when its speed reaches a value of 10 kilometres per hour or more. The capacity can be explained by the figure below, and is equal to the point where the flow is maximal and the corresponding speed is equal to the maximum velocity, v_{max}. Similarly the velocity corresponds with a speed where vehicles move in a free flow. This also coincides with a critical density (k_c) and is the maximum density a lane can carry before the flow will begin to decrease and the density will start to increase. After this point the vehicles will move by the speed of the wave. To put it in another way, they will just follow the speed determined by the congestion.

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[2] One will derive the values for vmaxF, vmaxs and v from our case study, vmaxF for example will be the average velocity a car has during its stay on the selected road.

This maintains until one arrives in a situation where the traffic is jammed and the velocity becomes equal to zero. This corresponds with the jam density (k_j).

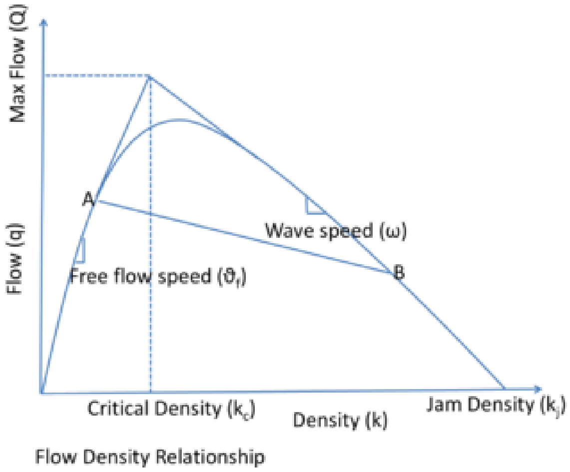


Figure 7.1: Relationship between flow and density (source: https://en.wikipedia.org/wiki/Traffic_flow)

On average a two-lane street with left turn lanes can carry 16,000 vehicles per day. (M. Spack, 2011). The capacity depends on many factors. In the example of this paper one will have to look for the lane group capacity for an approach to a signalized intersection. The first aspect one needs to know to define the capacity is the effective green light per cycle ratio (= g/c). The second aspect is the number of lanes (N). This seems obvious because two lanes can carry more cars compared to one lane. The next factor is a heavy vehicle adjustment factor (f_{hv}). This factor depends on the facility type, vehicle mix and the grade of the road. In this case study one may neglect the grade. Next is the proportion of heavy vehicles (P_T). Heavy vehicles are trucks and buses. The aspect that defines the heavy vehicle adjustment factor is the passenger-car equivalent for heavy vehicles. This represents the number of passenger cars that would use the same amount of freeway capacity as one truck/bus, under prevailing roadway and traffic conditions (N.J Garber and L.A. Hoel, 2014). Another factor that defines the capacity is base saturation flow rate per lane (pc/h/ln) and is symbolized by s_0. f_W is yet another factor that is of importance in the calculation of the capacity. It stand for the lane width adjustment factor. The table below will summarize the factors per width. Attention, f_W is only used in lanes with a width of 8 ft or more (N.J Garber and L.A. Hoel, 2014).

Average lane width (ft)	Adjustment factor (f_W)
<10	0,96
≥10-12,9	1,00
>12,9	1,04

Table 7.2: Adjustment factor (source: N.J. Garber and L.A. Hoel, Traffic and Highway Engineering SI Edition, 2014)

Next one needs to look for the grade adjustment factor, f_g, because the slope of the approach has an impact on the speed of all the vehicles. In this case study there also exists an on-street parking within 250 ft upstream of the stop line. Thus, one will need to insert a parking adjustment factor, f_p. This is because parking vehicles will disturb the non-parking vehicles. And because not all lanes are utilized equally one needs to correct the ideal saturation flow rate s_0. This is done by the lane utilization adjustment factor, f_{LU}. The area type adjustment factor, f_a, is used in streets with typical central business district characteristics such as frequent parking manoeuvres, narrow streets etc. Here one will use a f_a value that is equal to 0,9 (N.J Garber and L.A. Hoel, 2014). Next, if there are many buses driving on the selected street other vehicles could loose plenty of time due to the frequent stops of buses. This can result in a decrease in the maximum volume that can be handled by the lane and is related to the number of buses per hour that stop on the travel lane within 250 ft upstream or downstream. This decrease in capacity needs to be inserted in the formula and is symbolized by f_{bb}. The last four factors that could influence the capacity are linked with the left and right-turn movements. The first one discussed here is the right-turn adjustment factor for a protected movement on an exclusive lane, f_{RT}. This factor is the factor that reflects the effect on the saturation flow caused by a right-turn. The same needs to be done for the left-turn adjustment factor for a protected movement on an exclusive lane, f_{LT}. The last two-adjustment parameters that could influence the capacity (the adjustment for pedestrian-bicycle blockage on left turns, f_{Lpb} and the adjustment for pedestrian-bicycle blockage on right-turns f_{Rpb}) are both computed in the same way. Because the case study contains an intersection where pedestrians and bicycles have the ability to have a major impact one will need to go through a complex procedure for the calculation of these two factors, this procedure can be found in the Appendix page 77.

To end this complex and theoretical paragraph one will now provide the entire formula for the lane group capacity that approaches a signalized intersection (N.J Garber and L.A. Hoel, 2014). Namely,

$$s = \frac{g}{c} s_0 N f_W f_{HV} \, f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} \tag{3}$$

The previous paragraph encompasses the capacity of the road now one will look at the capacity of the queuing system. In the queuing theory one will normally use the Kendall's notation, the basic notation is given below (J. Sztrik, 2016):

A / B / m / K / n/ D,

With

A: Distribution function of the interarrival times

B: Distribution function of the service times

m: Number of servers

K: Capacity of the system, the maximum number of customers in the system including the one being serviced

n: Population size, number of sources of customers

D: Service discipline

In this study it will be clear that the capacity of the system is infinite. This because the vehicles that arrive in the queue will never be rejected no matter how many queuing cars there will be. Thus, one may neglect the K value for this case study.

7.1.3 Service system

There are many different methods to explore the service system of vehicles. In this paragraph one will apply a mathematical approach. To get a good understanding of the service systems one could employ the queuing theory, this theory is of excellent help because this paper mainly deals with queuing vehicles in front of traffic lights. The situation goes as follows, vehicles are arriving at a traffic light with a rate equal to λ and with a

certain probability distribution function. When the light is red they will have to wait, when doing this they are creating queues. The number of queues is equal to number of lanes. These queues will only disappear when the server (e.g. traffic light) turns green, this means that the server (e.g. traffic light) is available and can carry out its service (cars can claim the right to pass through an intersection). First one will symbolize everything. The most important parameter here is the average rate at which people are served and is characterised by μ. This parameter will determine the probability distribution function of x people being served per time period.
For example suppose that a doctor can help 6 customer per hour, the doctor will in other words serve μ=6/60 customer per minute. Knowing that μ=0,1 one can calculate the probability of a patient being served within 10 minutes. One assumes here an exponential probabilistic distribution, which commonly used is situations like these.

$F(x; \mu) = 1- e^{-\mu x} = 1-e^{-10*0,1} = 0,6321$

The same applies to the example for buses and cars in front of a traffic light. Here the average service rate is equal to the number of buses and cars that pass the traffic light per unit of time. It should be clear that one needs to separate the service time if a bus from the service time of cars. The service rate will also differ a lot from scenario to scenario. Another key parameter here is the presence of other customers in the service system. In this example the service rate of a bus will change a lot if there are vehicles in front of it. This is characterized by the probability of a system being empty, P_0. The probability of having i customers in the system is equal to P_i, where i stands for the number of customers in the system.
The most important aspect of the arrival is the statistical distribution of interarrival. In our example, the inter-arrival times are stochastic because we do not know exactly when the vehicles will arrive in the queue. This assumption will also be used to define the vehicle input in VISSIM. An example is given below.
Suppose that in a supermarket the mean number of arrivals 45 customers per hour is. This means that per minute λ = 45/60 = 0,75 customers arrive. What now is the probability that 1 (= x) customers arrive in one minute?

Poisson distribution: $P(x) = (\lambda^x \cdot e^{-\lambda})/x! = ((0,75)^1 \cdot e^{-0,75})/1! = 0,3543$

The symbols λ and i will from now on represent the average arrival rate and the amount of cars (customers) in the system respectively. The most important parameters in the queuing theory are summarized below (H. Brunel, 1994). It is important to note that the whole system relies on two factors, that is the average arrival rate and the average rate at which people are served.

Variable	Meaning	Formula
s	Number of servers	
λ	The average arrival rate of customers per time period	
i	The amount of customers in the system	
μ	The average rate at which people are served	

P	The probability that an item us waiting to be served	$\frac{\lambda}{\mu}$
P_0	The probability of a system being empty	$1-\left(\frac{\lambda}{\mu}\right)$
P_i	The probability of having i customers in the system	
P_n	The probability that n customers are in the system	$(1-P)P^n$
L	The number of customers in the system (waiting + being served)	$\frac{\lambda}{\mu-\lambda}$
L_q	The number of customers in the queue	$\frac{\lambda^2}{\mu(\mu-\lambda)}$
L_s	The number of customers being served	
W	The average time a customer waits in the system	$\frac{1}{\mu-\lambda}$
W_q	The average time a customer waits in the queue	$\frac{\lambda}{\mu(\mu-\lambda)}$
W_s	The average time a customer waits to be served	$W_q+\frac{1}{\mu}$
ρ	The traffic intensity	$\frac{\lambda}{s\,\mu_0}$
K	The traffic intention	$\frac{\lambda}{\mu_0}$

Note: The service rate must be greater than the arrival rate, that is, $\mu > \lambda$. If $\mu \leq \lambda$, the waiting line would eventually grow infinitely large. Before using the formulas, check this condition.

7.1.4 Interaction (Lane changing rules)

There will be no lane changing rules because we are restricted to the use of one lane.

7.1.5 Ratio of the number of buses to the total number of vehicles(R)

(H.B. Zhu, 2010)

$$R = \frac{Number\ of\ buses}{Total\ number\ of\ vehicles} \tag{4}$$

7.1.6 Density

Vehicle density (k) can be defined as the number of vehicles per unit of length. When talking about traffic flow, one may determine two important densities, namely the critical density (k_c), which is the maximum density available under free flow. And the jam density (k_j) which equal to the maximum density achieved under congestion. Studies have found that in general the jam density is seven times the critical density (H.B. Zhu, 2010). The formula for the total density is:

$$k = \frac{N}{\Delta x} \qquad (5)$$

For this case study it is important to subdivide the density into the density of fast vehicles (cars) and slow vehicles (buses). The partial density for fast cars is characterized by the symbol k_f and the partial density for slow cars is symbolized by k_s. The formulas are given below (H.B. Zhu, 2010):

$$k_f = \frac{N_F}{\Delta x\ L} \qquad k_s = \frac{N_S}{\Delta x\ L} \qquad k = \frac{N}{\Delta x\ L} \qquad (6) \quad (7) \quad (8)$$

The density, k, is in general the number of vehicles, N, divided by the distance, Δx. But when dealing with multiple lanes one needs to divide the density also by the number of lanes, L. If we now introduce the bus ratio R ($0 \leq R \leq 1$) we may adjust our formulas (H.B. Zhu, 2010):

$$k_s = k \cdot R \qquad k_f = k \cdot (1 - R) \qquad (9) \quad (10)$$

Where R is the ratio of the number of buses to the total number of vehicles, while (1-R) is the ratio of the non-bus vehicles to the total number of vehicles. With these formulas one will obtain the same result as in formula (9) and (10).

With:
- k: Total density
- k_s: Density of slow vehicles (buses)
- k_f: Density of fast vehicles (cars)
- N_f: The number of cars
- N_s: The number of buses
- $N = N_f + N_s$: The total number of vehicles
- L: The number of lanes
- Δx**:** The length of the roadway

7.1.7 Flow

The mean flow, q, is in general equal to the density, k, multiplied with the velocity, v. The formula of the mean flow is given below (this formula also remains accurate for every scenario) (H.B. Zhu, 2010):

$$q = k \cdot v \qquad (11)$$

With:
- q: Mean flow
- k: Global vehicle density
- v: Mean velocity

7.2 Scenario 2: The ordinary one-lane, with bus priority

This scenario is the same as the first one, the only difference is the use of the TSP system, this system gives the buses the possibility to interfere with the traffic signals, but because one is here restricted to the use of one lane for both cars and buses, it will be clear that the advantages of this system will be very limited.

7.2.1 Service system

One may assume the same service system as the first scenario, because earlier the assumption has been made that the change in the traffic light system will not affect the service system of cars because the traffic lights will rebalance the red and green light periods in a way that will not seriously inflate the delay of cars.

7.3 Scenario 3: The ordinary two-lane, without bus priority

7.3.1 Velocity

The velocity here will again be subdivided into v_{max}^F, v_{max}^s and v corresponding with the fast, slow and mean vehicle velocity respectively, just like in the first scenario. In this situation one is not obligated to subdivide the cars into cars that are bothered by buses and the ones that are cars not, because cars now have the possibility to change from lane in order to pass the slow bus. When one is dealing with congestion v_{max}^F and v_{max}^s will have the same value, this because a bus has no priority and will be stopped by traffic. Because the number of lanes has increased by one, it will be clear that the capacity will also increase, this results in a v_{max}^F value that will stay much longer at its optimal value. The formula for the mean velocity remains unchanged.

7.3.2 Capacity analyse

The difference in capacity of a system with two lanes and the one discussed in scenario 1 is that the capacity of a street with two lanes will be on average two times higher compared to the capacity of system with only one lane. This is proven in formula (3) where N stands for the number of lanes.

7.3.3 Service system

The service system will also change a lot if one increases the number of lanes by one. The number of servers is now equal to two. This will have the consequence that the previous discussed formulas change. The most important parameters in the queuing theory are summarized below (H. Brunel, 1994):

Variable	Meaning	Formula
s	Number of servers	
λ_k	The average arrival rate of customers per time period	$\lambda \quad , \quad n \geq 0$
i	The number of customers in the system	
n	The number of working server	

μ_k	The average rate at which people are served	$\begin{cases} n\mu & , \quad 1 \le n \le s \ , \\ s\mu & , \qquad \ge s \ . \end{cases}$
P	The probability that an item us waiting to be served	$\lambda \,/\, s\,\mu$
P_0	The probability of a system being empty	$\left[\sum_{n=0}^{s-1} \frac{(s\rho)^n}{n!} + \frac{(s\rho)^s}{s!}\left(\frac{1}{1-\rho}\right)\right]^{-1}$
P_i	The probability of having i customers in the system	
P_n	The probability that n customers are in the system	$\begin{cases} \frac{(s\rho)^n}{n!} P_0 & for\ 1 \le n \le s \\ \frac{s^s \rho^n}{n!} P_0 & for\ n \ge s \end{cases}$
L	The number of customers in the system (waiting + being served)	$\lambda\, W$
L_q	The number of customers in the queue	$\frac{P_0 (\lambda/\mu)^s P}{s!\,(1-P)^2}$
L_s	The number of customers being served	
W	The average time a customer waits in the system	
W_q	The average time a customer waits in the queue	$\frac{L_q}{\lambda}$
W_s	The average time a customer waits to be served	
ρ	The traffic intensity	$\frac{\lambda}{s\mu}$
K	The traffic intention	$\frac{\lambda}{\mu_0}$
$\overline{N}$	Average number of clients in the system	$s\rho + P_0 \frac{\rho (s\rho)^s}{s!\,(1-\rho)^2}$
$\overline{N}_s$	The average number of occupied servers	sp
q	The probability that a customer has to wait	$\frac{\frac{(s\rho)^s}{s!\,(1-\rho)}}{\sum_{k=0}^{s-1} \frac{(s\rho)^n}{n!} + \frac{(s\rho)^s}{s!\,(1-\rho)}}$
σ_N^2	Variance of the number of client in our system	$\sum_{n=0}^{\infty} n^2\, p_k - (\overline{N})^2$

Note: The service rate must be greater than the arrival rate, that is, $s\mu > \lambda$. If $s\mu \le \lambda$, the waiting line would eventually grow infinitely large. Before using the formulas, check this condition.

7.3.4 Interaction (Lane changing rules)

In an ordinary two-lane without bus priority, it is assumed that the lane changing rules are determined by the symmetric rules (Chowdhury et al, 1997). The probability that a vehicle changes lane is p_{lc} (the probability is assumed to be 1). Additional to the incentive of change it is also important to include a safety factor, to such a degree that vehicles can change lanes without endangering themselves or other road users. The rules will imply that drivers have the incentive to change when the current empty sites (d_n) in front of the vehicle is less than the minimum accelerated velocity at the next step and the maximum velocity. One may conclude that it will be save to change lane if the gap between the vehicle and its predecessor is bigger than the its velocity. A second condition is that the gap between the vehicle and its successor in the target lane is bigger than the safety distance. The formulas for these incentives are given below.

- Incentive criterion:

$$d_n < \min(v_n + 1, v_{max}) \tag{12}$$

- Safety criterion:

$$\begin{aligned} d_{pred} &> d_n \\ d_{succ} &> d_{safe} \end{aligned} \tag{13}$$

With:

- v_n: The velocity of the n^{th} vehicle at time t
- d_n: The current empty sites in front of the n^{th} vehicle ($d_n(t) = x_{n+1} - x_n - 1$)
- x_n: The position of the n^{th} vehicle at time t
- x_{n+1}: The position of the $(n+1)^{th}$ vehicle at time t
- d_{prep}: The gap between the n^{th} vehicle and its predecessor
- d_{succ}: The gap between the n^{th} vehicle and its successor
- d_{safe}: The safety distance, i.e. the maximum possible speed of the vehicle succeeding on the target lane

7.4 Scenario 4: The ordinary two-lane, with bus priority

This scenario is the same as the third scenario the only difference is the presence of the TSP system, because we are not making use of a BLIP or DBL system, it will be clear that the advantages of this system will be very limited.

7.4.1 Service system

One may assume the same service system as the third scenario, the only thing that could change is the time a server is available (green light) or is not available (red light). But because one made the assumption that the decrease in green light for the side streets and the increase in the green light of the main road will be rebalanced back to its original mode, one can make the assumption of a stable service system.

7.5 Scenario 5: A dedicated bus lane on a two-lane road

7.5.1 Velocity

The velocity will again be subdivided into v_{max}^F, v_{max}^s and v corresponding with the fast, slow and mean vehicle velocity respectively. The meaning of the symbols remain unchanged, what does change is the assumption that v_{max}^F and v_{max}^s will have the same value when there is congestion, because v_{max}^s (velocity of a bus) here will not be interrupted by traffic. Also v_{max}^F will decrease very fast when one increases the density, this because of the capacity loss. The formula of the mean velocity will remain the same.

7.5.2 Capacity analyse

By now one knows the consequences on the capacity when introducing a dedicated bus lane. The decreased in capacity is a logic response because vehicles other than buses will now have one lane instead of two. A study (M. Eichler and C.F. Daganzo, 2006) has developed a formula for this decrease caused by the insertion of a dedicated lane:

$$\left(\frac{100}{L}\right)\% \tag{14}$$

With

L = The number of lanes

The decrease in capacity can also be defined in another way. Namely, the capacity will decrease to a capacity equal to q_D. The formula is given below (M. Eichler and C.F. Daganzo, 2006):

$$q_D = q_M \frac{(L-1)}{L} \tag{15}$$

With:

q_M= The maximum flow = The system capacity

q_D= The capacity of the reduced system = The bottleneck capacity

7.5.3 Service system

Because of the change in the available lanes for both buses and cars one may assume a big difference in the service system . As a result the queuing discipline will separate the queues of cars from the queues of buses. Buses may only queue on their lane while cars may only queue on the other lane. One assumes that the time a server is available will be equal for both cars and buses. One will now have two individual roads with one lane. This means that the formulas from scenario three are no longer valid. One will need to make use of the formulas seen in scenario one. These formulas will be used for cars and buses separately.

7.5.4 Interaction (Lane changing rules)

In the DBL there are no lane changing rules because cars and buses move completely separated. A bus for example will stay on the right lane while cars move on the left lane. Because only two lanes are available, cars will not have the ability to pass other cars.

7.6 Scenario 6: A dedicated bus lane on a two-lane road with bus priority

7.6.1 Service system

The only change compared to the previous scenario will be the service system, this because buses now have the ability to extend the green signal. One has assumed earlier that this change will not affect the service system of cars because the traffic lights will rebalance the red and green light periods in a way that will not seriously inflate the delay of cars. The only advantage will be that the server is continuously available for buses, in other words the service system for buses is near its maximum.

7.7 Scenario 7: A bus lane with intermitted priority on a two-lane road

7.7.1 Velocity

In a road with two lanes there are two types of vehicles driving side-by-side, these two vehicles can be characterized by their difference in velocity, namely v_{max}^F and v_{max}^s, corresponding with the fast and slow vehicle respectively. The fast vehicle is assigned to the velocity of a car, while the slow vehicle corresponds to the velocity of a bus. The difference between our previous scenario is that the value v_{max}^F now will decrease less fast when our density is increased, this because in a BLIP system, cars can often still make use of the capacity of a bus lane.

7.7.2 Capacity analyse (M. Eichler and C.F. Daganzo, 2006)

In this analyse one may see, as described in section 2.2, a BLIP system as a set of cocoons (e.g. bus-lane sections with time-width equal to two cycle lengths), these cocoons will exclusively be in use of buses. A cocoon begins at the rear bumper of a bus and extend their length until a fixed distance in front of the bus. This extension will be determined per block, and will not move along with the movements of a bus. The cocoon is completely cleared from non-bus vehicles such that buses will not suffer from any delays. In the image below you may find an example of a cocoon, here is the cocoon represented by the orange surface.

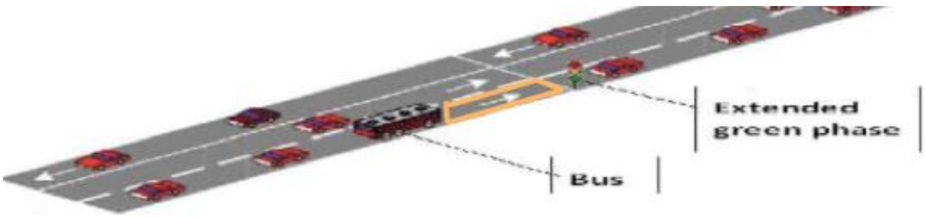


Figure 7.2: Cocoon

For example if a bus is on its way to a traffic light, the variable message signs (VMS) will clear the distance between the bus and the traffic light (e.g. the cocoon) from non-bus vehicles. By doing this the bus can pass the traffic light in a free flow and will not experience any difficulties. The same situation now with a red light, again

the variable message signs (VMS) will clear the distance between the bus and the traffic light (e.g. the cocoon) from non-bus vehicles, the difference is now that in scenario 8 the bus driver has the possibility to make use of its transit signal priority (TSP), this will change a red light into a green one such that the bus can again pass the traffic light in a free flow and without any obstacles. If we compare this with the same situation but on an ordinary two-lane, the bus will have to wait until the vehicle queue in front of him has passed the traffic light.
A drawback of this system is the loss of capacity due to the restriction of one lane. This may result in bottlenecks and delays. But these negative effects are nearly as bad as the loss of capacity one has due to a DBL system. These bottlenecks will form the subject of this paragraph and are mainly based on two studies, the first one is the representation of the bottlenecks (Shaheen et al, 2005) and the second one is based on the kinematic wave theory (Lighthill and Whitham, 1955). In these studies and also in this paper the first assumption that needs to be made is that intersections are sufficiently separated. This assumption is made to prevent the queues to spill back. So the system capacity will be equal to the maximum flow with signals (M. Eichler and C.F. Daganzo, 2006):

$$q_M = \frac{q_C g}{c} \tag{16}$$

With:
- g: Green phase
- c: Cycle length
- q_M: Maximum flow with signals
- q_c: Flow at a state where we have a full road with a free flow

Other assumptions:

- Signals run with the same cycle c and green light phase g, meaning all signals on the road have the same cycle lengths and the same percentage of green time.
- Turning traffic will be ignored.

In the case study one will implement some of these assumptions into the model developed in VISSIM. This program makes it possible to visualize an intersection without having to make all these assumption. Thus, the case study will provide a model that is closer to the reality.

As stated earlier, in this scenario one may see a bus as a moving bottleneck. This phenomenon will divide traffic into two parts. The first part will be the downstream traffic, these are the vehicles that drive before the bus and are not delayed by it, referred as state (D). While the second part will be the upstream traffic, they travel behind the bus and are delayed by it. They travel in a congested state (U). The flow at situation D (q_D) is assumed to be the capacity of the reduced system, this capacity includes the effects caused by signals and is also called the bottleneck capacity (M. Eichler and C.F. Daganzo, 2006):

$$q_D = \frac{q_m\,(L-1)}{L} \tag{17}$$

With:
- q_D: Flow of downstream traffic (in front of the bus), also known as the capacity of the reduced system or the bottleneck capacity
- q_M: Maximum flow with signals
- L: Number of lanes

A bus travels at an average speed of v_{max}^{s}. In the situation where a bus travels at a sufficiently high speed one will notice that the flow of q_U will exceed the flow of q_D and will approach the flow of q_M. And because the flow at state U is the maximum flow in this scenario one obtains q_{Max} = q_M= q_U. This proves that the introduction of a single BLIP bus does not significantly reduce the capacity, which was q_M to begin with. Comparing this capacity drop with the capacity drop caused by the introduction of a dedicated lane, which was equal to a drop from q_M to q_D, one can conclude that the introduction of a BLIP is notably less harmful compared to an introduction of a dedicated bus lane, when the demand exceeds q_D.
Until now one has assumed the presence of only one bus. On the next paragraph this assumption is expanded to multiple buses.

In this situation the BLIP makes up a portion of length l of the road and the buses follow each other separated by a length H (headway).
Assumptions:

- Buses are not coordinated with signals
- The time-dimension of the cocoon (which is comparable with the cycle c) is small compared with the headway (i.e. c << H)

The car-carrying capacity of a system with multiple buses, and with small headways in between buses can be calculated by prorating the maximum flows in the band and the inter-band regions (which are the regions between buses). In this situation one may not neglect the value of the cocoon length. The incorporation of the value is due to the fact that the distance between the buses is small. One will obtain the following formula for the car-carrying capacity when introducing the cocoon and headway lengths (M. Eichler and C.F. Daganzo, 2006):

$$q_{Max} = q_D \left(\frac{\hat{C}}{H}\right) + q_U \left(1 - \frac{\hat{C}}{H}\right) \text{ for } H \geq \hat{C} \tag{18}$$

With:
- q_D: The flow of downstream traffic (in front of the bus), also known as the capacity of the reduced system or the bottleneck capacity
- q_U: The flow of upstream traffic (behind the bus)
- $\hat{C}$**:** The length of the cocoon
- H: The length in which buses follow each other (headway)

The flow q_U will in this situation always be in use and $q_U \approx q_M$. If we use this information and in combine formula (17) and formula (18) one will find the following formula for the car-carrying capacity (M. Eichler and C.F. Daganzo, 2006):

$$q_{max} \approx \left[1 - \frac{\hat{C}}{LH}\right] q_M \tag{19}$$

With $\hat{C}$/LH as the fractional reduction in the street's car-carrying capacity caused by the BLIP.

7.7.3 Service system

Here the service system will change dramatically. In this situation there will be an alternation between the service system obtained in scenario three and the service system of scenario five. The former one is used when cars are allowed to use the bus lane, the latter one will be used when cars and buses are completely separated.

7.7.4 Flow (M. Eichler and C.F. Daganzo, 2006)

The capacity change caused by the introduction of a BLIP will result in an increase of the "average pace". The average pace is an expression for the average number of minutes required to travel one mile. One will first take a look at the effect it has on cars, afterwards one will take a look at the consequences it has on the bus flow.

Assumptions:

- The average speed of a bus is in a way such that $q_M \approx q_U$
- The demand is in the range $q_A \in [q_D, q_U]$

7.7.4.1 Automobile delay caused by BLIP

In the case study one will estimated the chances of success for a certain bus lane type based on the delay for all vehicles. For this reason one will choose to devote this paragraph to the delay of both vehicles and buses caused by the introduction of a BLIP. First one will need to make a distinction between a long and short road.

7.7.4.1.1 A long road

For a long road one will use the symbol Δ to denote the increase in the vehicle-minutes of automobile travel induced by one bus-kilometre. The study has chosen that the increase in travel time will increase linearly with, the demand, q_A, with a difference between the average bus paces equal to $1/v_B$ and the prevailing bus pace equal to 1/u. (M. Eichler and C.F. Daganzo, 2006).

$$\Delta = |AS| H = (q_A - q_D)\left(\frac{1}{v_B} - \frac{1}{u}\right) H \text{ for } H >> c \tag{20}$$

To obtain the overall delay incurred by the intermitted priority lane one will have to introduce the length of a cocoon, $\hat{C}$, this situation will bring us to state D which corresponds with a bus that travels at a free-flow speed, this will lead to an increase of the overall average speed between bus headways. The formula for Δ will change into (M. Eichler and C.F. Daganzo, 2006):

$$\Delta = \left(1 - \frac{\hat{C}}{H}\right)(q_A - q_D)\left(\frac{1}{v_B} - \frac{1}{u}\right) H \text{ for } H \geq c \tag{21}$$

Which leads to a penalty that is (1- $\hat{C}$/H) smaller than the previous one.

7.7.4.1.2 Short roads

When evaluating the consequences on a short road one will notice that the delays discussed earlier will overestimate the BLIP penalty. In case of short roads one only needs to include a penalty in the first x_0 miles of the road, this length is equal to the distance between the buses divided by two. One may neglect the length of the wedge. Thus one will obtain the following formula (M. Eichler and C.F. Daganzo, 2006):

$$\text{Total VHT penalty per bus} = \Delta\left(L - \frac{x_0}{2}\right) \quad \text{if } L \geq x_0 \tag{22}$$

If $L \leq x_0$, the formula for the penalty will become (M. Eichler and C.F. Daganzo, 2006):

$$\text{Total VHT penalty per bus} = \left(\frac{1}{2}\right)(\Delta L^2 x_0) \quad \text{if } L \leq x_0 \tag{23}$$

7.7.4.2 The effect of a BLIP system on bus pace

A BLIP will have some positive effects on the travel time for buses compared to ordinary roads, the bus pace will reduce from b to b_0, so the passenger-minutes saved per bus-km travelled can be formulated as (M. Eichler and C.F. Daganzo, 2006):

$$\delta = o(b - b_0) \tag{24}$$

With:

- δ: Passenger-minutes saved per bus-km travelled
- o: The number of passengers in the average
- τ: The bus stop-time per kilometre
- $p = 1/u$: The current pace
- $p_0 = 1/v_0$: The traffic free pace
- p_f: The signal-free pace
- τ: The bus stop-time per kilometre
- $b = p + \tau$
- $b_0 = p_0 + \tau$
- $b_f = p_f + \tau$

7.7.5 Interaction (Lane changing rules)

For this scenario it will again be possible to change lane, here the rules will differ from the situation discusses in section 7.3.4 but the method will be again based on the asymmetric lane changing rules proposed by Chowdhury (Chowdhury et al, 1997). The rules are named asymmetric because cars and buses will follow different lane changing rules and additionally the rules for moving from the left lane to the right lane will differ from the movements from the right lane to the left lane (knowing that the right lane is reserved for buses). For this reason one will make a separation for these movements. The rules are given below.

1. <u>Rules concerning the movement from the left lane to the right lane</u> (with a probability equal to P_{lc}. The meaning and symbols remain unchanged for this one would like to refer back to section 7.34). The rule for a BLIP are represented below (Chowdhury et al, 1997):

- Incentive criterion: $d_n < \min(v_n +1, v_{max})$ (25)

- Safety criterion: $d_{pred} > v_{max}$, $d_{succ} < d_{safe}$ (26)

These rules report that car drivers will have the incentive to change the lane when the current empty sites in front of him is smaller than the his accelerated velocity or the maximum velocity. Furthermore a car driver is able to change in a safe way if the gap between his car and its predecessor in the intended lane is larger than his maximum velocity and the gap between his car and its successor in the intended lane is larger than the safety distance.

2. <u>Rules concerning the movement from the right lane to the left lane</u> (Chowdhury et al, 1997):

- Incentive criterion: $d_{pred} < \min(v_n +1, v_{max})$ (27)

- Safety criterion: $d_{pred} > v_{max}$, $d_{succ} < d_{safe}$ (28)

In this rule a car driver has the incentive to change to another lane when the gap between his car and its predecessor is larger than the accelerated velocity in the next step and his maximum velocity. Furthermore a car driver now will be able to change in a safe way if the gap between his car and its successor is in the intended lane is larger than the safety distance.

7.8 Scenario 8: A bus lane with intermitted priority on a two-lane road with TSP

7.8.1 Service system (M. Eichler and C.F. Daganzo, 2006)

The introduction of a TSP system has the advantage of a further reduction of the bus pace b_f. The disadvantage is that it is more complex and that it could disrupt the automobile traffic.
Assumptions:

- Buses can pre-empt signals by shortening the red phase, they will do this in the most efficient way
- Buses will arrive at a signal immediately downstream of a stop independently of its cycle

Under these assumptions one may conclude that the probability of a bus arriving during the red phase is equal to (M. Eichler and C.F. Daganzo, 2006):

$$\frac{r}{c} \quad (29)$$

To handle the arrivals, the red phase will on average have to be reduced by 1/4 of its length, thus 1/4r. This brings us to an expected reduction in red time per bus arrival of (M. Eichler and C.F. Daganzo, 2006):

$$\left(\frac{r}{c}\right)\left(\frac{1}{4}\right)r = \frac{\frac{r^2}{4}}{c} \tag{30}$$

Also side streets feel these changes in red light, to leave them as unaffected as possible, one further assumed that the reduction in their green time due to passage of a bus is dissolved in the following cycles with an increase in green time of the same magnitude. This means that the red time of the main road will increase in the headway following the passage of a bus by an amount averaging $((1/4)r^2)/c$. The net loss of arterial capacity at an intersection is equal to (M. Eichler and C.F. Daganzo, 2006):

$$\text{Capacity loss due to TSP} = \left[\frac{\frac{r^2}{4}}{cH}\right]\left[\frac{q_M}{L}\right] \tag{31}$$

This should normally be a small number. With all aspects taken into consideration one may conclude that the introduction of a TSP will not seriously harm the delay of the other road users.

Now that one has analysed the theoretical part of the bus lanes. It is about time to begin with the case study itself. Before one begins with the case study a last theoretical part will be seen based on the possible methods that have the ability to compare the different types of bus lane priorities in an efficient way. Here one will discuss two possible approaches. The first approach is attributed to the simulation, while the last one is a more mathematical approach. In the case study one will prefer to use the first approach.

8 Methodology

8.1 Simulation (microscopic-cellular automata)

(S. Maerivoet and B. De Moor, 2005)

A first method to solve the problem discussed earlier is based on the use of simulations, more specifically microscopic-cellular automata. Cellular automaton is a specific computer model that can be used to study the organisation and comparison of certain events. In this case study one will make use of the model in order to find the best suitable bus lane type, this of course in combination with different kind of situations. Programs that make use of cellular automaton are based on the existence and movements of cells. A cell in this model can represent the place of an apartment, house, person, car etc. Four important characters define CA.

The first character is its special structure. The structure consists of a discrete rail of cells. These cells can be rectangular but can also have other shapes. The lattice can have one or more dimensions. For the study this means that the streets will be subdivided into cells, the length of a cell will be equal to the average length of a car, vehicles longer than the average car will occupy two cells. See the figure below. CA normally assumes a length (Δx) equal to 7.5 meters.

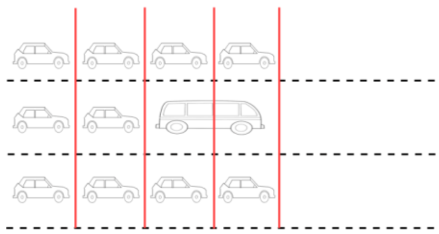


Figure 8.1: Representation cellular automaton

A second important aspect in CA simulation is the cells' state. Each cell has a specific state and these states are defined by integers. The cells' state can for example be binary. For instance if the cell is occupied it will have the number 1 otherwise one will use the number 0.

The cells' neighbourhood is another important aspect. The neighbourhood of a cell is important in order to forecast the evolution of a cell. In a one-dimensional model it is clear that the neighbourhood only consists of the cell itself and its adjacent cells. But in a more dimensional model we have multiple possibilities. The two most common ways to define the neighbourhood of a cell are the von Neumann neighbourhood and the Moore neighbourhood. The former one only includes (besides the cell itself) the north, east, west and south cell to the neighbourhood while the latter one also includes the north-east, south-east, south-west and north-west cells.

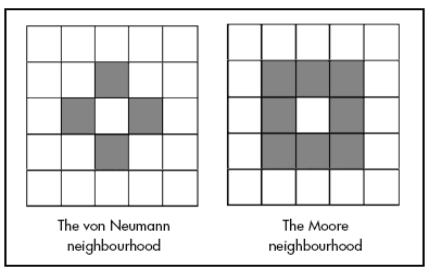


Figure 8.2: The cell's neighbourhood visualized in two ways

The final important characteristic is the local transition rule. This rule is of importance for the cell itself and its direct neighbourhood and will change the cell's state from one discrete time step (normally one will assume a time steps equal to 1 second, in other words Δt= 1s) to another. An example of the operation of a single-lane traffic cellular automaton is given below.

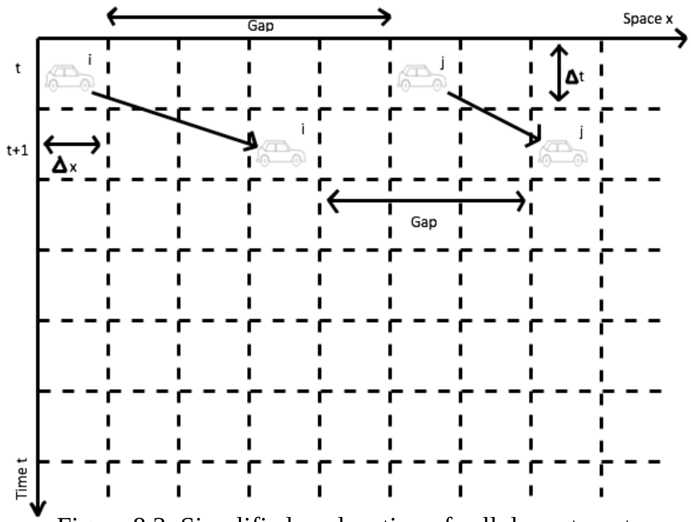


Figure 8.3: Simplified explanation of cellular automaton

In this figure one can see two vehicles, i and j, moving through the lattice. At time t the gap between the two cars is four cells, this while the gap between the two is only three cells at time t+1. The average speed of a car is equal to Δx/Δt, with this in mind and the knowledge about the distance between the two active cells one can easily determine the velocity. Of course this is a very simplified version of traffic in real life, to fully understand the scenarios discussed earlier one will need to expand this model and include all the parameters discussed earlier such as the car movements, agents, signs, also the lane changing behaviour of cars and the actions that take place at a roundabout, intersection, traffic light need to be included into the model and so on. When all the aspects that occur in real life are collected one needs to incorporate these aspects into a cellular automaton program. After doing this one will obtain the desired model.

VISSIM and SUMO are two commonly used micro simulation models for traffic engineering. An example of the case study by the use of SUMO is given below. But because of the advantages VISSIM provides one will choose to go on with VISSIM in the next part of the paper.

Figure 8.4: SUMO representation Rooigemlaan

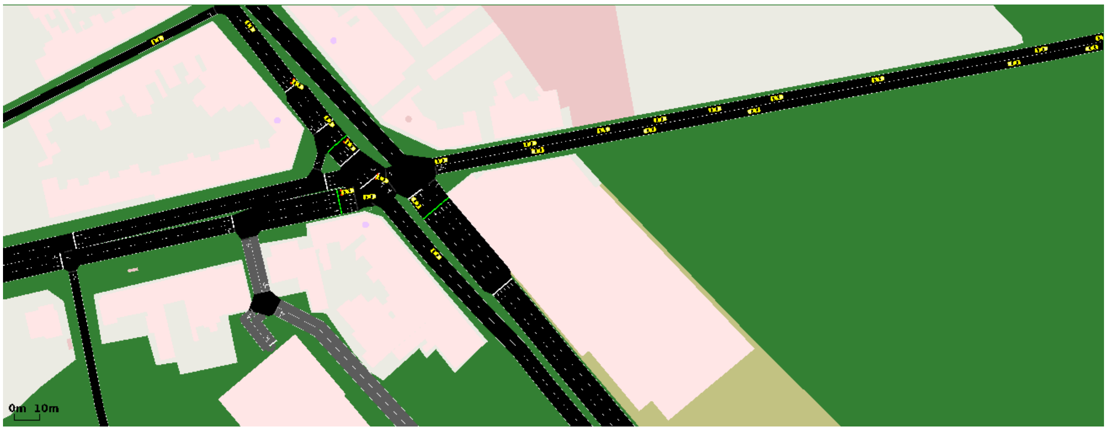


Figure 8.5: SUMO representation Rooigemlaan (2)

These figures are based on the circulation of traffic on the intersection between the Rooigemlaan and the Drongensesteenweg. Because a simulation is just a computerized imitation of a real-world system over time it will never cope with all the unexpected things that could happen in real life. The next technic will express a more mathematical side of traffic but because the level of complexity form the selected junction is very high one will not discuss this approach further into detail.

8.2 Analytic (queuing theory)

To begin this discussion one would like to point out that this section is based on the knowledge one obtained during courses of Queuing theory given by professor Herwig Bruneel.

The Queuing theory is a mathematical study on waiting lines or queues. This theory has the power to predict the development of the length of a queue (Sundarapandian, 2009). In traffic, the formation of queues can be formed for instance due to red lights, stop signs, bottlenecks, etc. The main objective of this paper is to handle traffic by optimizing the bus travel times. This optimization is made possible by taking multiple bus lane types into consideration and selecting the most optimal one according to the bus flow. In the example for this paper one will investigate the effect of a bus lane in the vicinity of traffic lights. Because the case here deals with traffic, and because traffic may be seen as a queue of vehicles, one can make use of the queuing theory to define the best suitable type of bus lane by determining the length of queues.

Situation 1

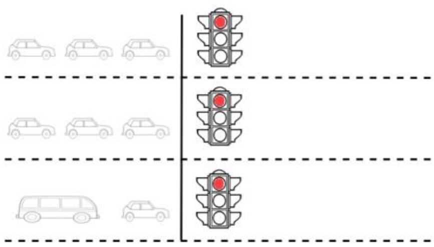


Figure 8.6: Red light, bus after queuing cars

Situation 2

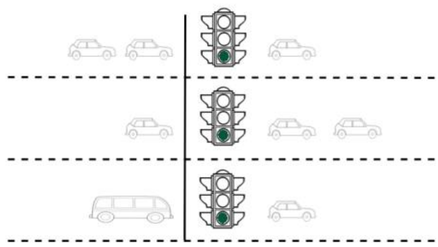


Figure 8.7: Green light, bus can pass the traffic lights after the queuing cars

There are two situations represented in the examples above. The first one is the situation where vehicles queue in front of a red light, the second one is where the red light turns into a green one and vehicles gain the permission to pass the traffic lights. If one now compares these situations with a general presentation of a queuing model (figure 8.8) it is safe to say that the objective of this paper is allied with the objective of the queuing theory. In this situation the customers are the vehicles. While these customers are waiting for a service (e.g. the permission to pass the traffic lights) from the server (e.g. the traffic lights) they are creating a queue. The vehicles only get the right to pass the lights when the server is available to perform its service, that is if the traffic light turning green.

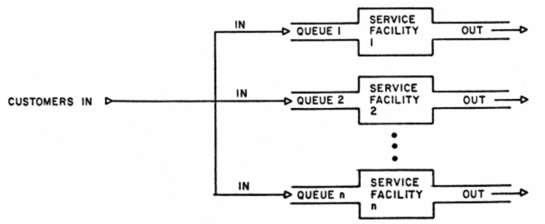


Figure 8.8: Queuing theory (three servers, three queues)

The queuing theory is subdivided into three parts, namely the arrival, the queue and the service. The following discussing will evaluate these parts more carefully. The Kendall's notation summarizes and symbolizes the six most important characteristics of the queuing theory. This notation is given below and has already been aggregated in section 7.1.2 (J. Sztrik, 2016):

$$A / B / m / K / n / D,$$

With:

1. A: The distribution function of the interarrival times,
2. B: The distribution function of the service times,
3. m: The number of servers,
4. K: Capacity of the system, the maximum number of customers in the system including the one being serviced,
5. n: The population size, number of sources of customers
6. D: service discipline.

Kendall's notation for the case study will be a M/M/m system. This means that the interarrival times have a Poisson distribution, while the service time have an Exponential distribution. The little m stand for the number of lanes in the case study and one may neglect the value K because there is no capacity limitation in the system. The value n will be obtained during the case study and the service discipline is of type FIFO, this will all be explained in the next sections.

The arrival

The most important aspects of the arrival are the statistical distribution of interarrivals (A), the interarrivals itself and the size of the population that arrives. The time between the successive arrivals for example can be known and fixed. In our example the interarrival times will be stochastic. This means that they will arrive at a time t with a certain probability, in this situation one cannot exactly determine the arrival times of the vehicles. This is important for the case study because one will use simulations to examine the effects of different scenarios, for this reason one will introduce the vehicle input as stochastic values. The probability distribution function of the interarrivals may in this case be seen as a Poisson distribution, because the process of queuing vehicles in front of a traffic light is an example of a specific type of continue distributions, this type is called the Poisson process. In this case one will use an exponential distribution for the service times. Other distributions that are often used for the interarrivals are the exponential, discrete or Erlang distribution. The next example gives an illustration of the interarrival process in relation to a queue. Suppose on average 45 customers arrive per hour in a supermarket. This means there will arrive $\lambda = 45/60 = 0,75$ customers per minute. What is now the probability that 1 (= x) customers arrive in one minute?

Poisson distribution: $P(x) = (\lambda^{x} \cdot e^{-\lambda})/x!$

$P(x) = ((0,75)^{1} \cdot e^{-0,75})/1!$ (Example see section seven)

$= 0,3543$

The symbols λ and i will from now on represent the average arrival rate and the number of cars (customers) in the system, respectively.

The queue

For the queue the most relevant characters are the queue discipline, the capacity and the number of queues. Commonly used queue disciplines are the first-in-first-out discipline (FIFO) and the last-in-last-out (LIFO). In the case study the former one will be most appropriate. For the case study one will select a road with two or more lanes, this means that the system will have two or more queues. The capacity is equal to the limited numbers of vehicles that the queuing model can carry at any time. This can be limited but it can also be infinite. In the case study the capacity of the system will be infinite, because it will not decline any vehicles.

The service

As for the service system one needs to obtain the statistical distribution of service times and the service design. The most important parameter here is the average rate at which people are served and is characterised by μ. For example suppose that a doctor can help 6 customer per hour, the doctor will in other words serve $\mu=6/60$ customer per minute. If one knows the value of μ (=0,1) one can calculate the probability of a patient to be served in 10 minutes or less. As discussed earlier, the distribution of the service times will for this example be equal to an exponential probabilistic distribution. Other distributions that are commonly used are the exponential, the discrete, the Erlang and the gamma distribution.

$F(x; \mu) = 1- e^{-\mu x}$

$= 1-e^{-10*0,1}$ (Example see section seven)

$= 0,6321$

The same applies for the example discussed in the case study. In the case study the average service rate is equal to the number of buses and cars that pass the traffic light per unit of time.

The service rate depends also a lot on the number of customers that are in the system. For this case study the service rate of a bus will change a lot if there are vehicles in front of it. And is characterized by the probability of a system being empty, P_0. The probability of having i customers in the system is equal to P_i, where i stands for the number of customers in the system. The fewer the number of vehicles that are queuing in front of the bus the faster the service time will be for that bus.

Also the number of queues, m, are of importance, in the case study this will be equal to the number of lanes, while the traffic lights will serve as servers.

The figure below represents the transitioning diagram of a queuing model, this example has k servers, this means that the moment the amount of customers in the system exceeds k a queue will be formed.

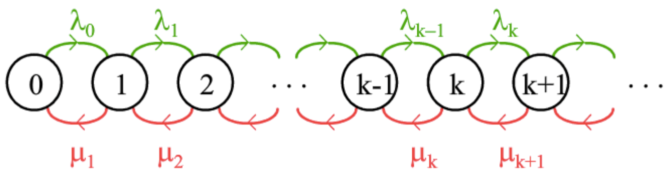


Figure 8.9: Queuing theory (arrival rate and service rate)

After gaining the basic information concerning the example one wants to examine, one can make use of analytical technics such as the little's law, the generating function, the pasta property etc. to compute the progress of the formation of a queue.

Little's law expresses that the average queue size (L, measured in vehicles) is equal to the arrival rate (λ , vehicles per unit time) multiplied by the average waiting time one needs to wait (both delay time in queue and activity time (W, in units of time)). The formula is given below (Little and Graves, 2008).

$$L = \lambda * W \tag{32}$$

Little's law may only be used if it is a system where customers arrive and stay for a certain amount of time and eventually leave the system. Another condition that needs to be met is that the $\overline{N}$, λ and T values are related to the same customer flow. A more general formula of little's law is given below.

$$\overline{N} = \lambda * T \tag{33}$$

The most important parameters in the queuing theory can be found in part seven explained per scenario. When writing down the parameters it became clear that one only needs the following three parameters to compute all other parameters.

Variable	Meaning
s	Number of servers
λ	The average arrival rate of customers per time period
μ	The average rate at which people are served

By now one will have an excellent basic insight of the evolution of congestion and public transport, the different types of bus lanes, the theoretical part and the applicability of these different types of bus lanes, the mechanism of queuing vehicles in front of traffic lights and as an end one has gained some information concerning the two most common manners in solving and analysing the discussed problem. One will here end the theoretical part of the paper and start with the more practical approach. This practical approach refers to a case study in Ghent. In this case study one will examine the consequences of the introduction of a bus lane on a selected street. This analyse will be supported by the use of VISSIM, as discussed earlier. To end this part one will discuss the applicability of each priority lane on the selected street based on a benefit-cost analysis.

PART II

9 Case study: Rooigemlaan and Drongensesteenweg, Ghent

9.1 Introduction

For the case study one has chosen to investigate the possibilities of the introduction of a bus lane on the Rooiegemlaan in Ghent. One has several reasons to choose this street, the most prevailing argument is that it is very dense street where buses lose a lot of time waiting in front of a traffic light, this aspect makes it very interesting to search for improvement. The particular part that one wants to investigate is indicated with a red circle on the figure below. This circle represents the intersection between the Drongegemsesteenweg and the Rooigemlaan. The interest in this paper will go to the area between the Appelstraat and the bus stop Eiland Malem.

Figure 9.1: Selected area for the case study

The goal will be here to appraise the possibilities for a bus to pass this intersection as fast as possible within the constraints stated in section 6. For this analysis one will employ the program VISSIM. VISSIM is a microscopic simulation tool that can easily be used to analyse the efficiency of traffic design. In that way one could for instance make changes to the design of a bridge, in order to measure the advantages or disadvantages of this change one will simulate the model of the new design and obtain some values that have the ability to compare the original model with a new one. In this case study one will not investigate the changes made to a bridge but one will change the priority of buses based on twelve scenario's. Each scenario will represent a difference or a combination of differences in the priority of a bus. The twelve scenarios are represented in the figure on the next page.

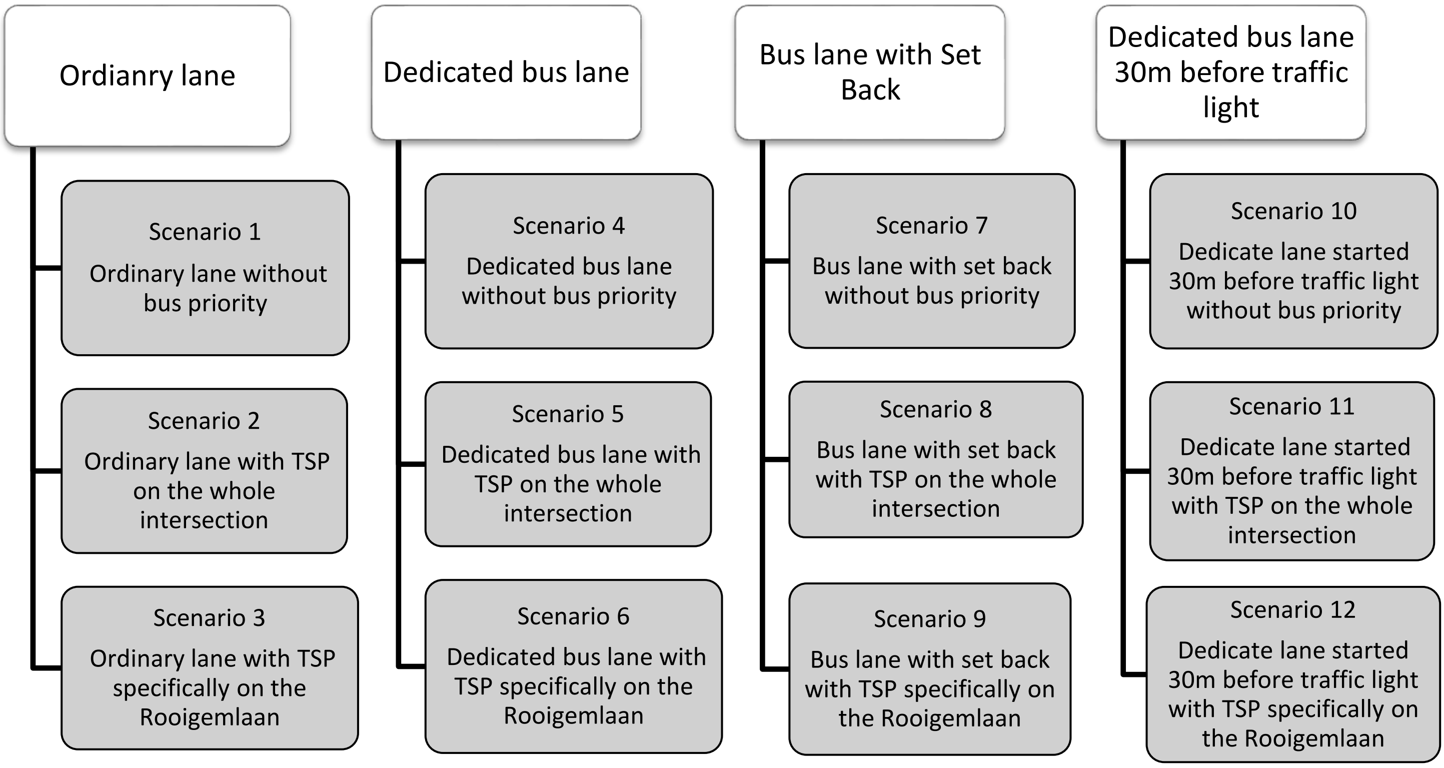


Figure 9.2: Scenarios

In the following sections one will model, simulate and compare the twelve scenarios. But first one will begin with a clear description of the selected road. This will be followed by a description on the parameters of the road afterwards one will begin with the explanation of the models.

9.2 Problem setting

Here one will begin with the description of the parameters discussed in the previous part of the paper. This will serve as a link between the theoretical part and the practical part. The main factors that one will consider here are the characteristics of the selected road and its main agents, the selected time span, the service system and the interarrival times.

9.2.1 Road characteristics

On page 99 in the appendix one can clearly see that the part of the Rooigemlaan in which one is interested contains four lanes at the arrival of the traffic lights. The two lanes on the left-hand side are the lanes that will turn left, while the two right lanes will drive straight on or make a right turn. In the case study one will neglect the possibility to make a right turn because only 1% of the vehicles will make use of this possibility. Another reason for this assumption is that the presence of this possibility will make it impossible to implement a dedicated lane.

As one mentioned in the introduction one will only look at the distance between the two bus stops (Appelstraat and Eiland Malem). This because this area contains the part that is most decisive, namely the intersection and its traffic lights.

The selected part of the Rooigemlaan contains two bus routes and four buses will make use of these routes. The buses with numbers 14 until 16 for example are buses that turn right while bus 9 will drive straight on to the bus stop “Appelstraat”. The table below summarizes the buses, the bus routes, their bus stops and their distances.

Case study intersection Drongensesteenweg-Rooigemlaan, Ghent					
Buses	Bus Stops				
Distance between Bus 14-15-16	Brughuis	230m	Malemstraat	690m	Einde Were
Distance between Bus 9	Appelstraat	302m	Eiland Malem		

Table 9.1: Buses, bus stops and their distances

In order to get a sight into the average delay buses obtain during the trip from “Eiland Malem” to “Appelstraat” one collected all the data concerning bus 9. With this information one could compute the delay times. After these calculations one could immediately see that the chosen intersection is a very interesting intersection because the time a bus needs to travel a distance of 690 meters will on average be twice the anticipated time. The information for these calculations have a time span of two weeks and is given in the Appendix in table 10.1. The results are showen in the table below.

	Anticipated Time	Average time needed	Anticipated speed	Average Real speed	Maximum time needed	Minimum speed
Bus 9	1 min	2 min 11 s	18,12 km/h	11,37 km/h	5 min 49 s	3,12 km/h

Table 9.2: Characteristics from bus 9

9.2.2 Selected time

Another decision one needs to make in order to get started is the time span. For this example one has chosen to work with the morning rush hours, these hours will be from 7:30 AM until 9:30 AM.

9.2.3 Service time

Based on the information one obtained and the information on the v-plan (see Appendix page 99) one could compute the average cycle length. The average cycle length at a rush hour will be equal to 105s, in extreme circumstances one will increase the cycle length up to 120s, in contrast during the off-peak hours the cycle time will reduce to only 90s.

It is also important to know that the buses at the selected traffic lights make use of the Transit signal Priority, in other words they have the power to extend the green light, but one has noticed that this priority is almost neglectable. The implied priority will only make sure that the buses will not have to wait too long for the green light to come. In the case study one will write a program that provides full bus priority, with this one means that buses will never have to wait for the green light to come.

9.2.4 Interarrival time

The interarrival time is another point for which one needs to obtain values. Because the selected intersection contains two inductive loops (see figure 9.3) it was possible to identify the precise interarrival times and services times. These values are expressed in JSON format, an example of this format is given in the Appendix. In that example one will see that the files will first initiate some parameters. The first parameter, "geometry", is the expression for the placement of the inductive loops and is expressed by its coordinates. Because one received the values of all the inductive loops in Ghent one will first needed to select the coordinates of the inductive loops on the Rooigemlaan. For the inductive loops in fig 9.3 we found the following coordinates:

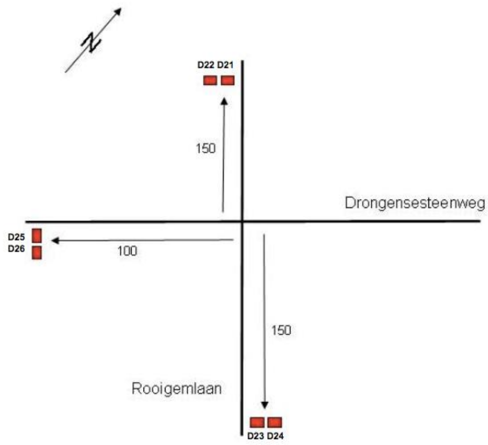
- D22/D21: [51.056700200752239,3.6941252698999687]
- D23/D24: [51.05500071867678,3.6963258368238208]
- D25/D26: [51.055780762648048,3.6928130580345471]

After one has found the needed coordinates one could obtain the following four parameters for that point. The parameters are given in the following order: Speed, OCC, Count and Timestamp. For the case study only the first, second and last parameter will have meaning. The speed refers to the average speed of the vehicles in a timestamp. Count gives the number of vehicles that have passed the loops in that precise timestamp. And the last parameter, the timestamp, is equal to the time interval and is expressed in Epoch in the JSON files. The timestamp will be equal to five minutes. One has built a table per day per loop that consist of all the values of these parameters, an example for the first of April is given in the Appendix table 10.1 this table will only represent the values for loop D23/D24. It is important to know that the values are measured in time intervals of five minutes but they are converted into values per hour. Unfortunately, because of the changes that were made at the beginning of April in Ghent (Circulation plan) and because of the vacations during this period one could not fully support on the obtained values for the interarrival and service times. This because the values were still volatile. For this reason one needed to consult the company, Sweco, they could offer an alternative. This alternative was an average value that already had the time to stabilize. The values for these averages are given in the table below:

The number of vehicles that drive straight through the intersection per hour	443
The number of vehicles that turn left per hour	504
The number vehicles that will turn right per hour	2

Table 9.3: Vehicle input

With this basic information one can start modeling the vehicle input for the intersection.



TASS	M10
M175	D21
M174	D22

TASS	M11
M173	D23
M172	D24

TASS	M12
M171	D25
M170	D26

Figure 9.3: Inductive loops Rooigemlaan

9.3 VISSIM

In order to compare the scenarios one will first need to model the twelve scenarios separately. As a start one received the VISSIM files of the basic model concerning the intersection between the Rooigemlaan and the Drongensesteenweg. These files had everything one needed to know about the current model. But one will need to make changes in order to represent every scenario. Thus, the first aspect one will discuss here is the modeling and the changes for every scenario.

9.3.1 The development of the scenarios

9.3.1.1 The ordinary lane with TSP on the whole intersection

The model that is currently used on the intersection is the one of scenario 2, namely the ordinary lane with TSP on the whole intersection. This scenario should normally be the optimal model. One thought it would be interesting to include this scenario into the developed scenarios. In that way one can compare the developed scenarios with an optimal one. It should be clear that the only changes one needs to make here are the assumptions that are made. The first assumption is that the possibility to turn right is left out. A second assumption is the fact that buses in reality have a bus stop 30 metres before the traffic light in the case study one will choose to neglect this bus stop. The reason for this second assumption is that a bus stop that is situated right before a traffic light makes it very difficult for the bus detector to estimate the arrival of the buses.
Further, one will also need to makes changes in the evaluation phase.
In the figure below one can see the design of the optimal model.

Figure 9.4 VISSIM design of the intersection

9.3.1.2 The ordinary lane without bus priority

The first scenario one would like to discuss is the scenario where there is no priority. This could simply be modelled by the elimination of all the bus detectors. These detectors are used to register the arrival of buses and are of value in the introduction of a TSP. With this in mind one could easily explain that without the bus detectors no buses will be registered, in other words there will also be no bus priority. The bus detector is symbolized by a blue rectangle and will normally be placed before and after a traffic light.

9.3.1.3 The ordinary lane with TSP specifically on the Rooigemlaan

The opposite of the previous discussed scenario is the scenario where an extra TSP is introduced. The introduction of this TSP is needed because the currently used TSP is not strict enough. The TSP that is currently used will only prevent that buses will not have to wait too long in front of a traffic light. But one wants to introduce a strict TSP system where buses will not have to wait to be served. This will again be modelled based on the use of bus detectors but now one will also use the vap.file to write the code. A vap.file is a file that contains the structure of the traffic light system. Normally this file will be combined with a pua.file, this file will consist of the execution of the phases. A cycle is typically subdivided into phases (green light) and interphases (amber and red light). One has chosen to write the model directly in the pua.file because of the simplicity of the model. One could also have chosen to write the model with the support of VisVap but this was not needed. The VisVap is in essence a method that helps you with the development of your model. It is represented by a flowchart in which questions will be asked. For this scenario one could for instance make use of VisVap, in this way one will need to write after every phase switch if a bus has been signalised by the detector, if this is the case one would command the VisVap to go back to a phase where the signal has last been green. The model written in the pua.file will work in the same way. After every phase one will write a code that asks if the bus detector has signalized a bus if this were not the case the phase will jump to the next stage. If the opposite were true and a bus has been detected one will jump to a phase where the signal has last been green. Because one wants to give priority for both the buses that turn left (buses with number 14 until 16) and the buses that go straight on (bus 9) one needed to refer back to a phase where both lights were green. This phase was a phase that was surrounded by phases where all other lights turned red, in order to meet the assumption on the traffic lights discussed in section seven one needed to create a new phase where both lights are green and that is put just before the cycle switch.

9.3.1.4 Dedicated bus lane with and without TSP

For the dedicated bus lane one will first need to make some changes in the characteristics of the road. One will need to separate the roads. In that way one could create a bus lane that is blocked for all other road users. The block option for a link is shown in the next figure.

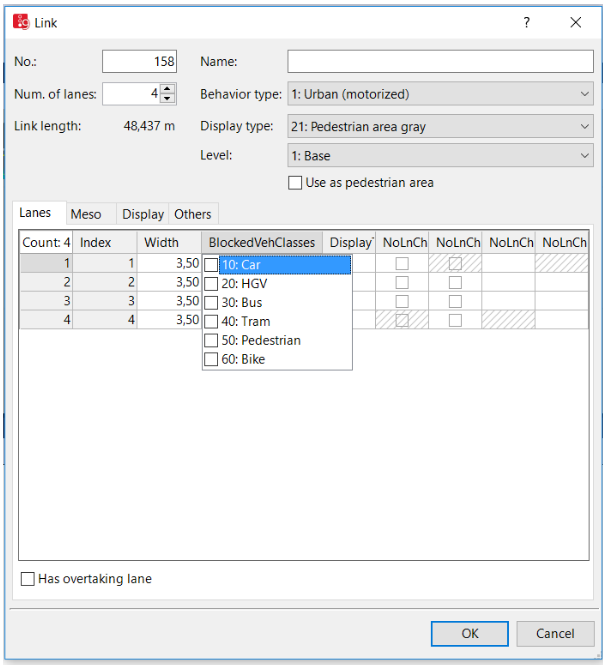


Figure 9.5: Block function in VISSIM to create a DBL

After one has executed the separation, one will need to redesign the vehicle and bus routes. Which is shown in the next figures. The orange one represents the bus routes while the yellow one represents the car routes.

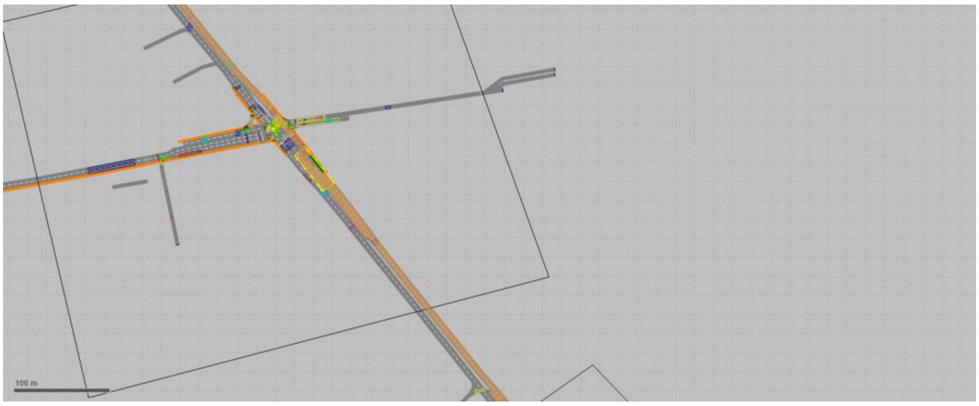


Figure 9.6: New bus routes

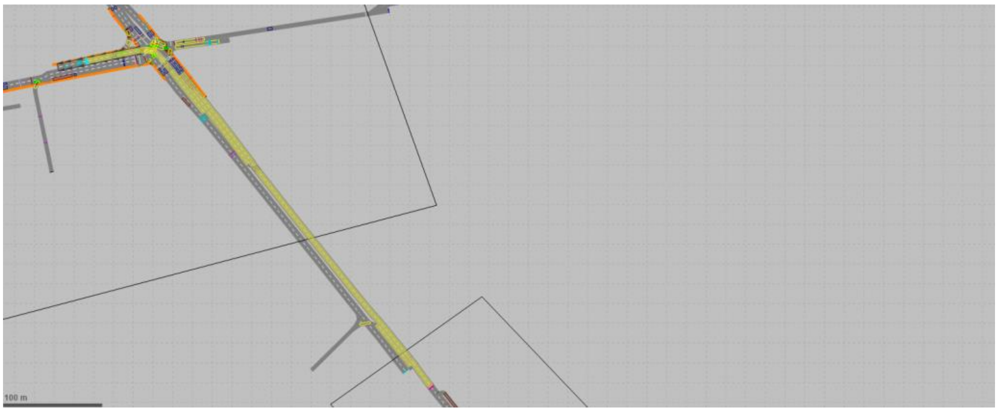


Figure 9.7: New car routes

After that is done one can implement the priority signals or delete them. For the other six scenarios one will use a combination of these technics. Because the technics remain unchanged. The next step will be the simulation and evaluation of the scenarios.

9.4 Simulation and Evaluation

After one has developed the scenarios one will need to evaluate the successes of these scenarios. In this case study one has chosen the node results and the delay results as output. For the former one, one will need to create a node. For this example one will create a node by selecting the area within 200 meters from the intersection. This surface will be used to obtain the overall results of the intersection. For this case study an example is of the node is given on the next figure. Here one can see three nodes, the yellow one is the one of importance for the case study.

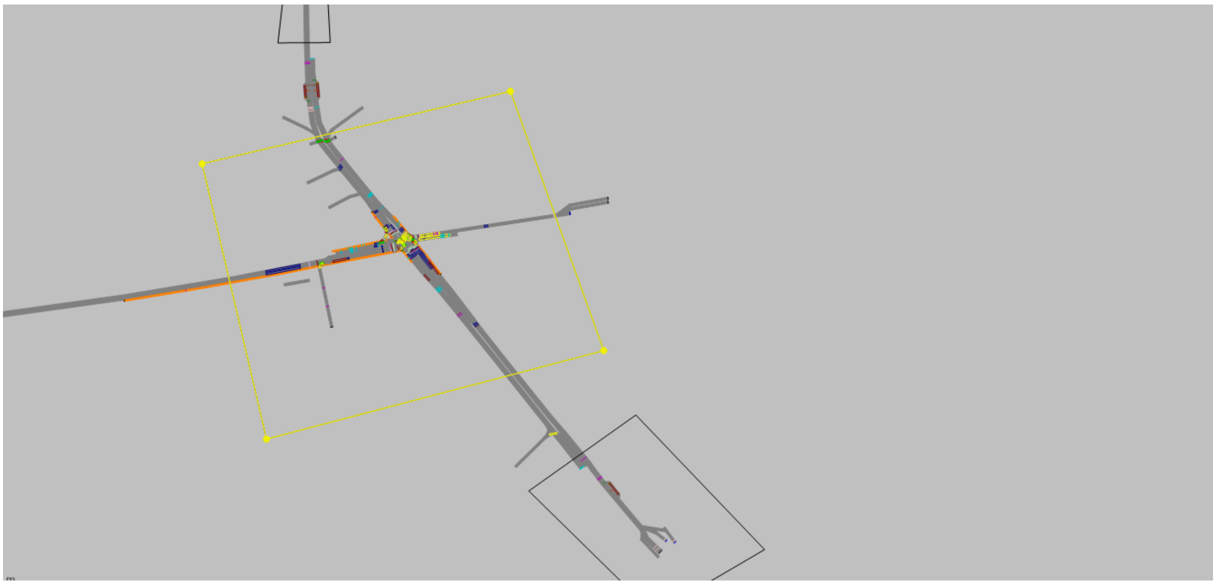


Figure 9.8: Representation of the nodes

After this one will need to select the parameters one wants to obtain the values of. Here one has chosen the attributes: Vehicle delay (for both cars (10) and buses (30)), the queue length, the CO emission and the fuel consumption. The last three attributes are purely selected out of one's own interest.

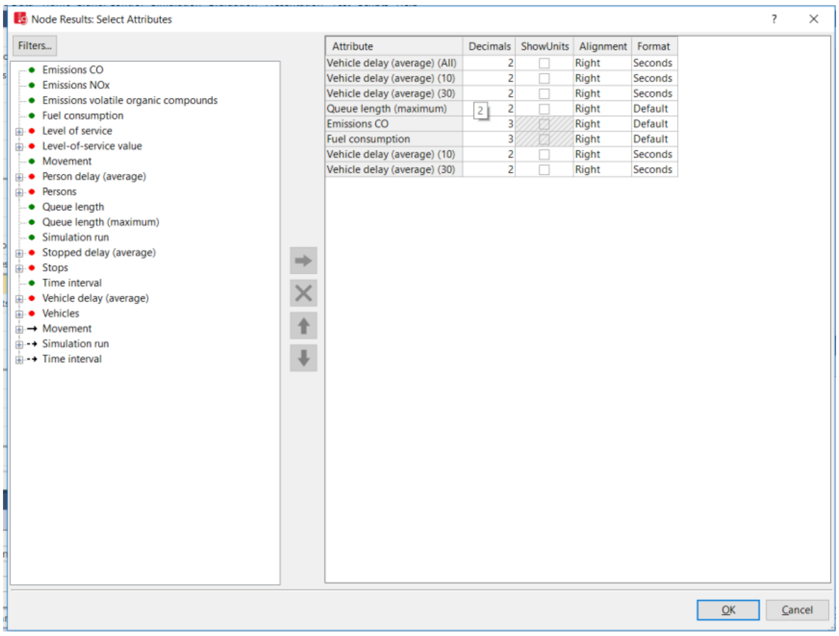


Figure 9.9: Node results selection of the attributes

In order to get a better look into the delay times per vehicle class and per time interval one needs to make vehicle travel times points and link them with the delay measurements. In this example one will start a vehicle travel time at the beginning of the lane and one will indicate the end of this vehicle travel time after the signal heads. In that way one can obtain the delays per lane per vehicle. An example is given in the next figure, the blue arrow is directed to the function that needs to be selected in order to make vehicle travel times, the circles represent the start and the end of a vehicle travel time.

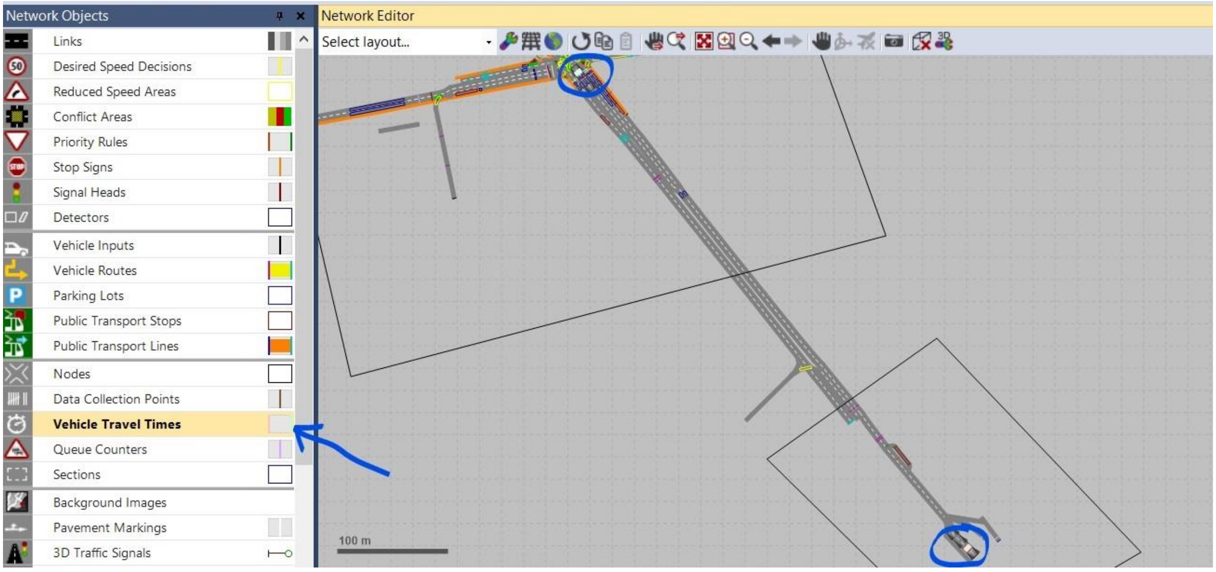


Figure 9.10: Creation of the vehicle travel times

After the creation of these point one selected the option "Delay results" which offers to give a clear overview of the delay times per vehicle class on the selected part of the Rooigemlaan. The figure below is the window for the selection of the attributes for the delay results.

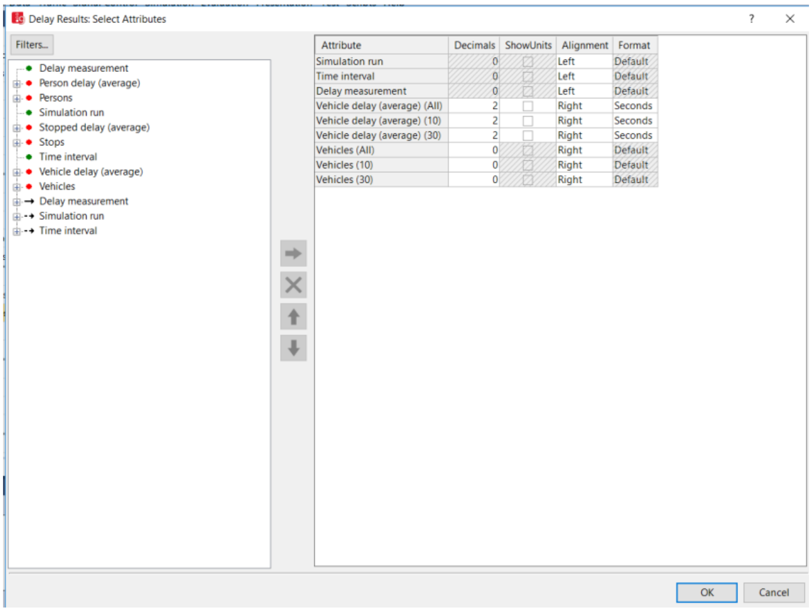


Figure 9.12 Window for the selection of the attributes for delay results

After selecting the output one can now start with to simulate. For this one needs to make a couple of decisions, such as the simulation speed, the time span of the simulation, the number of runs etc. For the number of runs and the time span one has contacted a firm that is familiar with the program. They recommended to use ten runs, this number will already give a very stable output that can represent the reality.

9.5 Results

For the results one will focus on the vehicle delays. The delays are important measures for the successes of the scenarios because the delays are both linked with the level of service and the queuing time. For the situation on the Rooigemlaan one can divide the vehicles into four types, the first one are the vehicles that turn left, the second one are the buses that turn left (these are the buses with number 14 until 16), the third option are the cars that will drive straight on and the last type will be the buses that drive straight on (this will be the bus number 9). One started here with this separation because the main goal of the case study was to find a way for the buses on the Rooigemlaan to cross the intersection with a delay as little as possible. After this exposition one will look at the delays in the other branches of the intersection. This will be followed by a sensitivity analysis, where one will let the vehicle input range from 50% of the input until 200%. This will show which scenarios remain suitable under a heavy congested road.

The results from the introduction of the scenarios are given in the next figure. Where one will see how the buses and cars will react per scenario. The buses are a combination of bus 9 and bus 14 until 16. For the cars one has decided to combine the left and straight moving cars as a whole (this of course with the weights of each car movement). The different colours represents the delays per five minutes.

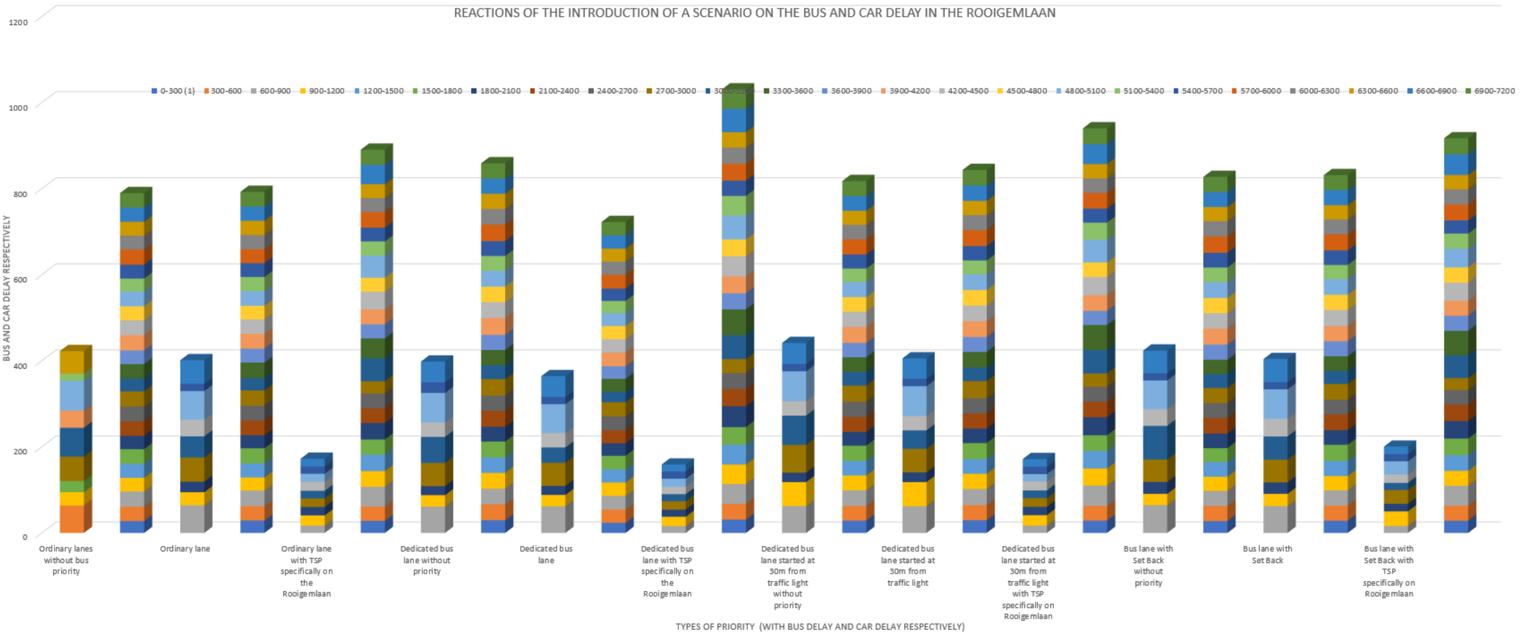


Figure 9.12: Reactions of the introduction of a scenario on the bus and cars delays

The original state of the intersection is visualized in the second scenario, namely the ordinary lane. Based on this graphic one can conclude that a decrease in the delay of buses will be corrected with a decrease in the delays of cars. Another aspect that is clearly shown in this graphic is that the introduction of the TSP will enormously lower the delay of buses, the net delay (is the delay minus the bus stops) will come near the value zero. This decrease will as a consequence increase the delay for cars. From this table one cannot directly select the best scenario. The selection of the most appropriate type will be done in section seven from the second part. But first one will look at the consequences of a changed vehicles input for every scenario this will be done in on the next page. The graphics per bus type and per car movement can be found on the next page.

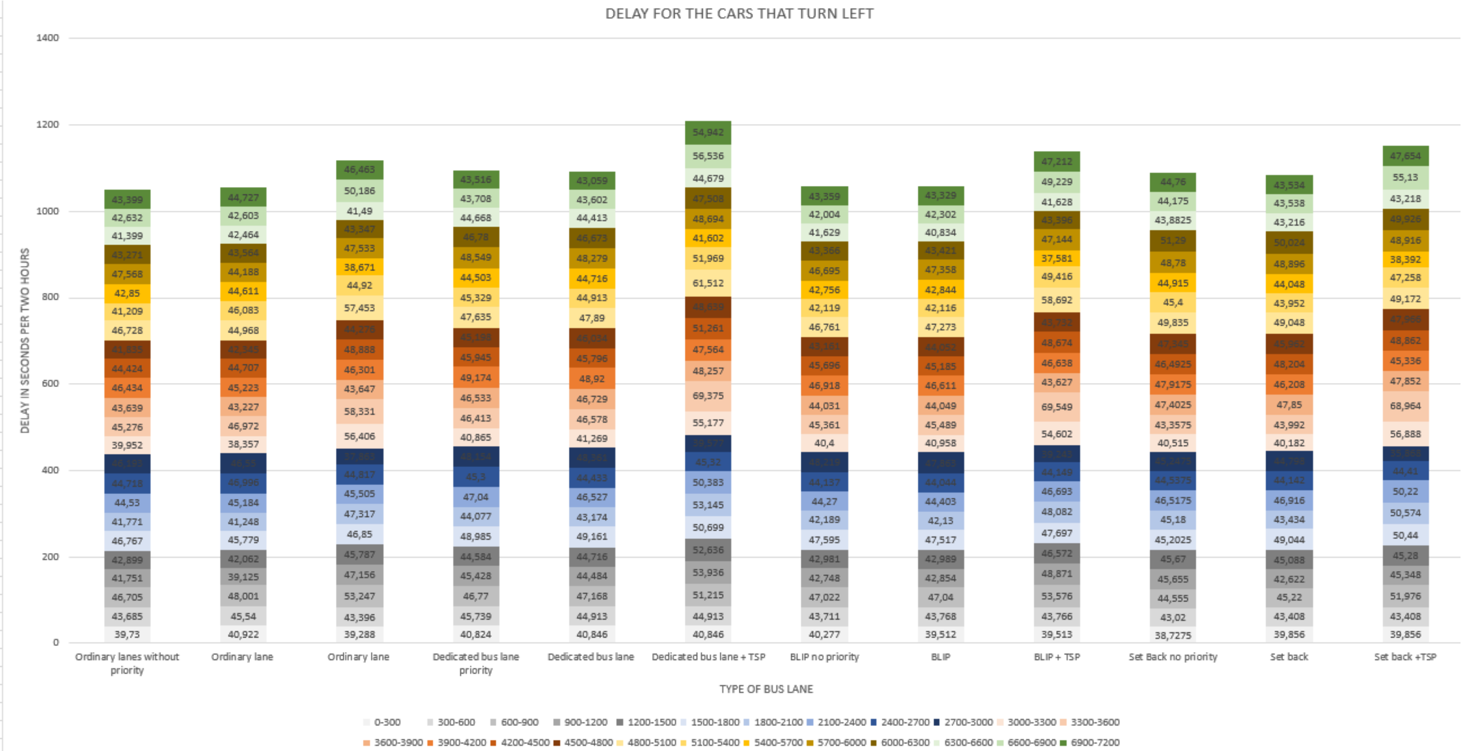


Figure 9.13: Delay per scenario for the cars that turn left

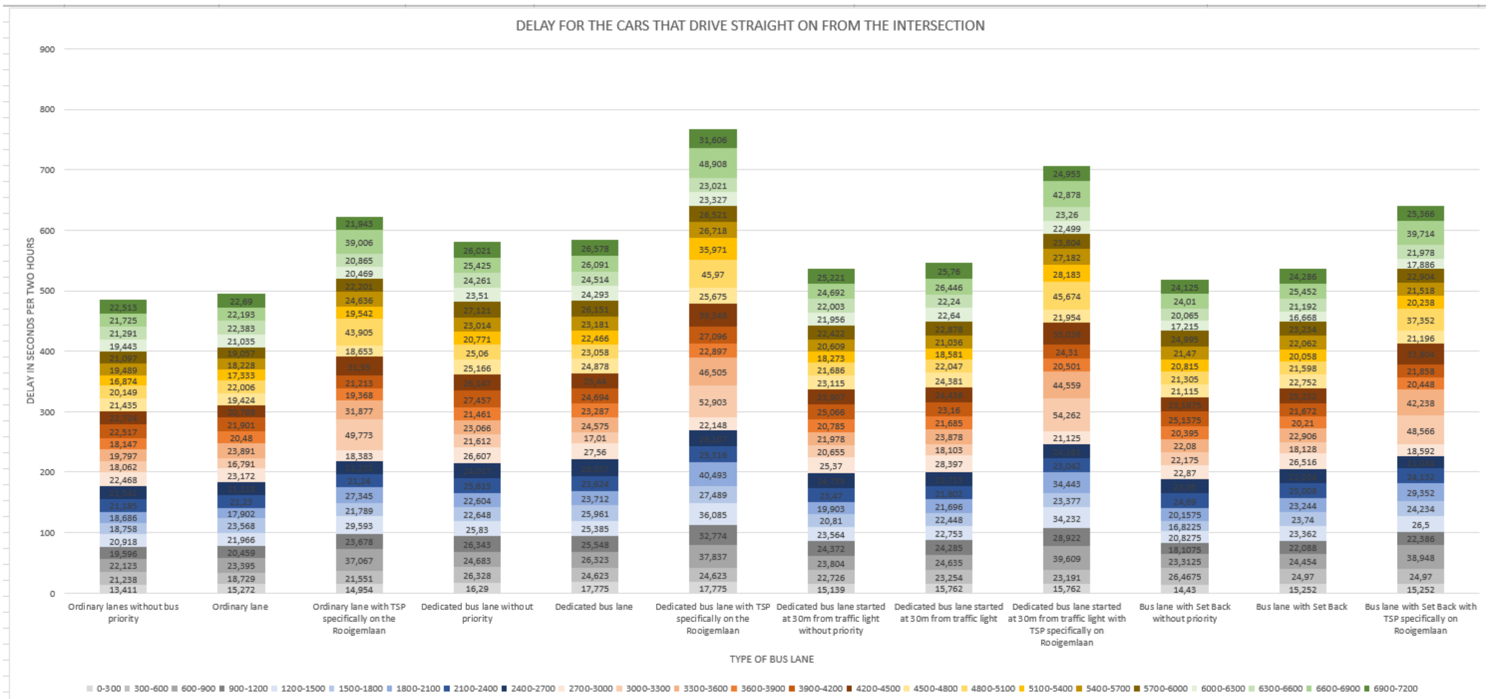


Figure 9.14: Delay per scenario for the cars that make no turning movements

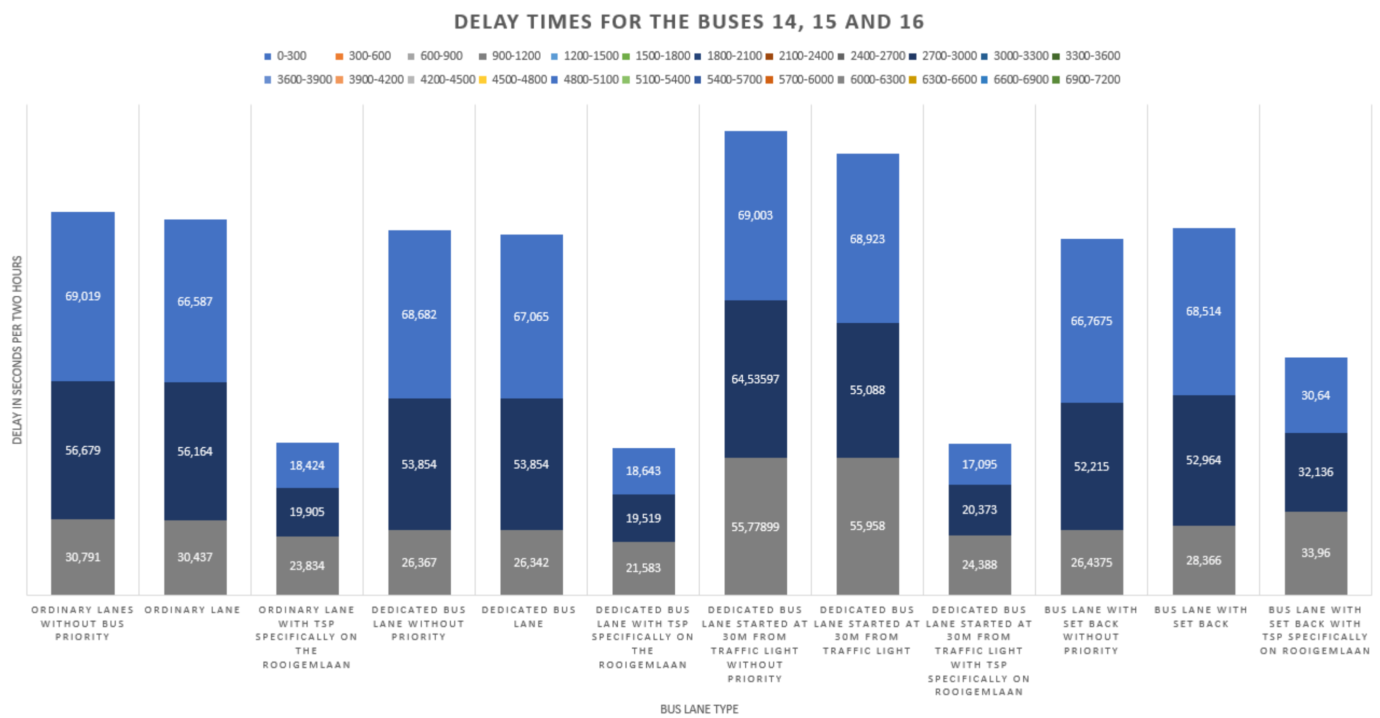


Figure 9.15: Delay per scenario for buses with number 14 until 16 (turn left)

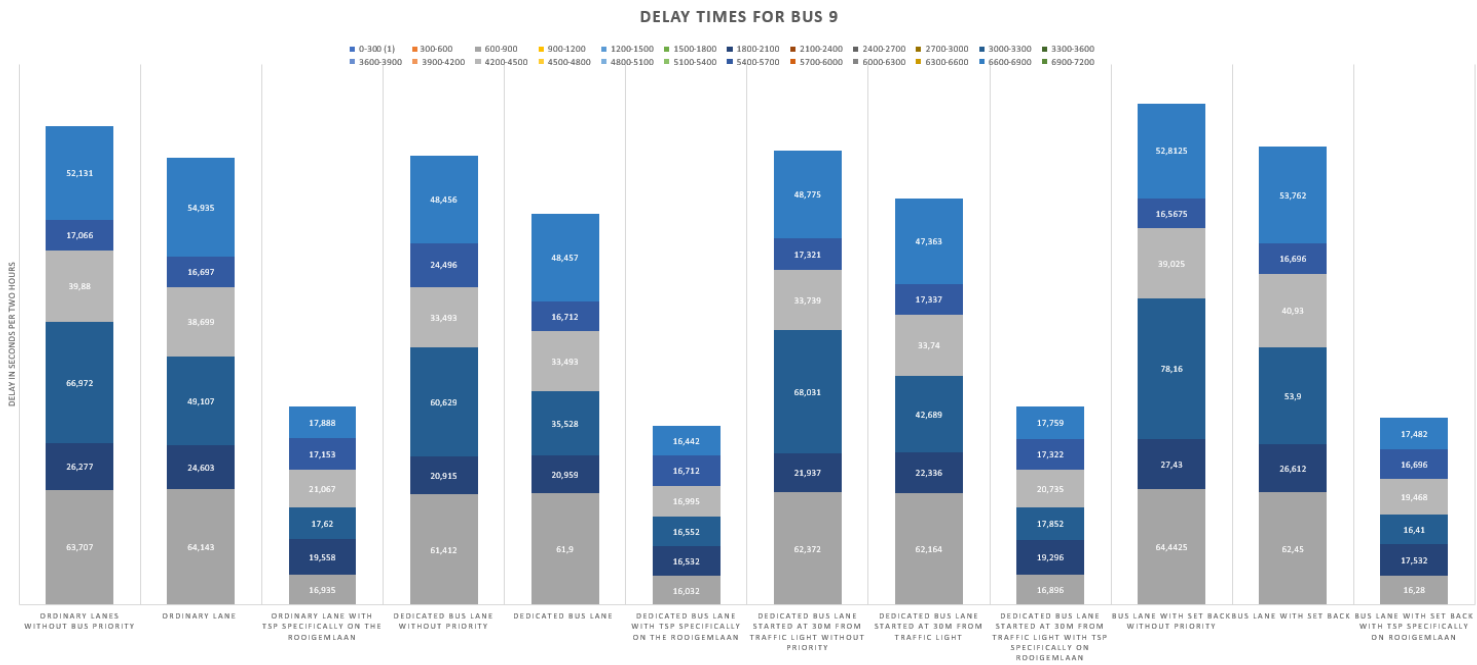


Figure 9.16: Delay for bus 9

9.6 Sensitivity analysis

Because traffic can be very volatile one will need to execute a sensitivity analysis, this analysis will decrease the vehicle input with steps of 10%. One will investigate the effects in both an increase and decrease of the vehicle input. The decrease will go until 50% of the actual input, while the increase will go-up to a value of 15%. The impact on the bus delay for every scenario are given on the next graph.

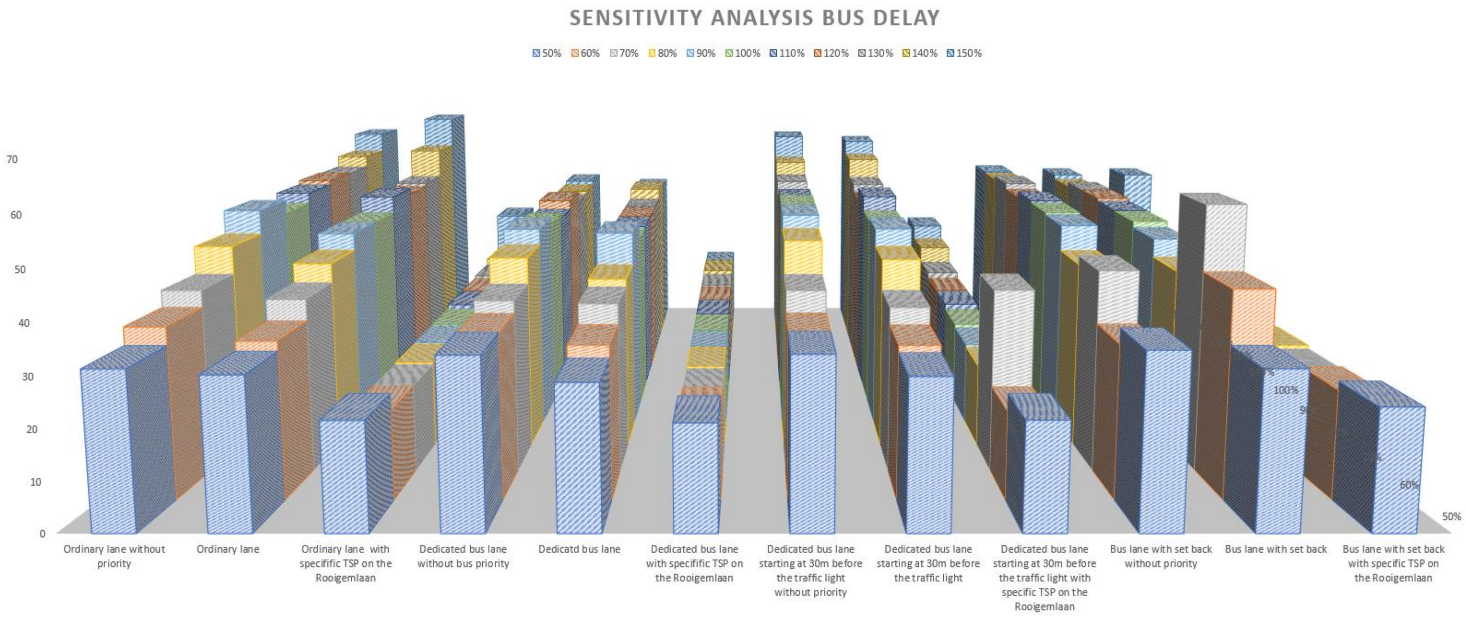


Figure 9.17: Sensitivity analysis bus delays

One will notice that the escalation in the delays is kept reasonable stable. Only in scenarios 1, 2, 7 and 8 will show an inflation in the delays. For scenario 1 and 2 this is an obvious consequence of the density of the vehicles. For scenario 7 and 8 one could see that this increase is caused by the interruption of the cars when buses try to make use of the dedicate lane. In other words cars will not have the ability to directly change form lane when a bus is in arrival.

A more interesting issue will be the continuing of the cars. This can be seen on the next graph. Here it will be proven that the introduction of a dedicated bus lane with an extra TSP on the Rooigemlaan will seriously hurt the vehicle travel times, this will be followed by the bus lane with set back and TSP and the three scenarios that include a dedicates lane. The scenarios that will hurt the travel times for cars the least are the ordinary lanes with and without priority. Based on the literature study in part I this seems to be an obvious event. The scenarios with a dedicated lane starting at 30m before a traffic light and the scenario of an ordinary lane with TSP will have also a reasonably good output on the delays. In order to find the best solution one will go to section seven. Here one will discuss the scenarios based on a cost and benefit analyse.

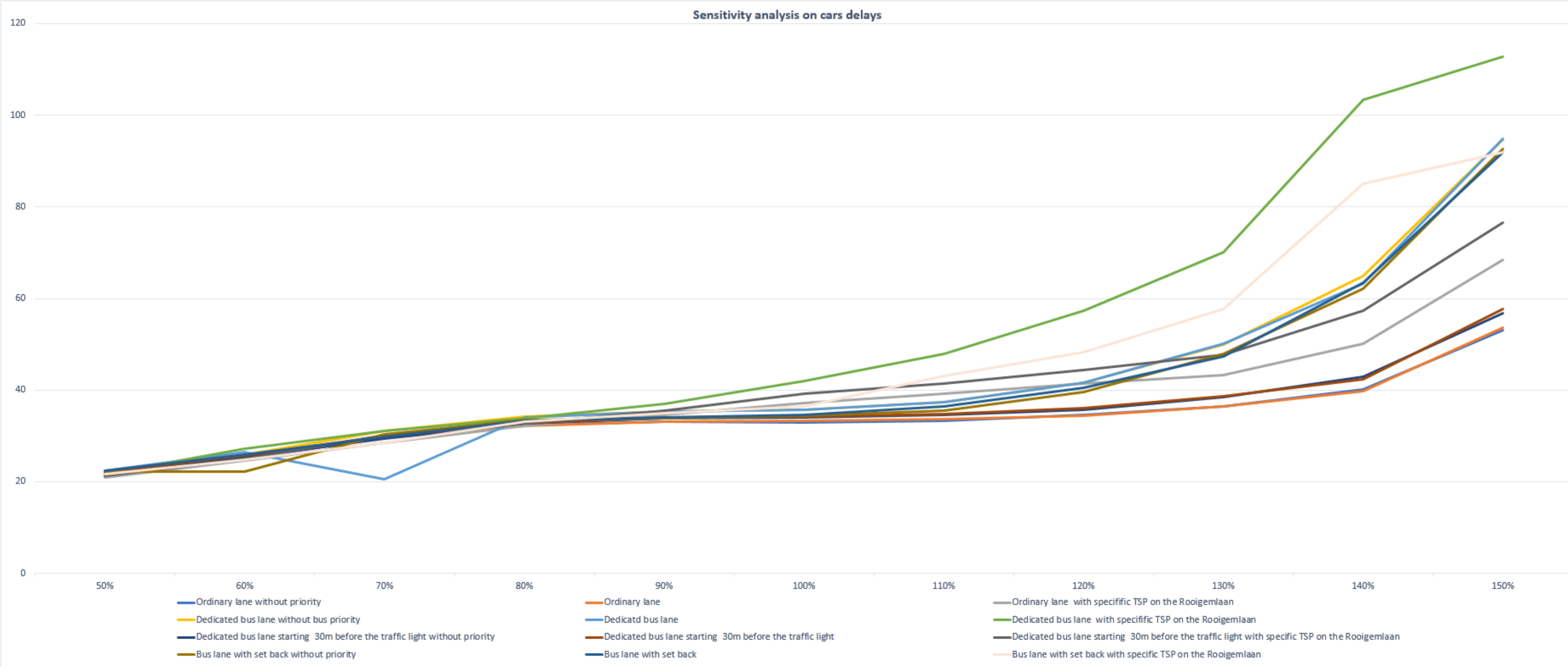


Figure 9.18: Sensitivity analysis car delays

9.7 Cost and benefit analysis

The cost and benefit analysis will include all the costs and benefits for each scenario. There are two costs that are of importance for this analysis. The first cost is the cost based on the time a car loses due to congestion. This cost will be equal to 11 euro/hour delay (WLO,2015). This number represents all the costs that are caused by a queuing car, for instance the fuel cost, the negative effects it has on the environment, the economic cost etc. This cost is obtained from a study executed by the WLO, this study has investigated the growth in travel times per scenario (see table in appendix 10.2). Based on this information one consulted a company that often used these cost measurements and they recommended to use 11 euro for this case study. The same has been done for the second value, which is the cost based on the time a bus loses due to congestion. For a bus one needed to look per hour per person per bus. The cost obtained for this is equal to 6 euro/traveller/ hour delay. One may also assume an average of 30 travellers per bus. This information is again obtained after consulting a company that has this needed knowledge. Thus one simply needs to obtain the delay times per bus per scenario and per hour. Because the case study has been working with delays expressed in seconds one will need to divide the delays by 3600. Afterwards one will multiply the obtained delays by the number of buses that pass the road during the morning rush hours. This value will be multiplied by number of passengers per bus and after that one needs the multiply this value with the cost. To end one will obtain the incurred cost due to the delay of buses per scenario. The same will be done for cars only one will here multiply the obtained delay times by the number of cars per time period, which will be equal to 947 number per hour (because on average 947 cars pass the selected area per hour), one will have to multiply this value with 2 to obtain the cost for the morning rush hours. The calculations are found in tables on the next page these cost are over a time interval of 2 hours, namely the morning rush hours.

	Delay per bus in seconds	Delay per bus in hours	Overall cost for the morning rush hours for buses only	Ranking cost for buses
Ordinary lane without priority	46,94688889	0,013040802	38,73118333	10
Ordinary lane	44,59688889	0,012388025	36,79243333	7
Ordinary lane **with specific TSP** on the Rooigemlaan	19,15377778	0,005320494	15,80186667	**3**
Dedicated bus lane without bus priority	44,256	0,012293333	36,5112	6
Dedicated bus lane	40,47888889	0,011244136	33,39508333	5
Dedicated bus lane **with specific TSP** on the Rooigemlaan	17,66777778	0,004907716	14,57591667	**1**
Dedicated bus lane starting at 30m before the traffic light without priority	49,05477778	0,013626327	40,47019167	12
Dedicated bus lane starting at 30m before the traffic light	45,06644444	0,012518457	37,17981667	9
Dedicated bus lane starting at 30m before the traffic light **with specific TSP** on the Rooigemlaan	19,07955556	0,005299877	15,74063333	**2**
Bus lane with set back without priority	47,09527778	0,013082022	38,85360417	11
Bus lane with set back	44,91044444	0,012475123	37,05111667	8
Bus lane with set back **with specific TSP** on the Rooigemlaan	22,28933333	0,006191481	18,3887	**4**

Table 9.4: Cost per scenario (buses)

Scenario	Delay per car in seconds	Delay per car in hours	Overall cost for the morning rush hours for cars only	Ranking cost for cars
Ordinary lane without priority	32,72695547	0,009090821	103,3080894	1
Ordinary lane	33,05521634	0,009182005	104,3442996	2
Ordinary lane with specific TSP on the Rooigemlaan	36,94538767	0,010262608	116,6242738	9
Dedicated bus lane without bus priority	35,62344329	0,009895401	112,451336	7
Dedicated bus lane	35,6277749	0,009896604	112,4650094	8
Dedicated bus lane with specific TSP on the Rooigemlaan	41,79272699	0,011609091	131,9257082	12
Dedicated bus lane starting 30m before the traffic light without priority	33,90080583	0,009416891	107,0135438	3
Dedicated bus lane starting 30m before the traffic light	34,1027522	0,009472987	107,6510211	4
Dedicated bus lane starting 30m before the traffic light with specific TSP on the Rooigemlaan	39,0427724	0,010845215	123,2450182	11
Bus lane with set back without priority	34,29210643	0,009525585	108,2487493	5
Bus lane with set back	34,46955306	0,009574876	108,8088892	6
Bus lane with set back with specific TSP on the Rooigemlaan	38,05075493	0,010569654	120,1135497	10

Table 9.5: Cost per scenario (cars)

From these results it is clear that the inclusion of a TSP will have a positive impact on the cost side for buses, this while the scenarios without any bus priority will seriously harm these costs. The conclusions for the costs based on the delay for cars are proven to be the opposite. Thus, one will need to make a sum of these cost per scenario to get the overall cost per scenario. These costs are given in the next table.

Number of the scenario	Scenario	Overall cost	Ranking overall costs
1	Ordinary lane without priority	142,0392728	5
2	Ordinary lane	141,1367329	4
3	Ordinary lane with specific TSP on the Rooigemlaan	132,4261404	1
4	Dedicated bus lane without bus priority	148,962536	12
5	Dedicated bus lane	145,8600928	8
6	Dedicated bus lane with specific TSP on the Rooigemlaan	146,5016249	9
7	Dedicated bus lane starting at 30m before the traffic light without priority	147,4837354	11
8	Dedicated bus lane starting at 30m before the traffic light	144,8308378	6
9	Dedicated bus lane starting at 30m before the traffic light with specific TSP on the Rooigemlaan	138,9856515	3
10	Bus lane with set back without priority	147,1023535	10
11	Bus lane with set back	145,8600058	7
12	Bus lane with set back with specific TSP on the Rooigemlaan	138,5022497	2

Table 9.6: Overall cost

For the case study on the Rooigemlaan one recommends to use the third scenario, namely the ordinary bus lane with specific TSP on the Rooigemlaan. This cost is six euros less expensive than the second best scenario which is the bus lane with set back with specific TSP on the Rooigemlaan and is almost seven euros less expensive compared to the third best scenario which is the dedicated bus lane starting at 30m before the traffic light with specific TSP on the Rooigemlaan. The worst scenario is scenario four, this followed by scenario seven. From these results one may conclude that every scenario (except for the ones with a dedicated bus lane) with the incorporation of a specific TSP on the Rooigemlaan performs better than the scenarios with bus priority over the whole intersection, this while the scenarios with bus priority over the whole intersection perform better than the scenarios without priority. Thus, one may conclude that the TSP has a crucial effect on the reduction of the costs. This can be explained by the higher costs incurred by the delay of buses. There are two reasons why the third scenario is the best scenario. The first reason is because it does not decrease the capacity for road-users other than buses, this in contrast to the last nine scenarios. The second reason is because buses now have the ability to pass the intersection without being interrupted. As stated earlier, this scenario may be compared with a BLIP, this because the TSP will change the red light into a green one a few seconds before the bus arrives at the intersection with the consequence that the queuing cars before the traffic light will be gone when the bus finally arrives. The reason why scenario four is the worst one is obviously because of the creation of enormous delays for cars. If one now takes includes the constraints discussed in section six one will see that the delays for a bus have jumped from level D, which means an approaching unstable flow where buses occasionally will have to wait through more than one signal before proceeding, to level B, which represent a stable flow with slight delays. As for the delays of the cars one will see a jump from C, which represents a stable flow with acceptable delays, to a level D. These conditions are within the conditions of the constraints, thus one may see this result as a good solution.

Now that one has selected the best and worst scenarios for the specific part on the Rooigemlaan it is time to look at the impact of the scenarios on the intersection as a whole. This will be done by the output obtained in the node results. This discussion will find place in the last section of this paper and can be found on the next page.

9.8 Discussion

In this last section one will first start with an investigation of the outputs obtained from the sensitivity analysis. These outputs represent the ability that each scenario has to handle different capacity loads. In order to find the best scenario one will first average the obtained values from the sensitivity analysis and afterwards one will follow the same procedure as discussed in the previous section. After this first investigation one will start with a second investigation. This second part will examine the effects that every scenario has on the whole intersection (Rooigemlaand – Drongensesteenweg). In order to get a clear overview, one will break down this part into a part where one will only take the 100% capacity rate (current situation) into consideration, and a part where one will analyse the effects on the whole intersection based on a second sensitivity analysis.

9.8.1 Discussion sensitivity analysis

For the first part, one computed the averages of the values obtained for every capacity from 50% until 150%. This is done in order to find the priority rule with the most attractive costs for every capacity percentage. The results are given below. (To be clear, these results came from the first sensitivity analyse, that is the analysis is still based only on the specific part of the Rooigemlaan and not on the entire intersection.)

	Delay per bus in seconds	Delay per bus in hours	Overall cost for the morning rush hours for buses only	Ranking cost for buses	Evolution
Ordinary lane without priority	46,29119517	0,012858665	38,19023602	12	↑(+2)
Ordinary lane	44,59374495	0,012387151	36,78983958	10	↑(+3)
Ordinary lane **with specific TSP** on the Rooigemlaan	21,07348485	0,005853746	17,385625	**2**	↓(-1)
Dedicated bus lane without bus priority	41,23411111	0,01145392	34,01814167	6	-
Dedicated bus lane	38,86079798	0,010794666	32,06015833	5	-
Dedicated bus lane **with specific TSP** on the Rooigemlaan	18,27093939	0,005075261	15,073525	**1**	-
Dedicated bus lane starting at 30m before the traffic light without priority	45,5710754	0,012658632	37,5961372	11	↓(-1)
Dedicated bus lane starting at 30m before the traffic light	43,55964983	0,012099903	35,93671111	8	↓(-1)
Dedicated bus lane starting at 30m before the traffic light **with specific TSP** on the Rooigemlaan	22,92548532	0,00636819	18,91352539	**3**	↑(+1)
Bus lane with set back without priority	43,46599495	0,012073887	35,85944583	7	↓ (-4)
Bus lane with set back	44,10051263	0,012250142	36,38292292	9	↑ (+1)
Bus lane with set back **with specific TSP** on the Rooigemlaan	24,99003232	0,006941676	20,61677667	**4**	-

Table 9.7: Cost per scenario (buses) based on the values obtained in the sensitivity analysis

Compared to the results for buses gathered in the previous section in turns out that the rankings of scenario 1, 2, 9 and 11 are increased. As seen in the figure 9.17 the delays for buses in the scenarios 1 and 2 will increase fast when one increases the capacity. The result will be that scenario 10 will catch up with these scenarios because the delays in scenario 10 will hardly increase.

Scenario	Delay per car in seconds	Delay per car in hours	Overall cost for the morning rush hours for cars only	Ranking cost for cars	Evolution
Ordinary lane without priority	33,60934548	0,009335929	106,0935006	1	-
Ordinary lane	33,66553287	0,009351537	106,2708654	2	-
Ordinary lane with specific TSP on the Rooigemlaan	38,03867083	0,010566297	120,0754043	5	↓ (-4)
Dedicated bus lane without bus priority	42,79581015	0,011887725	135,0921074	10	↑(+3)
Dedicated bus lane	41,82983783	0,011619399	132,0428548	9	↑ (+1)
Dedicated bus lane with specific TSP on the Rooigemlaan	52,94653302	0,01470737	167,1345559	12	-
Dedicated bus lane starting 30m before the traffic light without priority	34,8559198	0,0096822	110,0285202	3	-
Dedicated bus lane starting 30m before the traffic light	35,12883211	0,009758009	110,8900134	4	-
Dedicated bus lane starting 30m before the traffic light with specific TSP on the Rooigemlaan	40,87220693	0,011353391	129,0199332	6	↓ (-5)
Bus lane with set back without priority	41,08381731	0,011412171	129,6879166	7	↓ (-2)
Bus lane with set back	41,58675847	0,011551877	131,2755342	8	↑ (+2)
Bus lane with set back with specific TSP on the Rooigemlaan	45,90310928	0,012750864	144,900815	11	↑ (+1)

Table 9.8: Cost per scenario (cars) based on the values obtained in the sensitivity analysis

A conclusion that can be made from this table is that scenario 3 and 9 will seriously decrease the delay of the cars, this while de dedicates bus lane with and without priority will hurt the delays of the cars. In order to make a conclusion for the best scenario for both buses and cars one will need to make a sum of these cost per scenario to get the overall cost per scenario. The results are given below.

Number of the scenario	Scenario	Overall cost	Ranking overall costs	Evolution
1	Ordinary lane without priority	144,2837366	3	↓ (-2)
2	Ordinary lane	143,060705	2	↓ (-2)
3	Ordinary lane with specific TSP on the Rooigemlaan	137,4610293	1	-
4	Dedicated bus lane without bus priority	169,110249	11	↓ (-1)
5	Dedicated bus lane	164,1030131	7	↓ (-1)
6	Dedicated bus lane **with** specific TSP on the Rooigemlaan	182,2080809	12	↑ **(+3)**
7	Dedicated bus lane starting at 30m before the traffic light without priority	147,6246574	5	↓ (-6)
8	Dedicated bus lane starting at 30m before the traffic light	146,8267245	4	↓ (-2)
9	Dedicated bus lane starting at 30m before the traffic light **with** specific TSP on the Rooigemlaan	147,9334586	6	↑ **(+3)**
10	Bus lane with set back without priority	165,5473625	9	↓ (-1)
11	Bus lane with set back	167,6584571	10	↑ (+3)
12	Bus lane with set back **with** specific TSP on the Rooigemlaan	165,5175916	8	↑ **(+6)**

Table 9.9: Overall cost

The best scenario remains the same, namely scenario 3, for both buses and cars (especially) one can notice a decrease in the ranking of the delays for different capacities. Furthermore, the solution is again within the boundaries of the constraints, and the jumps remain unchanged. For the other scenarios with a specific TSP on the Rooigemlaan one will see that the rankings will enormously harm the rankings of the delay. This negative reaction on the capacity change can of course be explained by the increased delay for cars and buses. Also the worst scenario is now the dedicated bus lane with specific TSP instead of the dedicated bus lane without priority. These results are also given in the figure below.

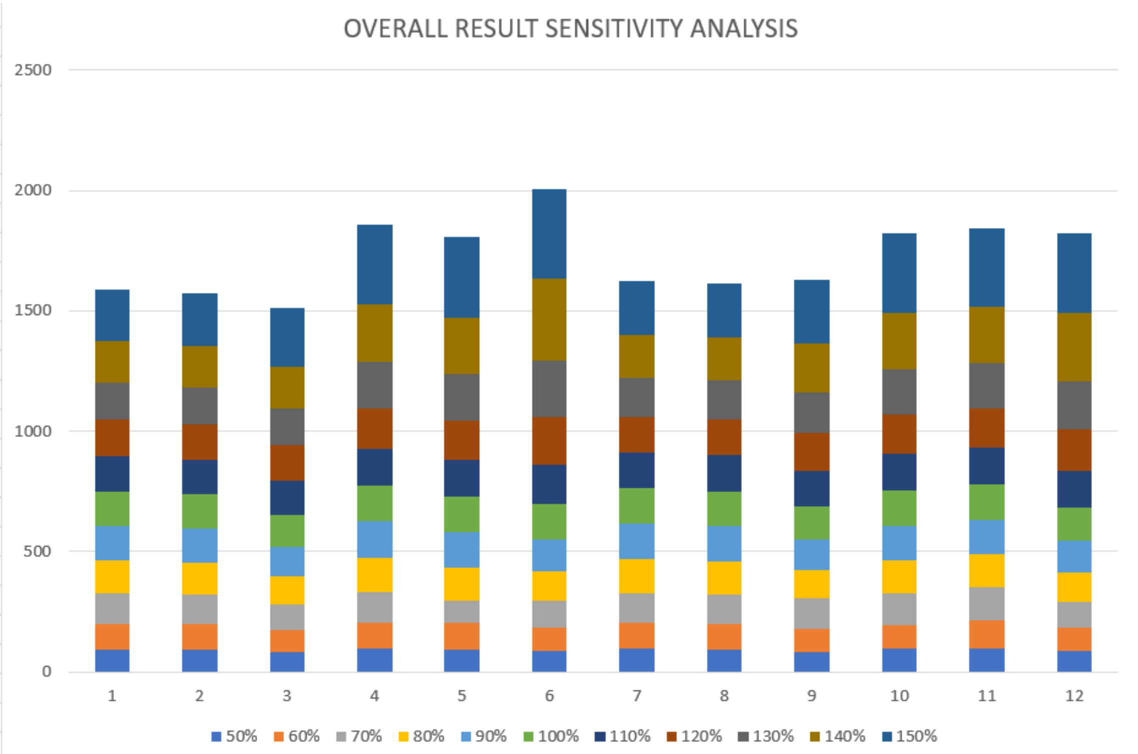


Figure 9.19: The overall results of the sensitivity analysis based on the specific area on the Rooigemlaan

As an end of this section one will take a closer look into the costs per capacity rate. Below one will find all the graphic sorted per percentage of vehicle input, in these graphics it will become clear which type is best suited for which percentage.

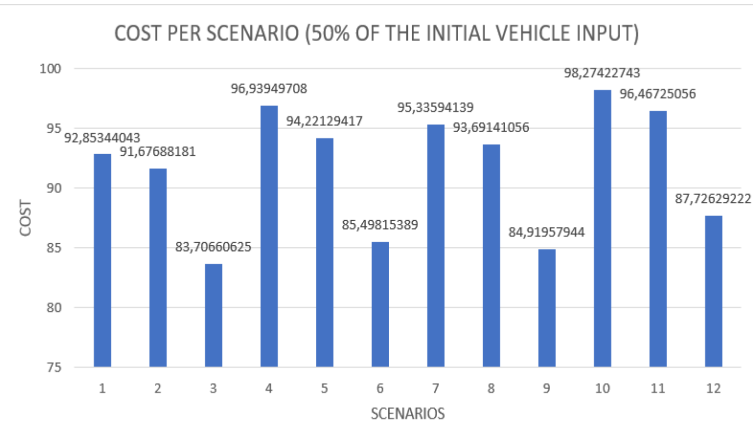


Figure 9.20: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 50% of the initial vehicle input)

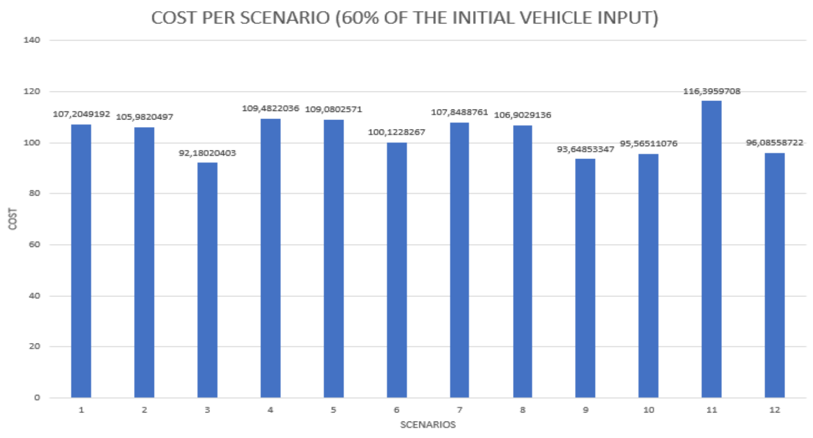


Figure 9.21: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 60% of the initial vehicle input)

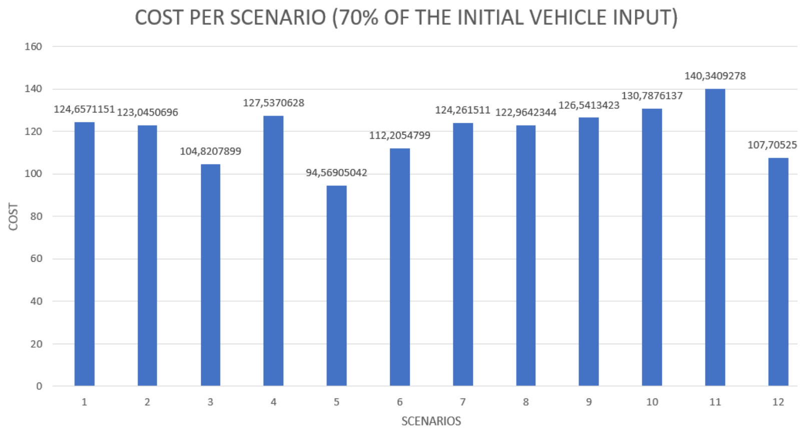


Figure 9.22: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 70% of the initial vehicle input)

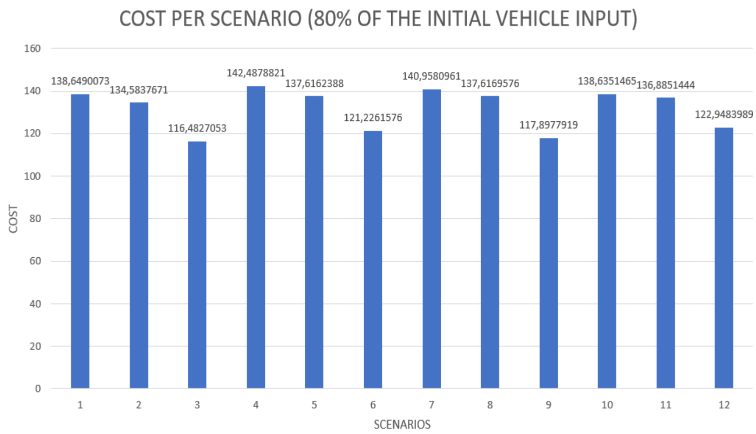


Figure 9.23: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 80% of the initial vehicle input)

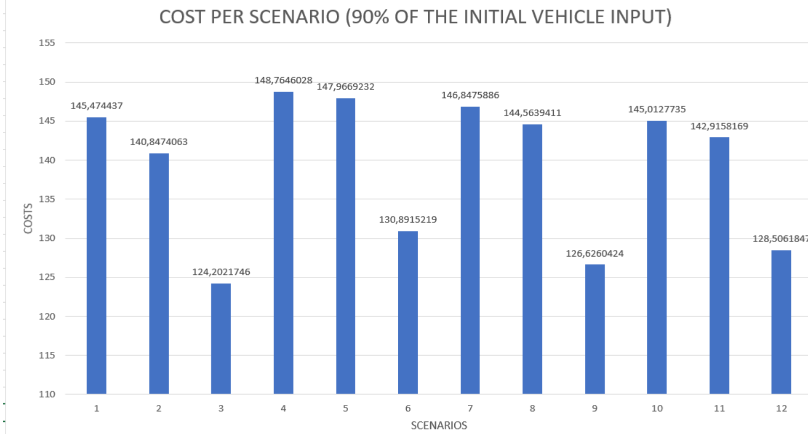


Figure 9.24: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 90% of the initial vehicle input)

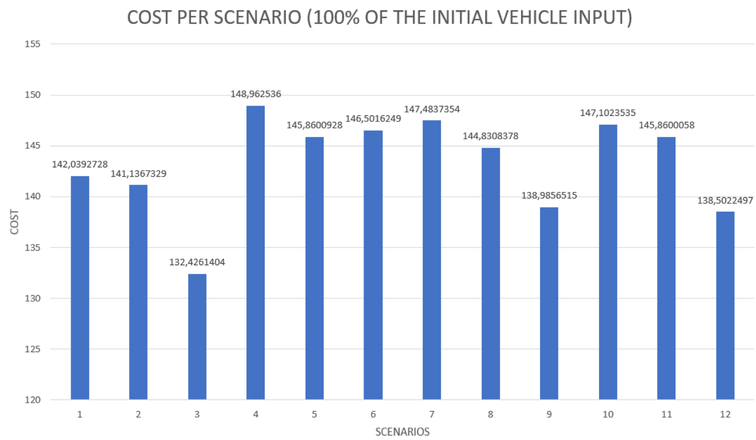


Figure 9.25: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 100% of the initial vehicle input)

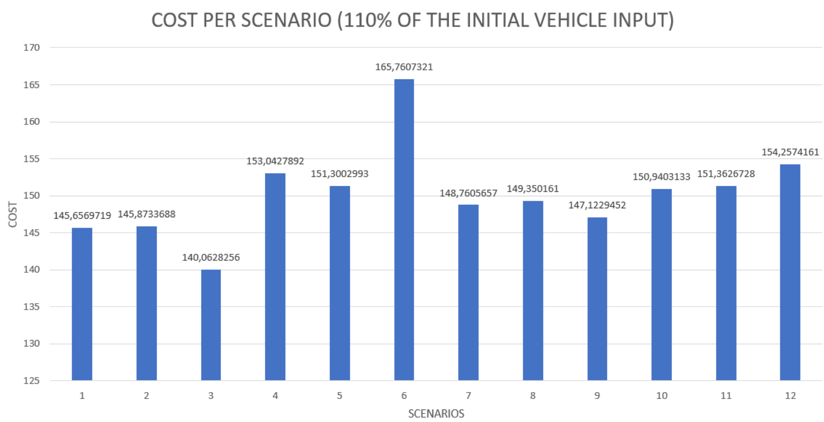


Figure 9.26: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 110% of the initial vehicle input)

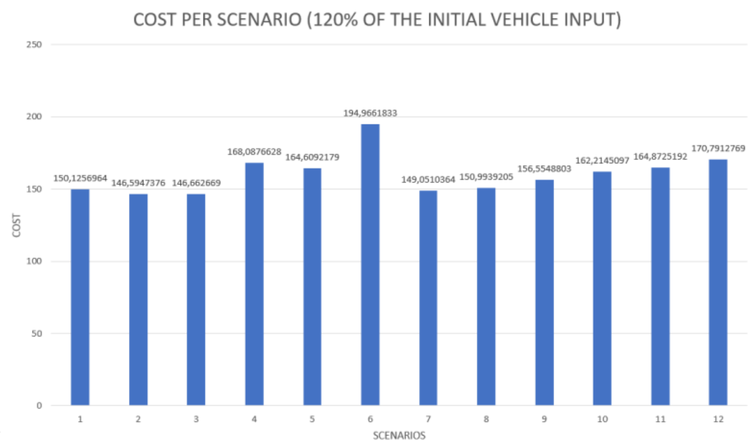


Figure 9.27: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 120% of the initial vehicle input)

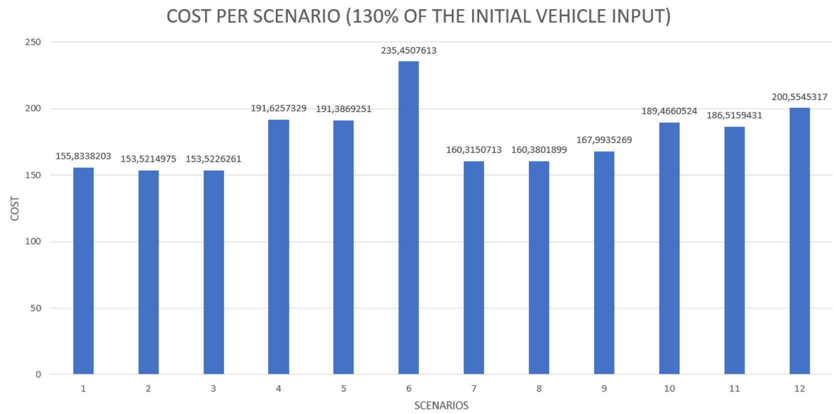


Figure 9.28: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 130% of the initial vehicle input)

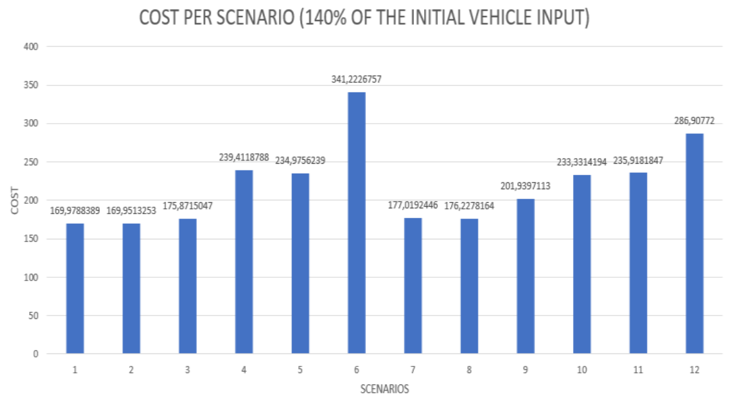


Figure 9.29: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 140% of the initial vehicle input)

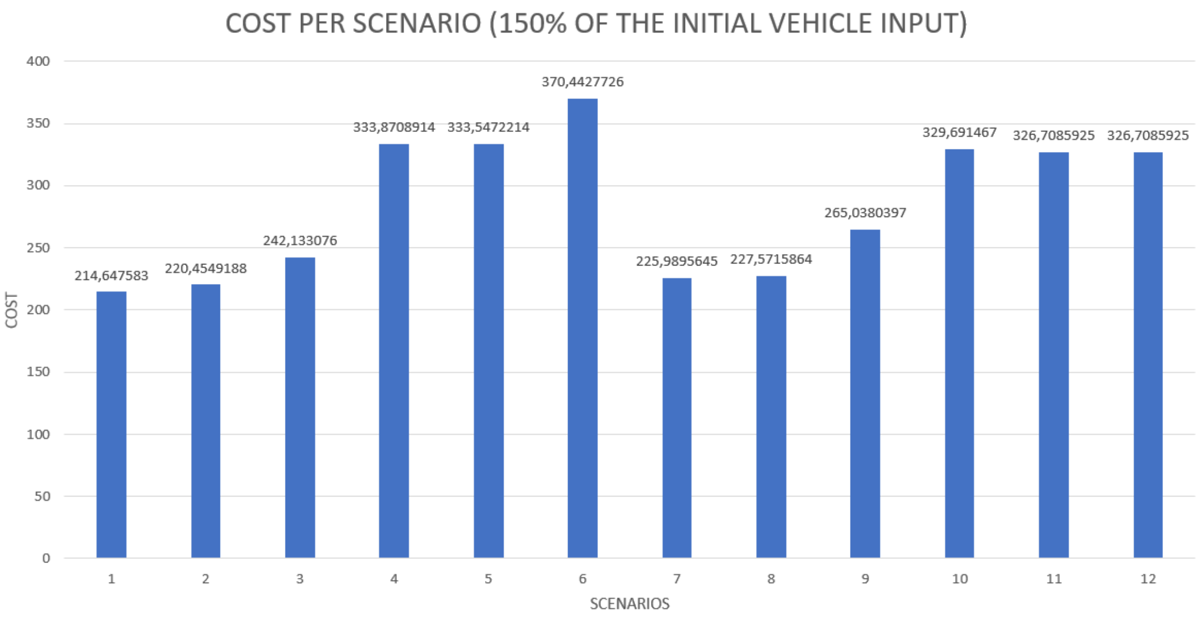


Figure 9.30: Cost per scenario based on the sensitivity analysis for the specific area of the Rooigemlaan (this for 150% of the initial vehicle input)

From these figures, one can conclude that it is optimal to introduce a TSP in a situation where the density is low (< 100% of the initial vehicle input). Also the introduction at of a dedicates lane at this situation is not that harmful for the delays, this has already been proven in the first part of the paper. At this situation the optimal scenarios are 3rd , 6th, 9th and 12th scenario. When the density gets bigger (>100% of the initial vehicle input) one will see that this will change. In this situation the scenarios that include a dedicated lane (e.g. scenarios 4,5,6,10,11 and 11) are becoming less attractive. This is again proven in the first part of the paper. Another finding is that the scenarios with an ordinary lane will become optimal. This all corresponds with the theory seen in section four on page 17.

9.8.2 Discussion node results

The second part is the part where one will look at the effects on the total intersection this will be done based on the output from the node results. First one will examine the effects at a 100% capacity rate afterwards one will look at the averages for the ranges between a 50% and a 200% capacity rate. The results for the 100% capacity rate are given in the next table.

	Average delay per bus in seconds	Delay per bus in hours	Overall cost for morning rush hours for buses only	Ranking cost for buses
Ordinary lane without priority	88,65648352	0,024626801	406,3422161	3
Ordinary lane	109,5200918	0,030422248	501,9670874	11
Ordinary lane with specific TSP on the Rooigemlaan	99,21679775	0,027560222	454,7436564	8
Dedicated bus lane without bus priority	88,11306748	0,024475852	403,8515593	2
Dedicated bus lane	99,22103825	0,0275614	454,763092	9
Dedicated bus lane with specific TSP on the Rooigemlaan	112,1644318	0,031156787	514,0869792	12
Dedicated bus lane starting at 30m before the traffic light without priority	92,36735955	0,0256576	423,3503979	5
Dedicated bus lane starting at 30m before the traffic light	100,6881921	0,027968942	461,4875471	10
Dedicated bus lane starting at 30m before the traffic light with specific TSP on the Rooigemlaan	94,10745763	0,02614096	431,3258475	7
Bus lane with set back without priority	80,67342466	0,022409285	369,7531963	1
Bus lane with set back	88,73208791	0,024647802	406,6887363	4
Bus lane with set back with specific TSP on the Rooigemlaan	92,88695652	0,025801932	425,7318841	6

Table 9.10: Cost per scenario for the entire intersection (buses) based on the node results

Scenario	Delay per car in seconds	Delay per car in hours	Overall cost for morning rush hours for cars only	Ranking cost for cars
Ordinary lane without priority	69,31879167	0,01925522	898,8336653	1
Ordinary lane	73,75816667	0,02048838	956,3975611	5
Ordinary lane with specific TSP on the Rooigemlaan	76,70241667	0,021306227	994,5746694	9
Dedicated bus lane without bus priority	73,76087963	0,020489133	956,4327392	6
Dedicated bus lane	74,41838174	0,020671773	964,9583499	7
Dedicated bus lane with specific TSP on the Rooigemlaan	84,89458333	0,023581829	1100,799764	12
Dedicated bus lane starting 30m before the traffic light without priority	73,15883817	0,020321899	948,6262683	3
Dedicated bus lane starting 30m before the traffic light	75,06676349	0,020851879	973,3656999	8
Dedicated bus lane starting 30m before the traffic light with specific TSP on the Rooigemlaan	77,6060166	0,021557227	1006,291349	10
Bus lane with set back without priority	73,63322917	0,020453675	954,7775382	4
Bus lane with set back	70,906	0,019696111	919,4144667	2
Bus lane with set back with specific TSP on the Rooigemlaan	79,96058333	0,022211273	1036,822231	11

Table 9.11: Cost per scenario for the entire intersection (cars) based on the node results

Number of scenario	Scenario	Overall cost	Ranking overall costs
1	Ordinary lane without priority	1305,175881	1
2	Ordinary lane	1458,364648	11
3	Ordinary lane with specific TSP on the Rooigemlaan	1449,318326	10
4	Dedicated bus lane without bus priority	1360,284299	4
5	Dedicated bus lane	1419,721442	7
6	Dedicated bus lane with specific TSP on the Rooigemlaan	1614,886743	6
7	Dedicated bus lane starting at 30m before the traffic light without priority	1371,976666	5
8	Dedicated bus lane starting at 30m before the traffic light	1434,853247	8
9	Dedicated bus lane starting at 30m before the traffic light with specific TSP on the Rooigemlaan	1437,617196	9
10	Bus lane with set back without priority	1324,530735	2
11	Bus lane with set back	1326,103203	3
12	Bus lane with set back with specific TSP on the Rooigemlaan	1462,554115	12

Table 9.12: Overall cost per scenario for the entire intersection

It is clear that the first scenario is the best one for the whole intersection. This is the original scenario without priority. Again one may conclude that the solution is within the boundaries of the constraints. The levels of service remain in the same level for both cars and buses. Important to know is that the rankings for this scenario are for both cars and buses in the top three of all rankings, and the results are for both vehicle types better than the original one. Another conclusion one can make is that based on the cost benefit analysis, it is shown that the scenarios without priority are preferred over the scenarios with bus priority for the whole intersection.

9.8.3 Discussion node results combined with a sensitivity analysis

If one now takes the capacity changes into consideration one will get another result. This will be done by averaging the delay times obtained for the capacity rates 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% and 200%. These averages will represent the delay times and one will again use the same procedure to find the costs of every scenario. The results are given below.

	Average delay per bus in seconds	Delay per bus in hours	Overall cost for the morning rush hours for buses only	Ranking cost for buses
Ordinary lane without priority	159,4215626	0,044283767	730,6821621	7
Ordinary lane	173,7558486	0,048265513	796,3809727	12
Ordinary lane with specific TSP on the Rooigemlaan	155,9252744	0,043312576	714,6575077	4
Dedicated bus lane without bus priority	149,4057937	0,041501609	684,7765547	2
Dedicated bus lane	150,5111061	0,041808641	689,8425696	3
Dedicated bus lane with specific TSP on the Rooigemlaan	148,7394197	0,041316505	681,7223402	1
Dedicated bus lane starting at 30m before the traffic light without priority	159,5969108	0,044332475	731,4858413	8
Dedicated bus lane starting at 30m before the traffic light	162,9955985	0,045276555	747,0631599	11
Dedicated bus lane starting at 30m before the traffic light with specific TSP on the Rooigemlaan	156,7745667	0,043548491	718,5500976	6
Bus lane with set back without priority	161,130884	0,044758579	738,5165517	9
Bus lane with set back	161,9231784	0,044978661	742,147901	10
Bus lane with set back with specific TSP on the Rooigemlaan	156,479959	0,043466655	717,1998119	5

Table 9.13: Cost per scenario for the entire intersection (buses) based on the node results and sensitivity analysis

Scenario	Delay per car in seconds	Delay per car in hours	Overall cost for the morning rush hours for cars only	Ranking cost for cars
Ordinary lane without priority	124,3758441	0,034548846	1612,740111	3
Ordinary lane	124,8715703	0,034686547	1619,168028	4
Ordinary lane with specific TSP on the Rooigemlaan	129,3037604	0,035917711	1676,63876	10
Dedicated bus lane without bus priority	121,4792766	0,033744244	1575,181287	2
Dedicated bus lane	121,0766131	0,033632393	1569,960083	1
Dedicated bus lane with specific TSP on the Rooigemlaan	127,547908	0,035429974	1653,871207	9
Dedicated bus lane starting 30m before the traffic light without priority	126,1236742	0,035034354	1635,403642	7
Dedicated bus lane starting 30m before the traffic light	125,9843076	0,034995641	1633,596522	6
Dedicated bus lane starting 30m before the traffic light with specific TSP on the Rooigemlaan	131,1001452	0,036416707	1699,931883	12
Bus lane with set back without priority	126,4079362	0,035113316	1639,089573	8
Bus lane with set back	125,792847	0,034942457	1631,113916	5
Bus lane with set back with specific TSP on the Rooigemlaan	129,5185729	0,035977381	1679,424162	11

Table 9.14: Cost per scenario for the entire intersection (cars) based on the node results and sensitivity analysis

Number of the scenario	Scenario	Overall cost	Ranking overall costs
1	Ordinary lane without priority	2343,422273	4
2	Ordinary lane	2415,549001	11
3	Ordinary lane with specific TSP on the Rooigemlaan	2391,296268	9
4	Dedicated bus lane without bus priority	2259,957842	2
5	Dedicated bus lane	2259,802652	1
6	Dedicated bus lane with specific TSP on the Rooigemlaan	2335,593547	3
7	Dedicated bus lane starting at 30m before the traffic light without priority	2366,889483	5
8	Dedicated bus lane starting at 30m before the traffic light	2380,659681	8
9	Dedicated bus lane starting at 30m before the traffic light with specific TSP on the Rooigemlaan	2418,481981	12
10	Bus lane with set back without priority	2377,606125	7
11	Bus lane with set back	2373,261817	6
12	Bus lane with set back with specific TSP on the Rooigemlaan	2396,623974	10

Table 9.15: Cost per scenario for the entire intersection based on the node results and sensitivity analysis

For these outputs, surprisingly is the dedicated bus lane the best option. Because of the sensitivity analysis and thus the increased capacity one will get delay times of more than 120 seconds for this reason one will obtain again a result that is within the boundaries of the constraints. This does not mean that the results for both the original scenario and the scenario with a dedicated bus lane perform the same because for both the bus and car delay one could see that the original scenario (scenario 2) will be the least preferred scenario in this situation. These findings are shown in the figure on the next page.

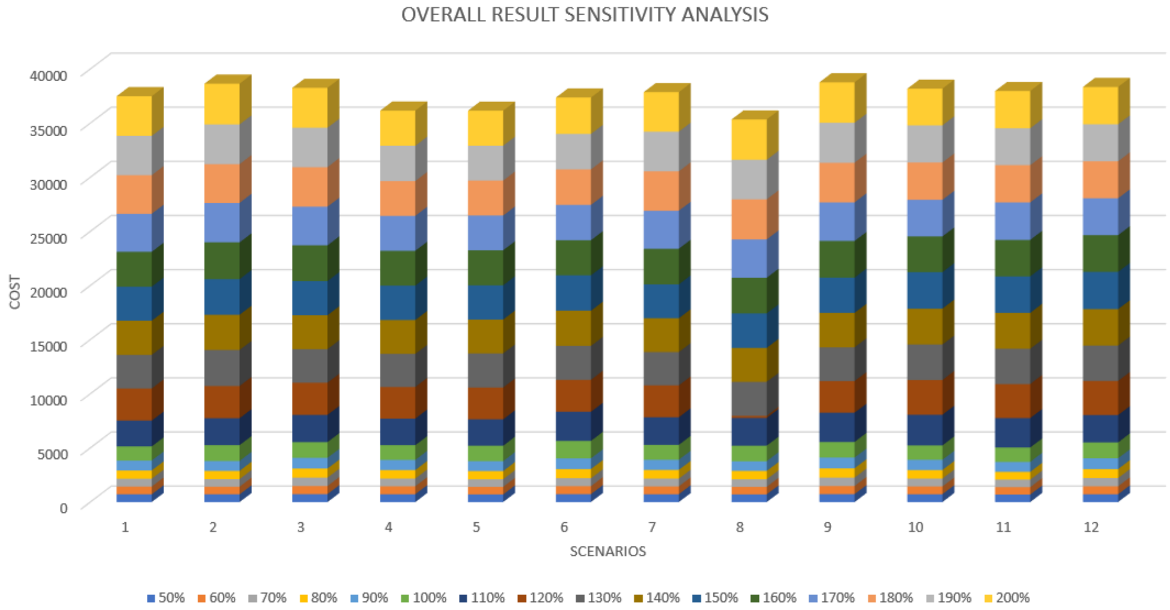


Figure 9.31: The overall results of entire intersection based on the sensitivity analysis and the node results

To end this section one will take a closer look into the costs per capacity rate. On the next page one will find all the graphic sorted per percentage of vehicle input, in these graphics it will become clear which type is best suited for which percentage.

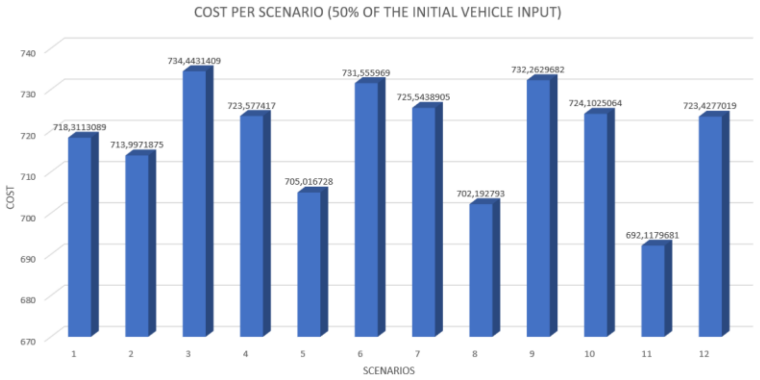


Figure 9.32: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 50% of the initial vehicle input)

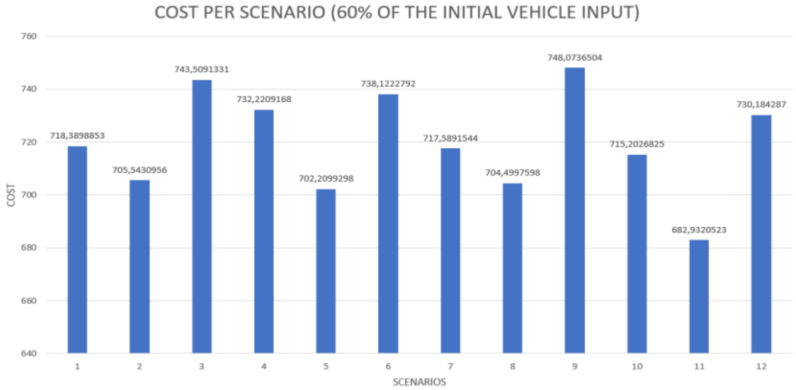


Figure 9.33: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 60% of the initial vehicle input)

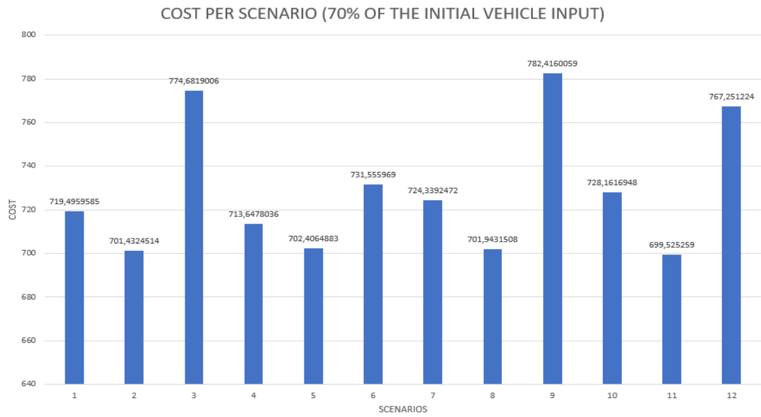


Figure 9.34: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 70% of the initial vehicle input)

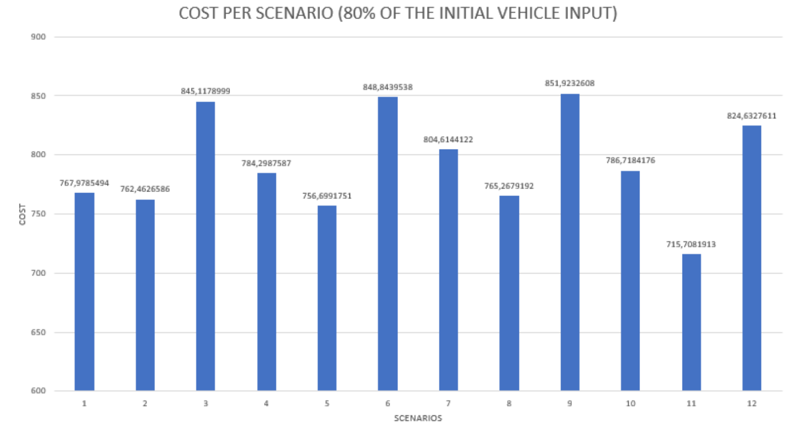


Figure 9.35: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 80% of the initial vehicle input)

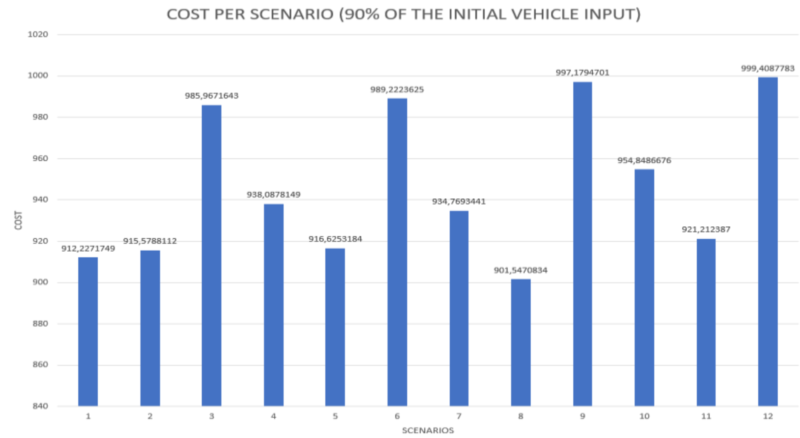


Figure 9.36: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 90% of the initial vehicle input)

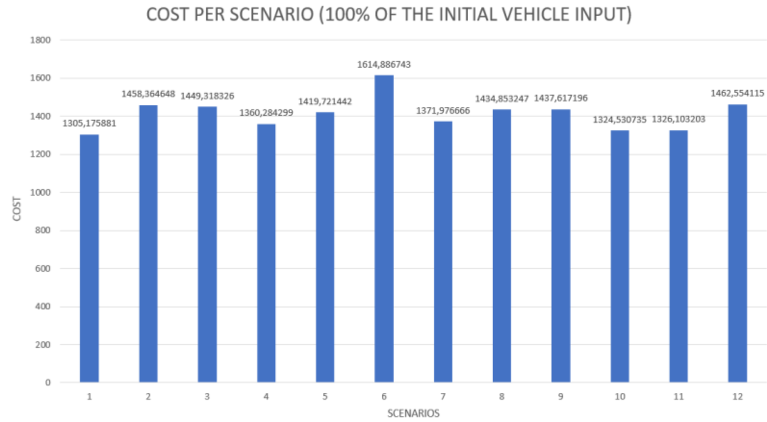


Figure 9.37: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 100% of the initial vehicle input)

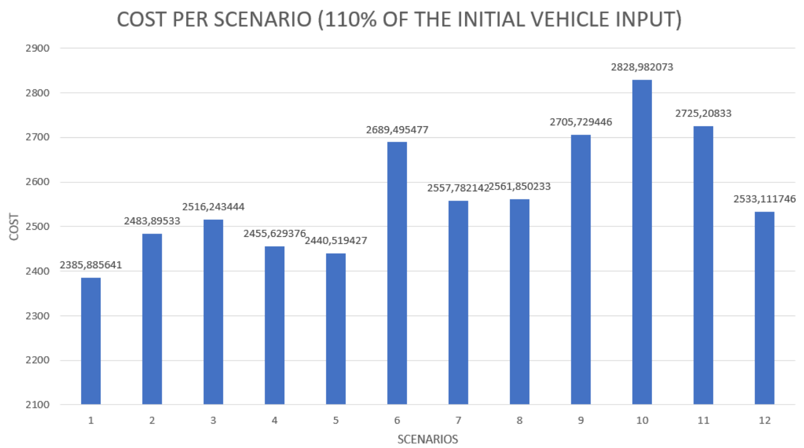


Figure 9.38: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 110% of the initial vehicle input)

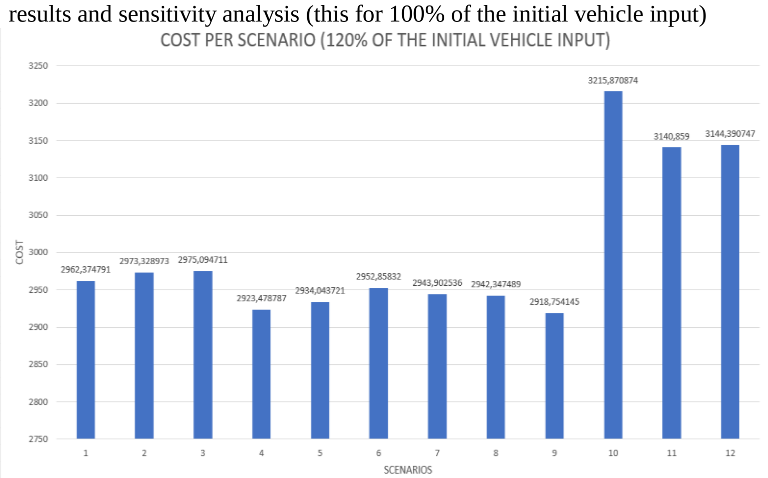


Figure 9.39: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 120% of the initial vehicle input)

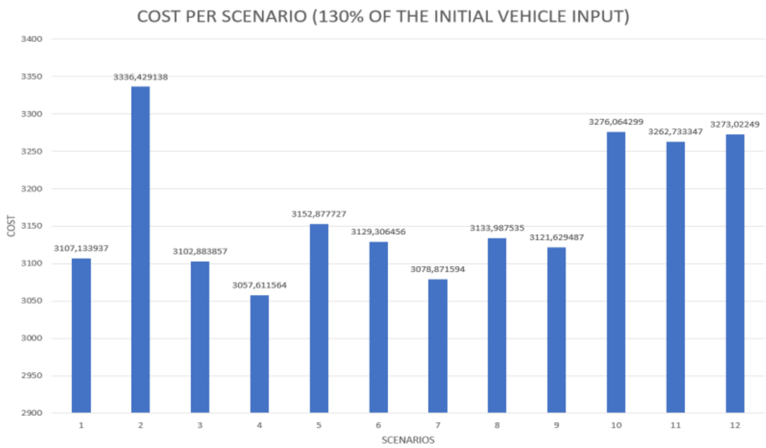


Figure 9.40: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 130% of the initial vehicle input)

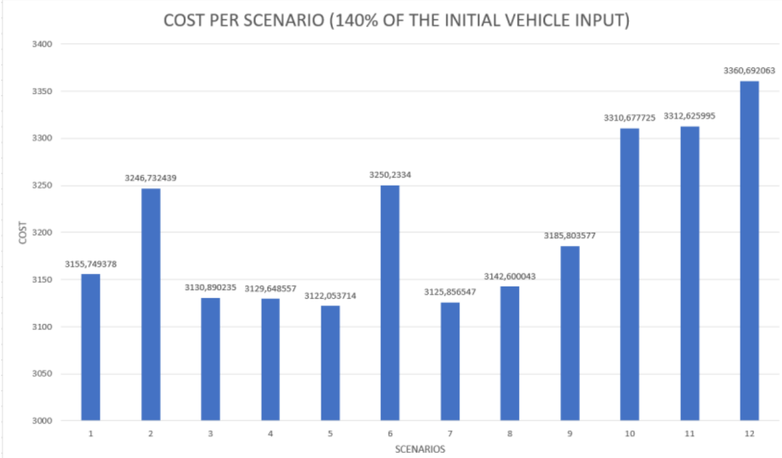


Figure 9.41: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 140% of the initial vehicle input)

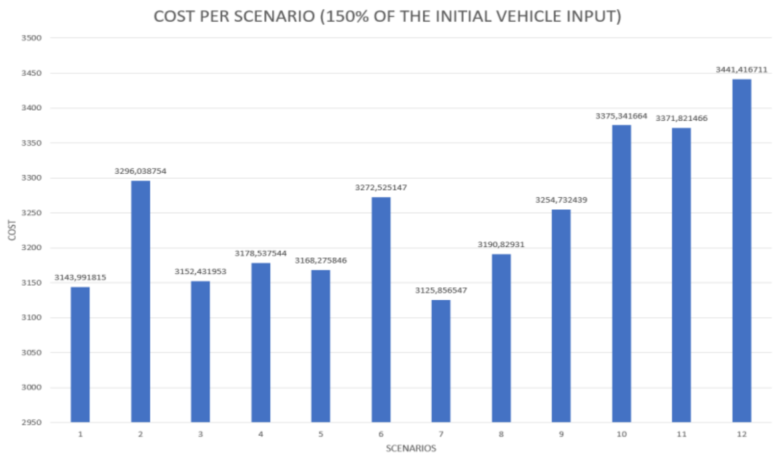


Figure 9.42: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 150% of the initial vehicle input)

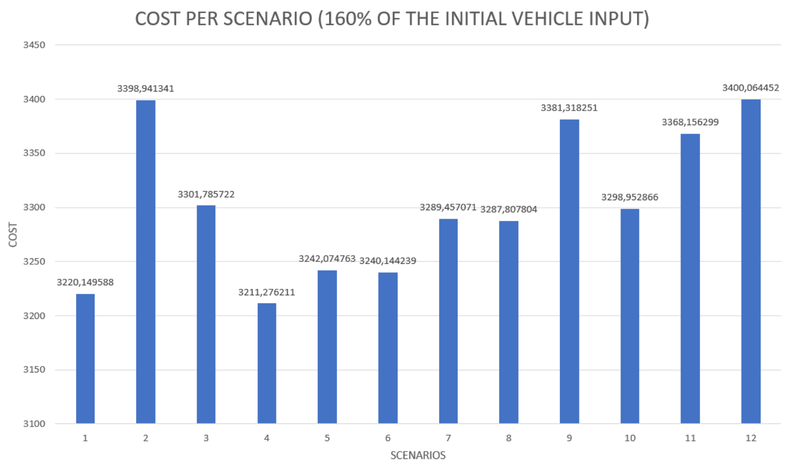


Figure 9.43: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 160% of the initial vehicle input)

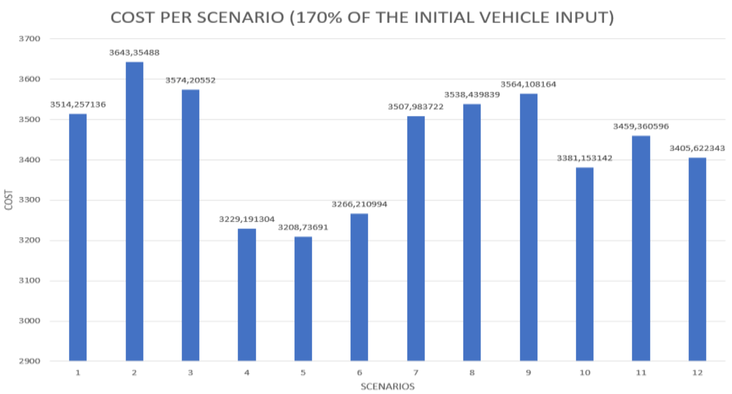


Figure 9.44: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 170% of the initial vehicle input)

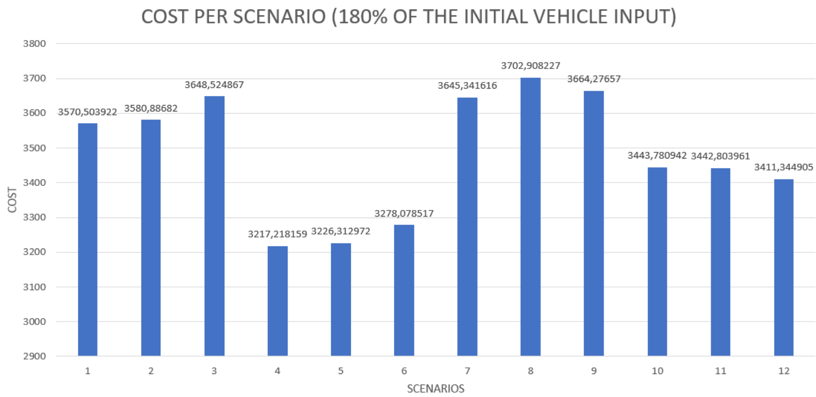


Figure 9.45: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 180% of the initial vehicle input)

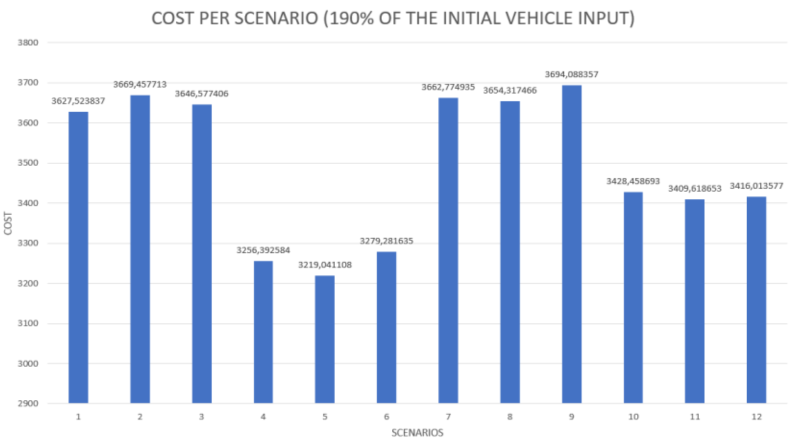


Figure 9.46: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 190% of the initial vehicle input)

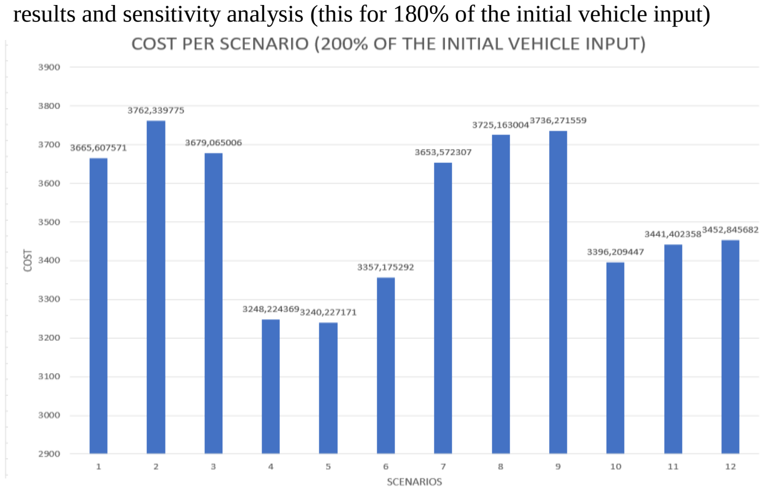


Figure 9.47: Cost per scenario for the entire intersection based on the node results and sensitivity analysis (this for 200% of the initial vehicle input)

From these figures one can learn plenty of things. The first aspect is that scenario 11 (Bus lane with set-back) will be the best suitable scenario for situations where the density is low (50% until 90%). In these situations it will also not be favourable to make use of a TSP. The inclusion of a TSP over the entire intersection is something that will be advantageous. One can conclude that the introduction of a dedicated bus lane is not that harmful for the delays at low density, this was already proven in the first part of the paper.
When approaching the 100% one will see that the outcomes are very volatile, because the system is moving from a low density to a high density system. After the system is again stabilized in a system with high density and long delays one will see that the use of the scenarios with a dedicated lane win in popularity. This may seem abnormal but let us not forget that this situation is for the entire intersection, one may conclude here is that overall delays in the intersection will decrease if one of the lanes are a dedicated bus lane.

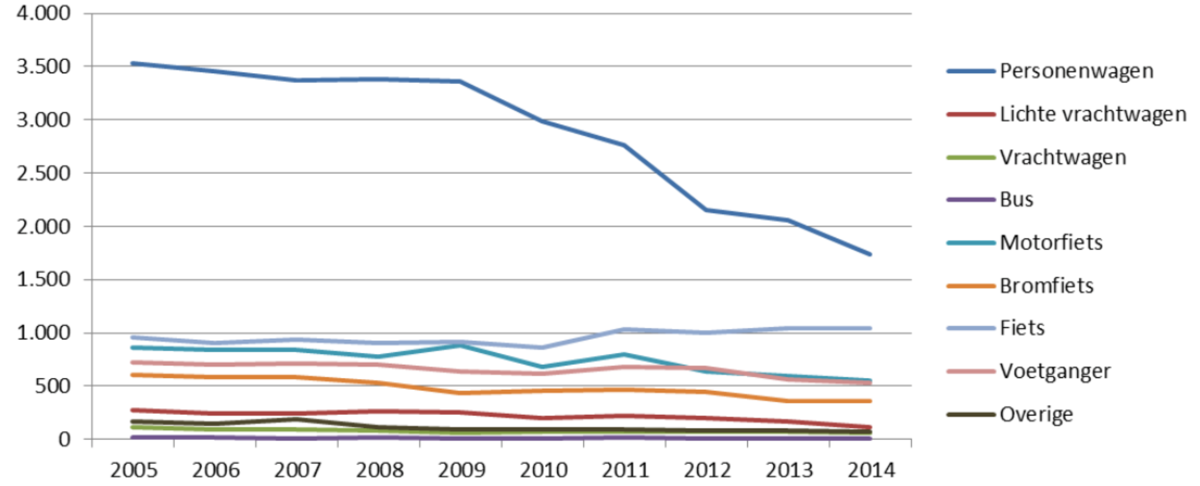
9.9 Conclusion

To end this paper one will briefly summarize the findings of this case study. By isolating the selected road from the entire intersection and by using the vehicle input that is equal to the current situation one has concluded that scenario 3 (Ordinary lane with specific TSP on the Rooigemlaan) is the optimal solution in this situation. After the execution of a sensitivity analysis this result will remain the same, that is scenario 3 will again be the best priority rule for both cars and buses. If one now includes the effect from the introduction of a scenario on the entire intersection, while maintaining the vehicle input at its current levels one will see that the optimal solution as changed,. The best solution in these circumstances will be an ordinary lane without priority. After expanding this situation to a situation where the averages of a second sensitivity are includes one will again notice a different outcome the best solution will here be the dedicated bus lane. To end the paper one would like to point out the similarities between the case study and the literature study. The case study clearly corresponds with the outcome one could expect based on the theoretical first part.

10 Appendix

PART I

<u>1 Introduction</u>



Bron: Algemene Directie Statistiek - Statistics Belgium.

Figure 10.1: Evolution of the amount of seriously injured people in traffic sorted per type of road user (Statistics Belgium)

2 Scenario 1: Capacity analysis

1. Calculations for the heavy vehicle adjustment factor, f_{HV}

$$f_{HV} = \frac{100}{100 + P_T(E_T - 1)} \tag{34}$$

With:

- P_T = The proportion of heavy vehicles
- E_T

2. Calculations for the grade adjustment factor, f_g

$$f_g = 1 - \frac{P_g}{200} \tag{35}$$

With:

- P_g = Approach grade for the subject movement group (%)

3. Calculations for the parking adjustment factor, f_p

$$f_p = \frac{N - 0,1 - \frac{18N_m}{3600}}{N} \tag{36}$$

With:

- N_m= Parking maneuver rate adjacent to lane group (maneuvers/h)
- N= Number of lanes in lane group

4. Calculations for the lane utilization adjustment factor, f_{LU}

$$f_{LU} = \frac{v_g}{v_{gi}N} \tag{37}$$

With:

- v_g= Unadjusted demand flow rate for lane group (veh/h)
- v_{gi}= Unadjusted demand flow rate on the single lane group with the highest volume
- N= Number of lanes in the lane group

5. Calculations for the bus stop adjustment factor, f_{bb}

$$f_{bb} = \frac{N - \frac{14.4N_b}{3600}}{N} \tag{38}$$

With:

- N = Number of lanes

- N_b= Bus stopping rate at the approach (buses/h)

6. Calculations for the right-turn adjustment factor for a protected movement on an exclusive lane, f_{RT}

$$f_{RT} = \frac{1}{E_R} \tag{39}$$

With:

- E_R = The equivalent number of through cars for a protected right-turning vehicle.
  =1.18

(40)

If the right-turn movement in on shared lane then we need to compute the adjusted saturation as follows:

$$\frac{v_i}{s_i} = \frac{\sum_{i=1}^{i=N_{th}} v_i}{\sum_{i=1}^{N_{th}} s_i}$$

With:

- v_i= The demand flow rate in lane i
- s_i= The saturation flow rate in lane i
- N_{th}= The number of through lanes (shared or exclusive)

7. Calculations for the left-turn adjustment factor for a protected movement on an exclusive lane, f_{LT}

$$f_{LT} = \frac{1}{E_L} = 0{,}95 \tag{41}$$

With:

- E_L= The equivalent number of through cars for a protected left-turning vehicle.

8. Procedure for calculating the adjustment for pedestrian-bicycle blockage on left turns, f_{Lpb} and the adjustment for pedestrian-bicycle blockage on right-turns f_{Rpb}

If we were handling a road with a low density and a few pedestrians/bicycles we could set these two parameters equal to 1. The process to compute the pedestrian-bicycle blockage is subdivided into six steps.

Step1: Determine the average pedestrian occupancy, OCC_{pedg} (pedestrian flow rate (p/h)).

In this step we first need to compute the pedestrian flow rate during the pedestrian service time, v_{pedg} (ped/h). v_{pedg} is calculated by the pedestrian flow rate in the subject crossing, v_{ped} (walking in both directions)((ped/h), the pedestrian service time g_{ped} (sec) and the cycle length, C (sec). This gives us the following formula (N.J Garber and L.A. Hoel, 2014):

$$v_{pedg} = v_{ped} \frac{C}{g_{ped}} \tag{42}$$

Normally the g_{ped} is equal to the effective green time for the phase, g. Now that we have the pedestrian flow rate during the pedestrian service we can calculate the average pedestrian occupancy. Because we assume the pedestrian flow rate is smaller than or equal to 1000 p/h we may use the following formula (N.J Garber and L.A. Hoel, 2014):

$$OCC_{pedg} = \frac{v_{pedg}}{2000} \; for\ pedestrian\ flow\ rate \leq 1000\ p/h \tag{43}$$

Step 2: The second step is the calculation of the average bicycle occupancy, OCC_{bicg}. This is done in the same way as in or step 1. First we need to determine the bicycle flow rate, v_{bicg} during the green light. (N.J Garber and L.A. Hoel, 2014)

$$v_{bicg} = v_{bic}\frac{C}{g} \tag{44}$$

With

v_{bicg} = The bicycle flow rate during the green indication (bic/h)

v_{bic} = The bicycle flow rate (bic/h)

g = The effective green time

C = The cycle length (sec)

Afterwards we can compute the average bicycle occupancy (N.J Garber and L.A. Hoel, 2014).

$$OCC_{bicg} = 0{,}02 + \frac{v_{bicg}}{2700} \tag{45}$$

Step 3: In the third step we need to determine the relevant conflict zone occupancy, OCC_r. Because our case study deals with the fact that there are pedestrian and bicycle interferences for right-turn movements we may use (N.J Garber and L.A. Hoel, 2014):

$$OCC_r = \left(\frac{g_{ped}}{g} OCC_{pedg}\right) + OCC_{bicg} - \left(\frac{g_{ped}}{g} OCC_{pedg} OCC_{bicg}\right) \tag{46}$$

With

OCC_{pedg}= The average pedestrian occupancy

OCC_{bicg}= The average bicycle occupancy

g_{ped}= The pedestrian service time

g= effective green time of the subject phase

Step 4: In the fourth step we need to determine the unoccupied time, A_{pbT}. In our case study we will see that the number of turning lanes (N_{turn}) is equal to the number of the cross-street receiving lanes (N_{rec}). If this is true we may use the next formula (N.J Garber and L.A. Hoel, 2014):

$$A_{pbT} = 1 - OCC_r \tag{47}$$

If this condition was not met, in other words $N_{turn} < N_{rec}$, we would need to use the following formula (N.J Garber and L.A. Hoel, 2014):

$$A_{pbT} = 1 - 0,6(OCC_r) \tag{48}$$

Step 5: In step 5 we need to determine the saturation flow adjustment factors for right-turn movements (f_{Rpb}) and for left-turn movements from one-way streets (f_{Lpb}). Here we will only do the calculations for one street because our case study is based on a one-way street.

- For permitted right turns in an exclusive lane we achieve the following formula (N.J Garber and L.A. Hoel, 2014):

$$f_{Rpb} = A_{pbT} \tag{49}$$

- For left-turn movements from a one-way street we achieve the following formula (N.J Garber and L.A. Hoel, 2014):

$$f_{Lpb} = A_{pbT} \tag{50}$$

10.3. Introduction and problem setting (case study) - Arrival time bus 9

Table 10.1: Characteristics bus 9

Bus stop	Name bus stop	Expected time	Real Time	Arrival bus (expected)	Arrival bus (real)	Extra time needed	Speed (exp)	Speed (real)
200515	Gent Appelstraat	20/03/17 06:39	20/3/17 06:38:41					
200533	Gent Eiland Malem	20/03/17 06:40	20/3/17 06:41:07	12:01:00 AM	12:02:26 AM	12:01:26 AM	18,12	7,45
200515	Gent Appelstraat	20/03/17 06:54	20/3/17 06:55:11					
200533	Gent Eiland Malem	20/03/17 06:55	20/3/17 06:57:18	12:01:00 AM	12:02:07 AM	12:01:07 AM	18,12	8,56
200515	Gent Appelstraat	20/03/17 07:09	20/3/17 07:09:23					
200533	Gent Eiland Malem	20/03/17 07:10	20/3/17 07:11:12	12:01:00 AM	12:01:49 AM	12:00:49 AM	18,12	9,97
200515	Gent Appelstraat	20/03/17 07:21	20/3/17 07:21:20					
200533	Gent Eiland Malem	20/03/17 07:22	20/3/17 07:22:55	12:01:00 AM	12:01:35 AM	12:00:35 AM	18,12	11,44
200515	Gent Appelstraat	20/03/17 07:31	20/3/17 07:29:02					
200533	Gent Eiland Malem	20/03/17 07:32	20/3/17 07:33:19	12:01:00 AM	12:04:17 AM	12:03:17 AM	18,12	4,23
200515	Gent Appelstraat	20/03/17 07:38	20/3/17 07:36:27					
200533	Gent Eiland Malem	20/03/17 07:39	20/3/17 07:39:07	12:01:00 AM	12:02:40 AM	12:01:40 AM	18,12	6,79
200515	Gent Appelstraat	20/03/17 08:21	20/3/17 08:17:27					
200533	Gent Eiland Malem	20/03/17 08:22	20/3/17 08:21:54	12:01:00 AM	12:04:27 AM	12:03:27 AM	18,12	4,07
200515	Gent Appelstraat	20/03/17 08:36	20/3/17 08:35:41					
200533	Gent Eiland Malem	20/03/17 08:37	20/3/17 08:39:12	12:01:00 AM	12:03:31 AM	12:02:31 AM	18,12	5,15
200515	Gent Appelstraat	20/03/17 09:08	20/3/17 09:03:29					
200533	Gent Eiland Malem	20/03/17 09:09	20/3/17 09:05:24	12:01:00 AM	12:01:55 AM	12:00:55 AM	18,12	9,45
200515	Gent Appelstraat	20/03/17 09:23	20/3/17 09:23:47					
200533	Gent Eiland Malem	20/03/17 09:24	20/3/17 09:24:43	12:01:00 AM	12:00:56 AM		18,12	19,41
200515	Gent Appelstraat	20/03/17 09:38	20/3/17 09:38:27					
200533	Gent Eiland Malem	20/03/17 09:39	20/3/17 09:40:40	12:01:00 AM	12:02:13 AM	12:01:13 AM	18,12	8,17
200515	Gent Appelstraat	20/03/17 09:53	20/3/17 09:54:02					
200533	Gent Eiland Malem	20/03/17 09:54	20/3/17 09:54:49	12:01:00 AM	12:00:47 AM		18,12	23,13
200515	Gent Appelstraat	20/03/17 10:03	20/3/17 10:02:08					
200533	Gent Eiland Malem	20/03/17 10:04	20/3/17 10:02:50	12:01:00 AM	12:00:42 AM		18,12	25,89
200515	Gent Appelstraat	20/03/17 10:23	20/3/17 10:19:17					
200533	Gent Eiland Malem	20/03/17 10:24	20/3/17 10:20:46	12:01:00 AM	12:01:29 AM	12:00:29 AM	18,12	12,22
200515	Gent Appelstraat	21/03/17 06:39	21/3/17 06:40:59					
200533	Gent Eiland Malem	21/03/17 06:40	21/3/17 06:42:08	12:01:00 AM	12:01:09 AM	12:00:09 AM	18,12	15,76
200515	Gent Appelstraat	21/03/17 06:54	21/3/17 06:55:09					
200533	Gent Eiland Malem	21/03/17 06:55	21/3/17 06:57:12	12:01:00 AM	12:02:03 AM	12:01:03 AM	18,12	8,84
200515	Gent Appelstraat	21/03/17 07:09	21/3/17 07:10:45					
200533	Gent Eiland Malem	21/03/17 07:10	21/3/17 07:13:12	12:01:00 AM	12:02:27 AM	12:01:27 AM	18,12	7,40
200515	Gent Appelstraat	21/03/17 07:21	21/3/17 07:17:36					
200533	Gent Eiland Malem	21/03/17 07:22	21/3/17 07:21:14	12:01:00 AM	12:03:38 AM	12:02:38 AM	18,12	4,99

200515	Gent Appelstraat	21/03/17 07:31	21/3/17 07:26:05					
200533	Gent Eiland Malem	21/03/17 07:32	21/3/17 07:31:11	12:01:00 AM	12:05:06 AM	12:04:06 AM	18,12	3,55
200515	Gent Appelstraat	21/03/17 07:38	21/3/17 07:37:15					
200533	Gent Eiland Malem	21/03/17 07:39	21/3/17 07:41:10	12:01:00 AM	12:03:55 AM	12:02:55 AM	18,12	4,63
200515	Gent Appelstraat	21/03/17 08:06	21/3/17 08:05:22					
200533	Gent Eiland Malem	21/03/17 08:07	21/3/17 08:07:57	12:01:00 AM	12:02:35 AM	12:01:35 AM	18,12	7,01
200515	Gent Appelstraat	21/03/17 08:36	21/3/17 08:41:19					
200533	Gent Eiland Malem	21/03/17 08:37	21/3/17 08:43:04	12:01:00 AM	12:01:45 AM	12:00:45 AM	18,12	10,35
200515	Gent Appelstraat	21/03/17 08:51	21/3/17 08:47:58					
200533	Gent Eiland Malem	21/03/17 08:52	21/3/17 08:49:42	12:01:00 AM	12:01:44 AM	12:00:44 AM	18,12	10,45
200515	Gent Appelstraat	21/03/17 09:08	21/3/17 09:07:08					
200533	Gent Eiland Malem	21/03/17 09:09	21/3/17 09:08:51	12:01:00 AM	12:01:43 AM	12:00:43 AM	18,12	10,56
200515	Gent Appelstraat	21/03/17 09:23	21/3/17 09:24:28					
200533	Gent Eiland Malem	21/03/17 09:24	21/3/17 09:25:13	12:01:00 AM	12:00:45 AM		18,12	24,16
200515	Gent Appelstraat	21/03/17 09:38	21/3/17 09:39:11					
200533	Gent Eiland Malem	21/03/17 09:39	21/3/17 09:40:28	12:01:00 AM	12:01:17 AM	12:00:17 AM	18,12	14,12
200515	Gent Appelstraat	21/03/17 09:53	21/3/17 09:51:28					
200533	Gent Eiland Malem	21/03/17 09:54	21/3/17 09:53:00	12:01:00 AM	12:01:32 AM	12:00:32 AM	18,12	11,82
200515	Gent Appelstraat	21/03/17 10:08	21/3/17 10:04:20					
200533	Gent Eiland Malem	21/03/17 10:09	21/3/17 10:05:40	12:01:00 AM	12:01:20 AM	12:00:20 AM	18,12	13,59
200515	Gent Appelstraat	22/03/17 06:25	22/3/17 06:22:35					
200533	Gent Eiland Malem	22/03/17 06:26	22/3/17 06:23:51	12:01:00 AM	12:01:16 AM	12:00:16 AM	18,12	14,31
200515	Gent Appelstraat	22/03/17 06:39	22/3/17 06:38:10					
200533	Gent Eiland Malem	22/03/17 06:40	22/3/17 06:38:58	12:01:00 AM	12:00:48 AM		18,12	22,65
200515	Gent Appelstraat	22/03/17 06:54	22/3/17 06:53:10					
200533	Gent Eiland Malem	22/03/17 06:55	22/3/17 06:57:53	12:01:00 AM	12:04:43 AM	12:03:43 AM	18,12	3,84
200515	Gent Appelstraat	22/03/17 07:09	22/3/17 07:07:53					
200533	Gent Eiland Malem	22/03/17 07:10	22/3/17 07:09:15	12:01:00 AM	12:01:22 AM	12:00:22 AM	18,12	13,26
200515	Gent Appelstraat	22/03/17 07:21	22/3/17 07:19:38					
200533	Gent Eiland Malem	22/03/17 07:22	22/3/17 07:21:03	12:01:00 AM	12:01:25 AM	12:00:25 AM	18,12	12,79
200515	Gent Appelstraat	22/03/17 08:06	22/3/17 08:02:23					
200533	Gent Eiland Malem	22/03/17 08:07	22/3/17 08:05:06	12:01:00 AM	12:02:43 AM	12:01:43 AM	18,12	6,67
200515	Gent Appelstraat	22/03/17 08:21	22/3/17 08:20:09					
200533	Gent Eiland Malem	22/03/17 08:22	22/3/17 08:21:38	12:01:00 AM	12:01:29 AM	12:00:29 AM	18,12	12,22
200515	Gent Appelstraat	22/03/17 08:36	22/3/17 08:33:19					
200533	Gent Eiland Malem	22/03/17 08:37	22/3/17 08:35:48	12:01:00 AM	12:02:29 AM	12:01:29 AM	18,12	7,30
200515	Gent Appelstraat	22/03/17 08:51	22/3/17 08:47:29					
200533	Gent Eiland Malem	22/03/17 08:52	22/3/17 08:48:32	12:01:00 AM	12:01:03 AM	12:00:03 AM	18,12	17,26
200515	Gent Appelstraat	22/03/17 09:23	22/3/17 09:23:48					

200533	Gent Eiland Malem	22/03/17 09:24	22/3/17 09:25:21	12:01:00 AM	12:01:33 AM	12:00:33 AM	18,12	11,69
200515	Gent Appelstraat	22/03/17 09:38	22/3/17 09:36:44					
200533	Gent Eiland Malem	22/03/17 09:39	22/3/17 09:37:32	12:01:00 AM	12:00:48 AM		18,12	22,65
200515	Gent Appelstraat	22/03/17 10:03	22/3/17 10:00:22					
200533	Gent Eiland Malem	22/03/17 10:04	22/3/17 10:02:32	12:01:00 AM	12:02:10 AM	12:01:10 AM	18,12	8,36
200515	Gent Appelstraat	22/03/17 10:23	22/3/17 10:23:17					
200533	Gent Eiland Malem	22/03/17 10:24	22/3/17 10:24:18	12:01:00 AM	12:01:01 AM	12:00:01 AM	18,12	17,82
200515	Gent Appelstraat	23/03/17 06:39	23/3/17 06:36:59					
200533	Gent Eiland Malem	23/03/17 06:40	23/3/17 06:38:57	12:01:00 AM	12:01:58 AM	12:00:58 AM	18,12	9,21
200515	Gent Appelstraat	23/03/17 06:54	23/3/17 06:54:23					
200533	Gent Eiland Malem	23/03/17 06:55	23/3/17 06:55:15	12:01:00 AM	12:00:52 AM		18,12	20,91
200515	Gent Appelstraat	23/03/17 07:09	23/3/17 07:08:29					
200533	Gent Eiland Malem	23/03/17 07:10	23/3/17 07:11:07	12:01:00 AM	12:02:38 AM	12:01:38 AM	18,12	6,88
200515	Gent Appelstraat	23/03/17 07:21	23/3/17 07:19:30					
200533	Gent Eiland Malem	23/03/17 07:22	23/3/17 07:21:13	12:01:00 AM	12:01:43 AM	12:00:43 AM	18,12	10,56
200515	Gent Appelstraat	23/03/17 07:31	23/3/17 07:27:00					
200533	Gent Eiland Malem	23/03/17 07:32	23/3/17 07:29:09	12:01:00 AM	12:02:09 AM	12:01:09 AM	18,12	8,43
200515	Gent Appelstraat	23/03/17 08:21	23/3/17 08:19:50					
200533	Gent Eiland Malem	23/03/17 08:22	23/3/17 08:23:08	12:01:00 AM	12:03:18 AM	12:02:18 AM	18,12	5,49
200515	Gent Appelstraat	23/03/17 08:36	23/3/17 08:38:12					
200533	Gent Eiland Malem	23/03/17 08:37	23/3/17 08:39:16	12:01:00 AM	12:01:04 AM	12:00:04 AM	18,12	16,99
200515	Gent Appelstraat	23/03/17 08:51	23/3/17 08:53:47					
200533	Gent Eiland Malem	23/03/17 08:52	23/3/17 08:55:46	12:01:00 AM	12:01:59 AM	12:00:59 AM	18,12	9,14
200515	Gent Appelstraat	23/03/17 09:08	23/3/17 09:04:24					
200533	Gent Eiland Malem	23/03/17 09:09	23/3/17 09:06:17	12:01:00 AM	12:01:53 AM	12:00:53 AM	18,12	9,62
200515	Gent Appelstraat	23/03/17 09:23	23/3/17 09:23:06					
200533	Gent Eiland Malem	23/03/17 09:24	23/3/17 09:25:18	12:01:00 AM	12:02:12 AM	12:01:12 AM	18,12	8,24
200515	Gent Appelstraat	23/03/17 09:38	23/3/17 09:36:46					
200533	Gent Eiland Malem	23/03/17 09:39	23/3/17 09:39:19	12:01:00 AM	12:02:33 AM	12:01:33 AM	18,12	7,11
200515	Gent Appelstraat	23/03/17 09:53	23/3/17 09:52:41					
200533	Gent Eiland Malem	23/03/17 09:54	23/3/17 09:53:42	12:01:00 AM	12:01:01 AM	12:00:01 AM	18,12	17,82
200515	Gent Appelstraat	23/03/17 10:03	23/3/17 10:02:59					
200533	Gent Eiland Malem	23/03/17 10:04	23/3/17 10:04:28	12:01:00 AM	12:01:29 AM	12:00:29 AM	18,12	12,22
200515	Gent Appelstraat	23/03/17 10:08	23/3/17 10:05:53					
200533	Gent Eiland Malem	23/03/17 10:09	23/3/17 10:07:14	12:01:00 AM	12:01:21 AM	12:00:21 AM	18,12	13,42
200515	Gent Appelstraat	23/03/17 10:23	23/3/17 10:21:30					
200533	Gent Eiland Malem	23/03/17 10:24	23/3/17 10:22:14	12:01:00 AM	12:00:44 AM		18,12	24,71
200515	Gent Appelstraat	24/03/17 06:39	24/3/17 06:38:50					
200533	Gent Eiland Malem	24/03/17 06:40	24/3/17 06:40:58	12:01:00	12:02:08	12:01:08	18,12	8,49

				AM	AM	AM		
200515	Gent Appelstraat	24/03/17 06:54	24/3/17 06:54:02					
200533	Gent Eiland Malem	24/03/17 06:55	24/3/17 06:54:58	12:01:00 AM	12:00:56 AM		18,12	19,41
200515	Gent Appelstraat	24/03/17 07:09	24/3/17 07:10:32					
200533	Gent Eiland Malem	24/03/17 07:10	24/3/17 07:13:08	12:01:00 AM	12:02:36 AM	12:01:36 AM	18,12	6,97
200515	Gent Appelstraat	24/03/17 07:21	24/3/17 07:17:34					
200533	Gent Eiland Malem	24/03/17 07:22	24/3/17 07:19:00	12:01:00 AM	12:01:26 AM	12:00:26 AM	18,12	12,64
200515	Gent Appelstraat	24/03/17 07:31	24/3/17 07:29:13					
200533	Gent Eiland Malem	24/03/17 07:32	24/3/17 07:31:11	12:01:00 AM	12:01:58 AM	12:00:58 AM	18,12	9,21
200515	Gent Appelstraat	24/03/17 07:38	24/3/17 07:36:57					
200533	Gent Eiland Malem	24/03/17 07:39	24/3/17 07:39:14	12:01:00 AM	12:02:17 AM	12:01:17 AM	18,12	7,94
200515	Gent Appelstraat	24/03/17 07:51	24/3/17 07:48:50					
200533	Gent Eiland Malem	24/03/17 07:52	24/3/17 07:53:43	12:01:00 AM	12:04:53 AM	12:03:53 AM	18,12	3,71
200515	Gent Appelstraat	24/03/17 08:21	24/3/17 08:20:05					
200533	Gent Eiland Malem	24/03/17 08:22	24/3/17 08:21:28	12:01:00 AM	12:01:23 AM	12:00:23 AM	18,12	13,10
200515	Gent Appelstraat	24/03/17 08:36	24/3/17 08:32:43					
200533	Gent Eiland Malem	24/03/17 08:37	24/3/17 08:35:15	12:01:00 AM	12:02:32 AM	12:01:32 AM	18,12	7,15
200515	Gent Appelstraat	24/03/17 08:51	24/3/17 08:49:32					
200533	Gent Eiland Malem	24/03/17 08:52	24/3/17 08:50:47	12:01:00 AM	12:01:15 AM	12:00:15 AM	18,12	14,50
200515	Gent Appelstraat	24/03/17 09:08	24/3/17 09:07:22					
200533	Gent Eiland Malem	24/03/17 09:09	24/3/17 09:09:43	12:01:00 AM	12:02:21 AM	12:01:21 AM	18,12	7,71
200515	Gent Appelstraat	24/03/17 09:23	24/3/17 09:26:50					
200533	Gent Eiland Malem	24/03/17 09:24	24/3/17 09:29:18	12:01:00 AM	12:02:28 AM	12:01:28 AM	18,12	7,35
200515	Gent Appelstraat	24/03/17 09:38	24/3/17 09:37:11					
200533	Gent Eiland Malem	24/03/17 09:39	24/3/17 09:38:18	12:01:00 AM	12:01:07 AM	12:00:07 AM	18,12	16,23
200515	Gent Appelstraat	24/03/17 09:53	24/3/17 09:53:36					
200533	Gent Eiland Malem	24/03/17 09:54	24/3/17 09:55:20	12:01:00 AM	12:01:44 AM	12:00:44 AM	18,12	10,45
200515	Gent Appelstraat	24/03/17 10:03	24/3/17 10:04:12					
200533	Gent Eiland Malem	24/03/17 10:04	24/3/17 10:05:45	12:01:00 AM	12:01:33 AM	12:00:33 AM	18,12	11,69
200515	Gent Appelstraat	24/03/17 10:23	24/3/17 10:21:20					
200533	Gent Eiland Malem	24/03/17 10:24	24/3/17 10:22:46	12:01:00 AM	12:01:26 AM	12:00:26 AM	18,12	12,64
200515	Gent Appelstraat	27/03/17 06:39	27/3/17 06:37:00					
200533	Gent Eiland Malem	27/03/17 06:40	27/3/17 06:38:00	12:01:00 AM	12:01:00 AM	12:00:00 AM	18,12	18,12
200515	Gent Appelstraat	27/03/17 06:54	27/3/17 06:53:00					
200533	Gent Eiland Malem	27/03/17 06:55	27/3/17 06:54:00	12:01:00 AM	12:01:00 AM		18,12	18,12
200515	Gent Appelstraat	27/03/17 07:09	27/3/17 07:09:00					
200533	Gent Eiland Malem	27/03/17 07:10	27/3/17 07:11:00	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06
200515	Gent Appelstraat	27/03/17 07:21	27/3/17 07:20:00					
200533	Gent Eiland Malem	27/03/17 07:22	27/3/17 07:21:00	12:01:00 AM	12:01:00 AM	12:00:00 AM	18,12	18,12

200515	Gent Appelstraat	27/03/17 07:31	27/3/17 07:30:00					
200533	Gent Eiland Malem	27/03/17 07:32	27/3/17 07:33:00	12:01:00 AM	12:03:00 AM	12:02:00 AM	18,12	6,04
200515	Gent Appelstraat	27/03/17 07:38	27/3/17 07:35:00					
200533	Gent Eiland Malem	27/03/17 07:39	27/3/17 07:38:00	12:01:00 AM	12:03:00 AM	12:02:00 AM	18,12	6,04
200515	Gent Appelstraat	27/03/17 07:51	27/3/17 07:50:00					
200533	Gent Eiland Malem	27/03/17 07:52	27/3/17 07:55:00	12:01:00 AM	12:05:00 AM	12:04:00 AM	18,12	3,62
200515	Gent Appelstraat	27/03/17 08:21	27/3/17 08:22:00					
200533	Gent Eiland Malem	27/03/17 08:22	27/3/17 08:27:00	12:01:00 AM	12:05:00 AM	12:04:00 AM	18,12	3,62
200515	Gent Appelstraat	27/03/17 08:36	27/3/17 08:37:00					
200533	Gent Eiland Malem	27/03/17 08:37	27/3/17 08:39:00	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06
200515	Gent Appelstraat	27/03/17 08:51	27/3/17 08:51:00					
200533	Gent Eiland Malem	27/03/17 08:52	27/3/17 08:53:00	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06
200515	Gent Appelstraat	27/03/17 09:23	27/3/17 09:23:00					
200533	Gent Eiland Malem	27/03/17 09:24	27/3/17 09:25:00	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06
200515	Gent Appelstraat	27/03/17 09:38	27/3/17 09:34:00					
200533	Gent Eiland Malem	27/03/17 09:39	27/3/17 09:35:00	12:01:00 AM	12:01:00 AM	12:00:00 AM	18,12	18,12
200515	Gent Appelstraat	27/03/17 09:53	27/3/17 09:54:00					
200533	Gent Eiland Malem	27/03/17 09:54	27/3/17 09:56:00	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06
200515	Gent Appelstraat	27/03/17 10:03	27/3/17 10:02:00					
200533	Gent Eiland Malem	27/03/17 10:04	27/3/17 10:04:00	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06
200515	Gent Appelstraat	27/03/17 10:23	27/3/17 10:21:00					
200533	Gent Eiland Malem	27/03/17 10:24	27/3/17 10:22:00	12:01:00 AM	12:01:00 AM		18,12	18,12
200515	Gent Appelstraat	28/03/17 06:25	28/3/17 06:24:04					
200533	Gent Eiland Malem	28/03/17 06:26	28/3/17 06:25:08	12:01:00 AM	12:01:04 AM	12:00:04 AM	18,12	16,99
200515	Gent Appelstraat	28/03/17 06:39	28/3/17 06:38:03					
200533	Gent Eiland Malem	28/03/17 06:40	28/3/17 06:39:13	12:01:00 AM	12:01:10 AM	12:00:10 AM	18,12	15,53
200515	Gent Appelstraat	28/03/17 06:54	28/3/17 06:53:33					
200533	Gent Eiland Malem	28/03/17 06:55	28/3/17 06:55:07	12:01:00 AM	12:01:34 AM	12:00:34 AM	18,12	11,57
200515	Gent Appelstraat	28/03/17 07:31	28/3/17 07:28:25					
200533	Gent Eiland Malem	28/03/17 07:32	28/3/17 07:31:19	12:01:00 AM	12:02:54 AM	12:01:54 AM	18,12	6,25
200515	Gent Appelstraat	28/03/17 07:38	28/3/17 07:35:06					
200533	Gent Eiland Malem	28/03/17 07:39	28/3/17 07:37:17	12:01:00 AM	12:02:11 AM	12:01:11 AM	18,12	8,30
200515	Gent Appelstraat	28/03/17 07:51	28/3/17 07:49:22					
200533	Gent Eiland Malem	28/03/17 07:52	28/3/17 07:53:08	12:01:00 AM	12:03:46 AM	12:02:46 AM	18,12	4,81
200515	Gent Appelstraat	28/03/17 08:06	28/3/17 08:06:40					
200533	Gent Eiland Malem	28/03/17 08:07	28/3/17 08:09:11	12:01:00 AM	12:02:31 AM	12:01:31 AM	18,12	7,20
200515	Gent Appelstraat	28/03/17 08:21	28/3/17 08:19:35					
200533	Gent Eiland Malem	28/03/17 08:22	28/3/17 08:25:24	12:01:00 AM	12:05:49 AM	12:04:49 AM	18,12	3,12

200515	Gent Appelstraat	28/03/17 08:36	28/3/17 08:33:55					
200533	Gent Eiland Malem	28/03/17 08:37	28/3/17 08:38:03	12:01:00 AM	12:04:08 AM	12:03:08 AM	18,12	4,38
200515	Gent Appelstraat	28/03/17 08:51	28/3/17 09:02:07					
200533	Gent Eiland Malem	28/03/17 08:52	28/3/17 09:06:14	12:01:00 AM	12:04:07 AM	12:03:07 AM	18,12	4,40
200515	Gent Appelstraat	28/03/17 09:08	28/3/17 09:08:39					
200533	Gent Eiland Malem	28/03/17 09:09	28/3/17 09:11:25	12:01:00 AM	12:02:46 AM	12:01:46 AM	18,12	6,55
200515	Gent Appelstraat	28/03/17 09:38	28/3/17 09:38:24					
200533	Gent Eiland Malem	28/03/17 09:39	28/3/17 09:39:38	12:01:00 AM	12:01:14 AM	12:00:14 AM	18,12	14,69
200515	Gent Appelstraat	28/03/17 09:53	28/3/17 09:55:09					
200533	Gent Eiland Malem	28/03/17 09:54	28/3/17 09:57:07	12:01:00 AM	12:01:58 AM	12:00:58 AM	18,12	9,21
200515	Gent Appelstraat	28/03/17 10:03	28/3/17 09:59:39					
200533	Gent Eiland Malem	28/03/17 10:04	28/3/17 10:00:16	12:01:00 AM	12:00:37 AM		18,12	29,38
200515	Gent Appelstraat	28/03/17 10:08	28/3/17 10:06:23					
200533	Gent Eiland Malem	28/03/17 10:09	28/3/17 10:07:17	12:01:00 AM	12:00:54 AM		18,12	20,13
200515	Gent Appelstraat	28/03/17 10:23	28/3/17 10:20:43					
200533	Gent Eiland Malem	28/03/17 10:24	28/3/17 10:22:27	12:01:00 AM	12:01:44 AM	12:00:44 AM	18,12	10,45
200515	Gent Appelstraat	29/03/17 06:25	29/3/17 06:28:37					
200533	Gent Eiland Malem	29/03/17 06:26	29/3/17 06:29:20	12:01:00 AM	12:00:43 AM		18,12	25,28
200515	Gent Appelstraat	29/03/17 06:39	29/3/17 06:37:57					
200533	Gent Eiland Malem	29/03/17 06:40	29/3/17 06:39:11	12:01:00 AM	12:01:14 AM	12:00:14 AM	18,12	14,69
200515	Gent Appelstraat	29/03/17 07:09	29/3/17 07:10:03					
200533	Gent Eiland Malem	29/03/17 07:10	29/3/17 07:11:19	12:01:00 AM	12:01:16 AM	12:00:16 AM	18,12	14,31
200515	Gent Appelstraat	29/03/17 07:31	29/3/17 07:29:28					
200533	Gent Eiland Malem	29/03/17 07:32	29/3/17 07:31:16	12:01:00 AM	12:01:48 AM	12:00:48 AM	18,12	10,07
200515	Gent Appelstraat	29/03/17 07:38	29/3/17 07:37:13					
200533	Gent Eiland Malem	29/03/17 07:39	29/3/17 07:38:37	12:01:00 AM	12:01:24 AM	12:00:24 AM	18,12	12,94
200515	Gent Appelstraat	29/03/17 07:51	29/3/17 07:48:59					
200533	Gent Eiland Malem	29/03/17 07:52	29/3/17 07:50:49	12:01:00 AM	12:01:50 AM	12:00:50 AM	18,12	9,88
200515	Gent Appelstraat	29/03/17 08:21	29/3/17 08:19:09					
200533	Gent Eiland Malem	29/03/17 08:22	29/3/17 08:23:08	12:01:00 AM	12:03:59 AM	12:02:59 AM	18,12	4,55
200515	Gent Appelstraat	29/03/17 08:36	29/3/17 08:34:06					
200533	Gent Eiland Malem	29/03/17 08:37	29/3/17 08:35:23	12:01:00 AM	12:01:17 AM	12:00:17 AM	18,12	14,12
200515	Gent Appelstraat	29/03/17 08:51	29/3/17 08:48:05					
200533	Gent Eiland Malem	29/03/17 08:52	29/3/17 08:50:31	12:01:00 AM	12:02:26 AM	12:01:26 AM	18,12	7,45
200515	Gent Appelstraat	29/03/17 09:08	29/3/17 09:04:04					
200533	Gent Eiland Malem	29/03/17 09:09	29/3/17 09:04:57	12:01:00 AM	12:00:53 AM		18,12	20,51
200515	Gent Appelstraat	29/03/17 09:23	29/3/17 09:22:09					
200533	Gent Eiland Malem	29/03/17 09:24	29/3/17 09:24:09	12:01:00 AM	12:02:00 AM	12:01:00 AM	18,12	9,06

200515	Gent Appelstraat	29/03/17 09:38	29/3/17 09:36:18					
200533	Gent Eiland Malem	29/03/17 09:39	29/3/17 09:38:02	12:01:00 AM	12:01:44 AM	12:00:44 AM	18,12	10,45
200515	Gent Appelstraat	29/03/17 09:53	29/3/17 09:52:55					
200533	Gent Eiland Malem	29/03/17 09:54	29/3/17 09:53:49	12:01:00 AM	12:00:54 AM		18,12	20,13
200515	Gent Appelstraat	29/03/17 10:08	29/3/17 10:04:40					
200533	Gent Eiland Malem	29/03/17 10:09	29/3/17 10:05:42	12:01:00 AM	12:01:02 AM	12:00:02 AM	18,12	17,54
200515	Gent Appelstraat	29/03/17 10:23	29/3/17 10:22:03					
200533	Gent Eiland Malem	29/03/17 10:24	29/3/17 10:23:58	12:01:00 AM	12:01:55 AM	12:00:55 AM	18,12	9,45
200515	Gent Appelstraat	30/03/17 06:39	30/3/17 06:37:23					
200533	Gent Eiland Malem	30/03/17 06:40	30/3/17 06:39:13	12:01:00 AM	12:01:50 AM	12:00:50 AM	18,12	9,88
200515	Gent Appelstraat	30/03/17 06:54	30/3/17 06:54:00					
200533	Gent Eiland Malem	30/03/17 06:55	30/3/17 06:54:57	12:01:00 AM	12:00:57 AM		18,12	19,07
200515	Gent Appelstraat	30/03/17 07:09	30/3/17 07:09:33					
200533	Gent Eiland Malem	30/03/17 07:10	30/3/17 07:10:52	12:01:00 AM	12:01:19 AM	12:00:19 AM	18,12	13,76
200515	Gent Appelstraat	30/03/17 07:21	30/3/17 07:20:18					
200533	Gent Eiland Malem	30/03/17 07:22	30/3/17 07:21:23	12:01:00 AM	12:01:05 AM	12:00:05 AM	18,12	16,73
200515	Gent Appelstraat	30/03/17 07:31	30/3/17 07:28:21					
200533	Gent Eiland Malem	30/03/17 07:32	30/3/17 07:31:05	12:01:00 AM	12:02:44 AM	12:01:44 AM	18,12	6,63
200515	Gent Appelstraat	30/03/17 07:38	30/3/17 07:37:31					
200533	Gent Eiland Malem	30/03/17 07:39	30/3/17 07:39:43	12:01:00 AM	12:02:12 AM	12:01:12 AM	18,12	8,24
200515	Gent Appelstraat	30/03/17 07:51	30/3/17 07:48:38					
200533	Gent Eiland Malem	30/03/17 07:52	30/3/17 07:51:08	12:01:00 AM	12:02:30 AM	12:01:30 AM	18,12	7,25
200515	Gent Appelstraat	30/03/17 08:06	30/3/17 08:02:50					
200533	Gent Eiland Malem	30/03/17 08:07	30/3/17 08:05:19	12:01:00 AM	12:02:29 AM	12:01:29 AM	18,12	7,30
200515	Gent Appelstraat	30/03/17 08:21	30/3/17 08:21:02					
200533	Gent Eiland Malem	30/03/17 08:22	30/3/17 08:23:10	12:01:00 AM	12:02:08 AM	12:01:08 AM	18,12	8,49
200515	Gent Appelstraat	30/03/17 08:36	30/3/17 08:37:26					
200533	Gent Eiland Malem	30/03/17 08:37	30/3/17 08:39:03	12:01:00 AM	12:01:37 AM	12:00:37 AM	18,12	11,21
200515	Gent Appelstraat	30/03/17 08:51	30/3/17 08:47:07					
200533	Gent Eiland Malem	30/03/17 08:52	30/3/17 08:49:37	12:01:00 AM	12:02:30 AM	12:01:30 AM	18,12	7,25
200515	Gent Appelstraat	30/03/17 09:08	30/3/17 09:06:07					
200533	Gent Eiland Malem	30/03/17 09:09	30/3/17 09:08:29	12:01:00 AM	12:02:22 AM	12:01:22 AM	18,12	7,66
200515	Gent Appelstraat	30/03/17 09:23	30/3/17 09:24:18					
200533	Gent Eiland Malem	30/03/17 09:24	30/3/17 09:25:41	12:01:00 AM	12:01:23 AM	12:00:23 AM	18,12	13,10
200515	Gent Appelstraat	30/03/17 09:38	30/3/17 09:39:44					
200533	Gent Eiland Malem	30/03/17 09:39	30/3/17 09:41:54	12:01:00 AM	12:02:10 AM	12:01:10 AM	18,12	8,36
200515	Gent Appelstraat	30/03/17 09:53	30/3/17 09:53:56					
200533	Gent Eiland Malem	30/03/17 09:54	30/3/17 09:55:29	12:01:00 AM	12:01:33 AM	12:00:33 AM	18,12	11,69
200515	Gent Appelstraat	30/03/17 10:03	30/3/17 09:59:52					

200533	Gent Eiland Malem	30/03/17 10:04	30/3/17 10:01:19	12:01:00 AM	12:01:27 AM	12:00:27 AM	18,12	12,50
200515	Gent Appelstraat	30/03/17 10:23	30/3/17 10:26:31					
200533	Gent Eiland Malem	30/03/17 10:24	30/3/17 10:28:12	12:01:00 AM	12:01:41 AM	12:00:41 AM	18,12	10,76
200515	Gent Appelstraat	31/03/17 06:25	31/3/17 06:24:07					
200533	Gent Eiland Malem	31/03/17 06:26	31/3/17 06:25:10	12:01:00 AM	12:01:03 AM	12:00:03 AM	18,12	17,26
200515	Gent Appelstraat	31/03/17 06:39	31/3/17 06:38:30					
200533	Gent Eiland Malem	31/03/17 06:40	31/3/17 06:40:44	12:01:00 AM	12:02:14 AM	12:01:14 AM	18,12	8,11
200515	Gent Appelstraat	31/03/17 06:54	31/3/17 06:55:20					
200533	Gent Eiland Malem	31/03/17 06:55	31/3/17 06:57:18	12:01:00 AM	12:01:58 AM	12:00:58 AM	18,12	9,21
200515	Gent Appelstraat	31/03/17 07:09	31/3/17 07:09:49					
200533	Gent Eiland Malem	31/03/17 07:10	31/3/17 07:10:59	12:01:00 AM	12:01:10 AM	12:00:10 AM	18,12	15,53
200515	Gent Appelstraat	31/03/17 07:21	31/3/17 07:18:53					
200533	Gent Eiland Malem	31/03/17 07:22	31/3/17 07:21:12	12:01:00 AM	12:02:19 AM	12:01:19 AM	18,12	7,82
200515	Gent Appelstraat	31/03/17 07:38	31/3/17 07:42:05					
200533	Gent Eiland Malem	31/03/17 07:39	31/3/17 07:43:33	12:01:00 AM	12:01:28 AM	12:00:28 AM	18,12	12,35
200515	Gent Appelstraat	31/03/17 07:51	31/3/17 07:49:29					
200533	Gent Eiland Malem	31/03/17 07:52	31/3/17 07:53:07	12:01:00 AM	12:03:38 AM	12:02:38 AM	18,12	4,99
200515	Gent Appelstraat	31/03/17 08:21	31/3/17 08:24:17					
200533	Gent Eiland Malem	31/03/17 08:22	31/3/17 08:26:40	12:01:00 AM	12:02:23 AM	12:01:23 AM	18,12	7,60
200515	Gent Appelstraat	31/03/17 08:36	31/3/17 08:34:46					
200533	Gent Eiland Malem	31/03/17 08:37	31/3/17 08:37:30	12:01:00 AM	12:02:44 AM	12:01:44 AM	18,12	6,63
200515	Gent Appelstraat	31/03/17 08:51	31/3/17 08:51:38					
200533	Gent Eiland Malem	31/03/17 08:52	31/3/17 08:54:46	12:01:00 AM	12:03:08 AM	12:02:08 AM	18,12	5,78
200515	Gent Appelstraat	31/03/17 09:23	31/3/17 09:22:59					
200533	Gent Eiland Malem	31/03/17 09:24	31/3/17 09:25:46	12:01:00 AM	12:02:47 AM	12:01:47 AM	18,12	6,51
200515	Gent Appelstraat	31/03/17 09:38	31/3/17 09:39:34					
200533	Gent Eiland Malem	31/03/17 09:39	31/3/17 09:42:00	12:01:00 AM	12:02:26 AM	12:01:26 AM	18,12	7,45
200515	Gent Appelstraat	31/03/17 09:53	31/3/17 10:01:49					
200533	Gent Eiland Malem	31/03/17 09:54	31/3/17 10:02:43	12:01:00 AM	12:00:54 AM		18,12	20,13
200515	Gent Appelstraat	31/03/17 10:03	31/3/17 10:03:28					
200533	Gent Eiland Malem	31/03/17 10:04	31/3/17 10:04:15	12:01:00 AM	12:00:47 AM		18,12	23,13

9.4. Queuing theory - Inter arrival time - Speed (Example)

Below you will find an example of information we gained because of the inductive loops. In this example we received the inter arrival times for the first of April but we have this information for the whole month. (The information is written in JSON format).


```
{
  "type":"FeatureCollection",
  "features":[
    {
      "type":"Feature",
      "geometry":{
        "type":"Point",
        "coordinates":[
          3.7202457700359748,
          51.041201364632059
        ]
      },
      "properties":{
        "attributes":[
          {
            "attributeName":"speed",
            "value":35
          },
          {
            "attributeName":"OCC",
            "value":1
          },
          {
            "attributeName":"Count",
            "value":60
          },
          {
            "attributeName":"Timestamp",
            "value":1491004635
          }
        ],
        "contextEntity":"M004"
      }
    }
....
{
  "type":"Feature",
  "geometry":{
```

```
      "type":"Point",
      "coordinates":[
        3.704950927420267,
        51.048204099093041
      ]
    },
    "properties":{
      "attributes":[
        {
          "attributeName":"speed",
          "value":28
        },
        {
          "attributeName":"OCC",
          "value":1
        },
        {
          "attributeName":"Count",
          "value":0
        },
        {
          "attributeName":"Timestamp",
          "value":1491090735
        }
      ],
      "contextEntity":"M034"
    }
}
],
"EventProcessedUtcTime":"2017-04-01T23:55:01.0938820Z",
"PartitionId":1,
"EventEnqueuedUtcTime":"2017-04-01T23:55:01.0510000Z"
}
```

Table 10.2 Inductive loops

Data induction loop with coordinates [51.05500071867678,3.6963258368238208], 04/01/2017				
Epoch Time Stamp	**Regular Time Stamp**	**Speed (km/h)**	**Nr Cars/ Timestamp**	**Difference between Time stamps**
1491004635	=> Fri, 31 Mar 2017 23:57:15 +0000	61	120	
1491004995	=> Sat, 01 Apr 2017 00:03:15 +0000	60	320	360
1491005236	=> Sat, 01 Apr 2017 00:07:16 +0000	54	200	241
1491005595	=> Sat, 01 Apr 2017 00:13:15 +0000	61	0	359
1491005835	=> Sat, 01 Apr 2017 00:17:15 +0000	54	260	240
1491006195	=> Sat, 01 Apr 2017 00:23:15 +0000	54	60	360
1491006435	=> Sat, 01 Apr 2017 00:27:15 +0000	61	40	240
1491006795	=> Sat, 01 Apr 2017 00:33:15 +0000	61	0	360
1491007155	=> Sat, 01 Apr 2017 00:39:15 +0000	61	0	360
1491007395	=> Sat, 01 Apr 2017 00:43:15 +0000	54	60	240
1491007635	=> Sat, 01 Apr 2017 00:47:15 +0000	62	60	240
1491007995	=> Sat, 01 Apr 2017 00:53:15 +0000	54	60	360
1491008355	=> Sat, 01 Apr 2017 00:59:15 +0000	54	60	360
1491008595	=> Sat, 01 Apr 2017 01:03:15 +0000	62	60	240
1491008835	=> Sat, 01 Apr 2017 01:07:15 +0000	61	0	240
1491009195	=> Sat, 01 Apr 2017 01:13:15 +0000	57	200	360
1491009555	=> Sat, 01 Apr 2017 01:19:15 +0000	54	120	360
1491009795	=> Sat, 01 Apr 2017 01:23:15 +0000	61	0	240
1491010035	=> Sat, 01 Apr 2017 01:27:15 +0000	54	60	240
1491010395	=> Sat, 01 Apr 2017 01:33:15 +0000	54	120	360
1491010635	=> Sat, 01 Apr 2017 01:37:15 +0000	59	200	240
1491010995	=> Sat, 01 Apr 2017 01:43:15 +0000	54	60	360
1491011235	=> Sat, 01 Apr 2017 01:47:15 +0000	54	120	240
1491011595	=> Sat, 01 Apr 2017 01:53:15 +0000	54	60	360
1491011955	=> Sat, 01 Apr 2017 01:59:15 +0000	54	60	360
1491012075	=> Sat, 01 Apr 2017 02:01:15 +0000	54	60	120
1491012435	=> Sat, 01 Apr 2017 02:07:15 +0000	54	60	360
1491012675	=> Sat, 01 Apr 2017 02:11:15 +0000	61	0	240
1491012915	=> Sat, 01 Apr 2017 02:15:15 +0000	61	0	240
1491013275	=> Sat, 01 Apr 2017 02:21:15 +0000	61	120	360
1491013515	=> Sat, 01 Apr 2017 02:25:15 +0000	54	60	240
1491013875	=> Sat, 01 Apr 2017 02:31:15 +0000	54	60	360
1491014115	=> Sat, 01 Apr 2017 02:35:15 +0000	61	0	240

1491014475	=> Sat, 01 Apr 2017 02:41:15 +0000	61	0	360
1491014715	=> Sat, 01 Apr 2017 02:45:15 +0000	61	0	240
1491015075	=> Sat, 01 Apr 2017 02:51:15 +0000	54	180	360
1491015315	=> Sat, 01 Apr 2017 02:55:15 +0000	61	0	240
1491015675	=> Sat, 01 Apr 2017 03:01:15 +0000	61	60	360
1491015915	=> Sat, 01 Apr 2017 03:05:15 +0000	54	60	240
1491016275	=> Sat, 01 Apr 2017 03:11:15 +0000	61	0	360
1491016635	=> Sat, 01 Apr 2017 03:17:15 +0000	54	60	360
1491016875	=> Sat, 01 Apr 2017 03:21:15 +0000	54	60	240
1491017115	=> Sat, 01 Apr 2017 03:25:15 +0000	54	120	240
1491017475	=> Sat, 01 Apr 2017 03:31:15 +0000	54	120	360
1491017715	=> Sat, 01 Apr 2017 03:35:15 +0000	54	120	240
1491018075	=> Sat, 01 Apr 2017 03:41:15 +0000	54	60	360
1491018435	=> Sat, 01 Apr 2017 03:47:15 +0000	54	60	360
1491018675	=> Sat, 01 Apr 2017 03:51:15 +0000	58	180	240
1491019035	=> Sat, 01 Apr 2017 03:57:15 +0000	54	60	360
1491019275	=> Sat, 01 Apr 2017 04:01:15 +0000	54	180	240
1491019515	=> Sat, 01 Apr 2017 04:05:15 +0000	62	180	240
1491019935	=> Sat, 01 Apr 2017 04:12:15 +0000	61	0	420
1491020295	=> Sat, 01 Apr 2017 04:18:15 +0000	54	120	360
1491020535	=> Sat, 01 Apr 2017 04:22:15 +0000	54	180	240
1491020895	=> Sat, 01 Apr 2017 04:28:15 +0000	61	0	360
1491021135	=> Sat, 01 Apr 2017 04:32:15 +0000	54	60	240
1491021375	=> Sat, 01 Apr 2017 04:36:15 +0000	57	240	240
1491021735	=> Sat, 01 Apr 2017 04:42:15 +0000	54	60	360
1491021975	=> Sat, 01 Apr 2017 04:46:15 +0000	61	0	240
1491022335	=> Sat, 01 Apr 2017 04:52:15 +0000	54	60	360
1491022575	=> Sat, 01 Apr 2017 04:56:15 +0000	54	100	240
1491022935	=> Sat, 01 Apr 2017 05:02:15 +0000	58	180	360
1491023175	=> Sat, 01 Apr 2017 05:06:15 +0000	62	60	240
1491023535	=> Sat, 01 Apr 2017 05:12:15 +0000	54	120	360
1491023775	=> Sat, 01 Apr 2017 05:16:15 +0000	60	60	240
1491024135	=> Sat, 01 Apr 2017 05:22:15 +0000	54	120	360
1491024495	=> Sat, 01 Apr 2017 05:28:15 +0000	54	60	360
1491024735	=> Sat, 01 Apr 2017 05:32:15 +0000	54	60	240
1491024975	=> Sat, 01 Apr 2017 05:36:15 +0000	61	0	240
1491025335	=> Sat, 01 Apr 2017 05:42:15 +0000	58	180	360
1491025575	=> Sat, 01 Apr 2017 05:46:15 +0000	54	300	240

1491025935	=> Sat, 01 Apr 2017 05:52:15 +0000	61	0	360
1491026175	=> Sat, 01 Apr 2017 05:56:15 +0000	58	180	240
1491026535	=> Sat, 01 Apr 2017 06:02:15 +0000	59	180	360
1491026775	=> Sat, 01 Apr 2017 06:06:15 +0000	54	120	240
1491027135	=> Sat, 01 Apr 2017 06:12:15 +0000	57	240	360
1491027375	=> Sat, 01 Apr 2017 06:16:15 +0000	57	240	240
1491027735	=> Sat, 01 Apr 2017 06:22:15 +0000	58	180	360
1491027975	=> Sat, 01 Apr 2017 06:26:15 +0000	57	260	240
1491028335	=> Sat, 01 Apr 2017 06:32:15 +0000	61	200	360
1491028695	=> Sat, 01 Apr 2017 06:38:15 +0000	61	480	360
1491028935	=> Sat, 01 Apr 2017 06:42:15 +0000	54	360	240
1491029295	=> Sat, 01 Apr 2017 06:48:15 +0000	54	400	360
1491029535	=> Sat, 01 Apr 2017 06:52:15 +0000	54	240	240
1491029895	=> Sat, 01 Apr 2017 06:58:15 +0000	54	620	360
1491030135	=> Sat, 01 Apr 2017 07:02:15 +0000	59	360	240
1491030495	=> Sat, 01 Apr 2017 07:08:15 +0000	56	480	360
1491030735	=> Sat, 01 Apr 2017 07:12:15 +0000	57	560	240
1491031095	=> Sat, 01 Apr 2017 07:18:15 +0000	59	320	360
1491031335	=> Sat, 01 Apr 2017 07:22:15 +0000	58	720	240
1491031575	=> Sat, 01 Apr 2017 07:26:15 +0000	59	580	240
1491031935	=> Sat, 01 Apr 2017 07:32:15 +0000	61	420	360
1491032175	=> Sat, 01 Apr 2017 07:36:15 +0000	60	820	240
1491032535	=> Sat, 01 Apr 2017 07:42:15 +0000	61	480	360
1491032775	=> Sat, 01 Apr 2017 07:46:15 +0000	57	660	240
1491033135	=> Sat, 01 Apr 2017 07:52:15 +0000	58	840	360
1491033495	=> Sat, 01 Apr 2017 07:58:15 +0000	58	760	360
1491033735	=> Sat, 01 Apr 2017 08:02:15 +0000	59	520	240
1491034095	=> Sat, 01 Apr 2017 08:08:15 +0000	62	900	360
1491034335	=> Sat, 01 Apr 2017 08:12:15 +0000	52	780	240
1491034575	=> Sat, 01 Apr 2017 08:16:15 +0000	60	780	240
1491034935	=> Sat, 01 Apr 2017 08:22:15 +0000	53	800	360
1491035295	=> Sat, 01 Apr 2017 08:28:15 +0000	56	900	360
1491035535	=> Sat, 01 Apr 2017 08:32:15 +0000	59	660	240
1491035775	=> Sat, 01 Apr 2017 08:36:15 +0000	55	840	240
1491036135	=> Sat, 01 Apr 2017 08:42:15 +0000	60	680	360
1491036375	=> Sat, 01 Apr 2017 08:46:15 +0000	52	640	240
1491036735	=> Sat, 01 Apr 2017 08:52:15 +0000	60	920	360
1491036975	=> Sat, 01 Apr 2017 08:56:15 +0000	60	720	240

1491037335	=> Sat, 01 Apr 2017 09:02:15 +0000	60	860	360
1491037575	=> Sat, 01 Apr 2017 09:06:15 +0000	59	760	240
1491037936	=> Sat, 01 Apr 2017 09:12:16 +0000	60	740	361
1491038295	=> Sat, 01 Apr 2017 09:18:15 +0000	59	540	359
1491038535	=> Sat, 01 Apr 2017 09:22:15 +0000	61	940	240
1491038895	=> Sat, 01 Apr 2017 09:28:15 +0000	59	780	360
1491039135	=> Sat, 01 Apr 2017 09:32:15 +0000	59	840	240
1491039375	=> Sat, 01 Apr 2017 09:36:15 +0000	57	700	240
1491039735	=> Sat, 01 Apr 2017 09:42:15 +0000	60	700	360
1491039975	=> Sat, 01 Apr 2017 09:46:15 +0000	58	640	240
1491040335	=> Sat, 01 Apr 2017 09:52:15 +0000	60	660	360
1491040695	=> Sat, 01 Apr 2017 09:58:15 +0000	63	680	360
1491040935	=> Sat, 01 Apr 2017 10:02:15 +0000	60	840	240
1491041175	=> Sat, 01 Apr 2017 10:06:15 +0000	59	900	240
1491041535	=> Sat, 01 Apr 2017 10:12:15 +0000	55	880	360
1491041895	=> Sat, 01 Apr 2017 10:18:15 +0000	59	900	360
1491042136	=> Sat, 01 Apr 2017 10:22:16 +0000	59	900	241
1491042375	=> Sat, 01 Apr 2017 10:26:15 +0000	61	660	239
1491042735	=> Sat, 01 Apr 2017 10:32:15 +0000	58	720	360
1491042975	=> Sat, 01 Apr 2017 10:36:15 +0000	61	800	240
1491043335	=> Sat, 01 Apr 2017 10:42:15 +0000	60	800	360
1491043575	=> Sat, 01 Apr 2017 10:46:15 +0000	61	720	240
1491043935	=> Sat, 01 Apr 2017 10:52:15 +0000	61	1020	360
1491044295	=> Sat, 01 Apr 2017 10:58:15 +0000	61	660	360
1491044535	=> Sat, 01 Apr 2017 11:02:15 +0000	59	960	240
1491044775	=> Sat, 01 Apr 2017 11:06:15 +0000	57	540	240
1491045135	=> Sat, 01 Apr 2017 11:12:15 +0000	58	720	360
1491045375	=> Sat, 01 Apr 2017 11:16:15 +0000	60	720	240
1491045735	=> Sat, 01 Apr 2017 11:22:15 +0000	58	860	360
1491046095	=> Sat, 01 Apr 2017 11:28:15 +0000	59	1080	360
1491046335	=> Sat, 01 Apr 2017 11:32:15 +0000	58	660	240
1491046576	=> Sat, 01 Apr 2017 11:36:16 +0000	60	660	241
1491046935	=> Sat, 01 Apr 2017 11:42:15 +0000	55	800	359
1491047175	=> Sat, 01 Apr 2017 11:46:15 +0000	59	800	240
1491047535	=> Sat, 01 Apr 2017 11:52:15 +0000	57	720	360
1491047775	=> Sat, 01 Apr 2017 11:56:15 +0000	62	720	240
1491048135	=> Sat, 01 Apr 2017 12:02:15 +0000	60	1000	360
1491048375	=> Sat, 01 Apr 2017 12:06:15 +0000	58	660	240

1491048735	=> Sat, 01 Apr 2017 12:12:15 +0000	59	700	360
1491049096	=> Sat, 01 Apr 2017 12:18:16 +0000	60	660	361
1491049335	=> Sat, 01 Apr 2017 12:22:15 +0000	61	880	239
1491049696	=> Sat, 01 Apr 2017 12:28:16 +0000	54	980	361
1491049936	=> Sat, 01 Apr 2017 12:32:16 +0000	56	980	240
1491050175	=> Sat, 01 Apr 2017 12:36:15 +0000	57	980	239
1491050535	=> Sat, 01 Apr 2017 12:42:15 +0000	59	660	360
1491050895	=> Sat, 01 Apr 2017 12:48:15 +0000	54	960	360
1491051135	=> Sat, 01 Apr 2017 12:52:15 +0000	56	980	240
1491051495	=> Sat, 01 Apr 2017 12:58:15 +0000	56	1040	360
1491051735	=> Sat, 01 Apr 2017 13:02:15 +0000	63	1140	240
1491051975	=> Sat, 01 Apr 2017 13:06:15 +0000	60	1100	240
1491052335	=> Sat, 01 Apr 2017 13:12:15 +0000	57	840	360
1491052695	=> Sat, 01 Apr 2017 13:18:15 +0000	59	900	360
1491052995	=> Sat, 01 Apr 2017 13:23:15 +0000	59	700	300
1491053235	=> Sat, 01 Apr 2017 13:27:15 +0000	56	720	240
1491053595	=> Sat, 01 Apr 2017 13:33:15 +0000	56	960	360
1491053836	=> Sat, 01 Apr 2017 13:37:16 +0000	59	920	241
1491054195	=> Sat, 01 Apr 2017 13:43:15 +0000	58	800	359
1491054435	=> Sat, 01 Apr 2017 13:47:15 +0000	55	660	240
1491054795	=> Sat, 01 Apr 2017 13:53:15 +0000	62	1080	360
1491055035	=> Sat, 01 Apr 2017 13:57:15 +0000	59	760	240
1491055395	=> Sat, 01 Apr 2017 14:03:15 +0000	57	600	360
1491055755	=> Sat, 01 Apr 2017 14:09:15 +0000	54	1060	360
1491055995	=> Sat, 01 Apr 2017 14:13:15 +0000	60	860	240
1491056235	=> Sat, 01 Apr 2017 14:17:15 +0000	59	820	240
1491056595	=> Sat, 01 Apr 2017 14:23:15 +0000	50	780	360
1491056835	=> Sat, 01 Apr 2017 14:27:15 +0000	54	860	240
1491057195	=> Sat, 01 Apr 2017 14:33:15 +0000	60	840	360
1491057435	=> Sat, 01 Apr 2017 14:37:15 +0000	60	760	240
1491057795	=> Sat, 01 Apr 2017 14:43:15 +0000	52	1140	360
1491058035	=> Sat, 01 Apr 2017 14:47:15 +0000	61	900	240
1491058395	=> Sat, 01 Apr 2017 14:53:15 +0000	60	540	360
1491058635	=> Sat, 01 Apr 2017 14:57:15 +0000	60	920	240
1491058995	=> Sat, 01 Apr 2017 15:03:15 +0000	60	900	360
1491059355	=> Sat, 01 Apr 2017 15:09:15 +0000	60	900	360
1491059595	=> Sat, 01 Apr 2017 15:13:15 +0000	60	840	240
1491059955	=> Sat, 01 Apr 2017 15:19:15 +0000	60	660	360

1491060195	=> Sat, 01 Apr 2017 15:23:15 +0000	59	580	240
1491060555	=> Sat, 01 Apr 2017 15:29:15 +0000	59	780	360
1491060795	=> Sat, 01 Apr 2017 15:33:15 +0000	58	700	240
1491061155	=> Sat, 01 Apr 2017 15:39:15 +0000	57	700	360
1491061395	=> Sat, 01 Apr 2017 15:43:15 +0000	60	980	240
1491061755	=> Sat, 01 Apr 2017 15:49:15 +0000	61	900	360
1491061995	=> Sat, 01 Apr 2017 15:53:15 +0000	61	960	240
1491062235	=> Sat, 01 Apr 2017 15:57:15 +0000	60	920	240
1491062595	=> Sat, 01 Apr 2017 16:03:15 +0000	58	800	360
1491062835	=> Sat, 01 Apr 2017 16:07:15 +0000	59	1040	240
1491063195	=> Sat, 01 Apr 2017 16:13:15 +0000	58	540	360
1491063435	=> Sat, 01 Apr 2017 16:17:15 +0000	59	820	240
1491063795	=> Sat, 01 Apr 2017 16:23:15 +0000	60	900	360
1491064155	=> Sat, 01 Apr 2017 16:29:15 +0000	56	720	360
1491064395	=> Sat, 01 Apr 2017 16:33:15 +0000	57	660	240
1491064635	=> Sat, 01 Apr 2017 16:37:15 +0000	59	440	240
1491064995	=> Sat, 01 Apr 2017 16:43:15 +0000	59	540	360
1491065235	=> Sat, 01 Apr 2017 16:47:15 +0000	59	840	240
1491065595	=> Sat, 01 Apr 2017 16:53:15 +0000	59	800	360
1491065835	=> Sat, 01 Apr 2017 16:57:15 +0000	58	760	240
1491066195	=> Sat, 01 Apr 2017 17:03:15 +0000	58	600	360
1491066435	=> Sat, 01 Apr 2017 17:07:15 +0000	61	660	240
1491066795	=> Sat, 01 Apr 2017 17:13:15 +0000	60	800	360
1491067035	=> Sat, 01 Apr 2017 17:17:15 +0000	57	480	240
1491067395	=> Sat, 01 Apr 2017 17:23:15 +0000	58	540	360
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1491067995	=> Sat, 01 Apr 2017 17:33:15 +0000	55	380	360
1491068355	=> Sat, 01 Apr 2017 17:39:15 +0000	57	520	360
1491068595	=> Sat, 01 Apr 2017 17:43:15 +0000	59	420	240
1491068955	=> Sat, 01 Apr 2017 17:49:15 +0000	59	600	360
1491069195	=> Sat, 01 Apr 2017 17:53:15 +0000	59	360	240
1491069435	=> Sat, 01 Apr 2017 17:57:15 +0000	55	500	240
1491069795	=> Sat, 01 Apr 2017 18:03:15 +0000	60	300	360
1491070035	=> Sat, 01 Apr 2017 18:07:15 +0000	59	700	240
1491070395	=> Sat, 01 Apr 2017 18:13:15 +0000	59	500	360
1491070635	=> Sat, 01 Apr 2017 18:17:15 +0000	55	120	240
1491070995	=> Sat, 01 Apr 2017 18:23:15 +0000	58	460	360
1491071355	=> Sat, 01 Apr 2017 18:29:15 +0000	61	540	360

1491071595	=> Sat, 01 Apr 2017 18:33:15 +0000	62	440	240
1491071955	=> Sat, 01 Apr 2017 18:39:15 +0000	59	540	360
1491072195	=> Sat, 01 Apr 2017 18:43:15 +0000	63	280	240
1491072555	=> Sat, 01 Apr 2017 18:49:15 +0000	58	320	360
1491072795	=> Sat, 01 Apr 2017 18:53:15 +0000	55	280	240
1491073155	=> Sat, 01 Apr 2017 18:59:15 +0000	60	240	360
1491073395	=> Sat, 01 Apr 2017 19:03:15 +0000	61	420	240
1491073635	=> Sat, 01 Apr 2017 19:07:15 +0000	58	240	240
1491073995	=> Sat, 01 Apr 2017 19:13:15 +0000	55	400	360
1491074355	=> Sat, 01 Apr 2017 19:19:15 +0000	60	280	360
1491074595	=> Sat, 01 Apr 2017 19:23:15 +0000	61	420	240
1491074835	=> Sat, 01 Apr 2017 19:27:15 +0000	55	240	240
1491075195	=> Sat, 01 Apr 2017 19:33:15 +0000	55	320	360
1491075435	=> Sat, 01 Apr 2017 19:37:15 +0000	55	360	240
1491075795	=> Sat, 01 Apr 2017 19:43:15 +0000	59	180	360
1491076155	=> Sat, 01 Apr 2017 19:49:15 +0000	57	500	360
1491076395	=> Sat, 01 Apr 2017 19:53:15 +0000	58	480	240
1491076755	=> Sat, 01 Apr 2017 19:59:15 +0000	55	300	360
1491076995	=> Sat, 01 Apr 2017 20:03:15 +0000	58	300	240
1491077355	=> Sat, 01 Apr 2017 20:09:15 +0000	58	240	360
1491077595	=> Sat, 01 Apr 2017 20:13:15 +0000	55	480	240
1491077956	=> Sat, 01 Apr 2017 20:19:16 +0000	61	240	361
1491078195	=> Sat, 01 Apr 2017 20:23:15 +0000	59	660	239
1491078435	=> Sat, 01 Apr 2017 20:27:15 +0000	55	360	240
1491078795	=> Sat, 01 Apr 2017 20:33:15 +0000	59	180	360
1491078915	=> Sat, 01 Apr 2017 20:35:15 +0000	57	360	120
1491079275	=> Sat, 01 Apr 2017 20:41:15 +0000	55	180	360
1491079515	=> Sat, 01 Apr 2017 20:45:15 +0000	55	240	240
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1491080835	=> Sat, 01 Apr 2017 21:07:15 +0000	60	400	360
1491081075	=> Sat, 01 Apr 2017 21:11:15 +0000	55	480	240
1491081315	=> Sat, 01 Apr 2017 21:15:15 +0000	57	360	240
1491081675	=> Sat, 01 Apr 2017 21:21:15 +0000	58	300	360
1491081915	=> Sat, 01 Apr 2017 21:25:15 +0000	55	280	240
1491082275	=> Sat, 01 Apr 2017 21:31:15 +0000	59	380	360
1491082515	=> Sat, 01 Apr 2017 21:35:15 +0000	55	300	240

1491082875	=> Sat, 01 Apr 2017 21:41:15 +0000	55	60	360
1491083235	=> Sat, 01 Apr 2017 21:47:15 +0000	55	340	360
1491083475	=> Sat, 01 Apr 2017 21:51:15 +0000	55	240	240
1491083835	=> Sat, 01 Apr 2017 21:57:15 +0000	59	420	360
1491084075	=> Sat, 01 Apr 2017 22:01:15 +0000	58	240	240
1491084315	=> Sat, 01 Apr 2017 22:05:15 +0000	55	180	240
1491084675	=> Sat, 01 Apr 2017 22:11:15 +0000	58	300	360
1491085035	=> Sat, 01 Apr 2017 22:17:15 +0000	55	380	360
1491085275	=> Sat, 01 Apr 2017 22:21:15 +0000	59	280	240
1491085515	=> Sat, 01 Apr 2017 22:25:15 +0000	58	300	240
1491085875	=> Sat, 01 Apr 2017 22:31:15 +0000	62	380	360
1491086116	=> Sat, 01 Apr 2017 22:35:16 +0000	63	320	241
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1491086895	=> Sat, 01 Apr 2017 22:48:15 +0000	58	260	360
1491087135	=> Sat, 01 Apr 2017 22:52:15 +0000	62	380	240
1491087375	=> Sat, 01 Apr 2017 22:56:15 +0000	58	240	240
1491087735	=> Sat, 01 Apr 2017 23:02:15 +0000	59	180	360
1491088095	=> Sat, 01 Apr 2017 23:08:15 +0000	61	0	360
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1491088695	=> Sat, 01 Apr 2017 23:18:15 +0000	55	120	360
1491088935	=> Sat, 01 Apr 2017 23:22:15 +0000	55	60	240
1491089175	=> Sat, 01 Apr 2017 23:26:15 +0000	59	180	240
1491089535	=> Sat, 01 Apr 2017 23:32:15 +0000	59	320	360
1491089775	=> Sat, 01 Apr 2017 23:36:15 +0000	55	120	240
1491090135	=> Sat, 01 Apr 2017 23:42:15 +0000	61	120	360
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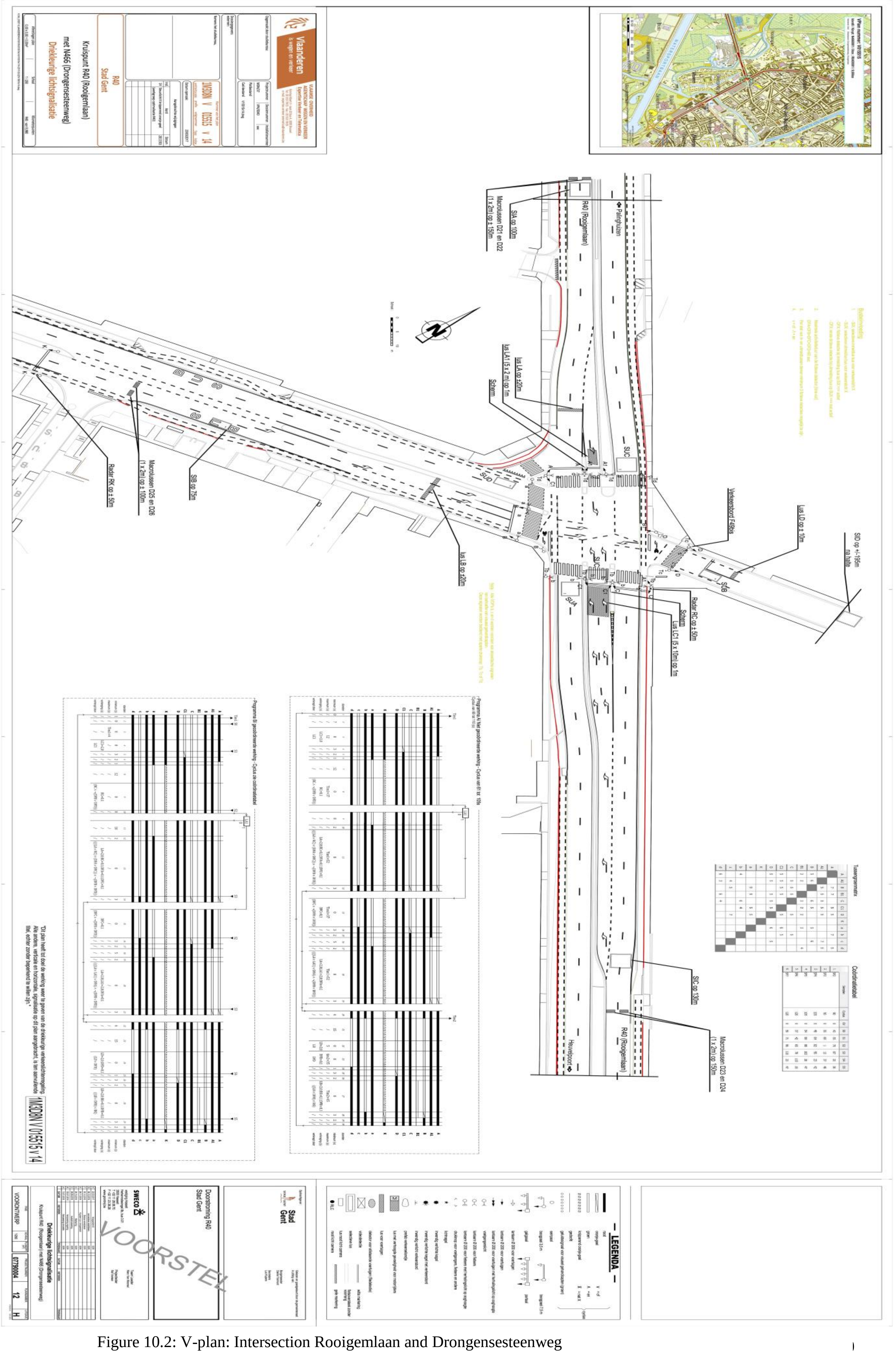

Figure 10.2: V-plan: Intersection Rooigemlaan and Drongensesteenweg

Tables 10.3: WLO scenario´s: Regional Communities (RC), Strong Europe (SE), Transatlantic Market (TM), Global Economy (GE)

Bron:

AVV, 1998, "Advies inzake reistijdwaarderingen van personen", Rotterdam.
Ministerie van Verkeer en Waterstaat en Ministerie van Economische Zaken, 2004, "Aanvulling leidraad OEI-directe effecten", Den Haag.
CPB, 2006, "Centraal economisch plan 2006", Den Haag.
CPB, 2004, “Vier vergezichten op Nederland; productie, arbeid en sectorstructuur in vier scenario's tot 2040”, Den Haag.

Cost value for cars:

Regional Communities (RC)

Jaar	VoT woon-werk in Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	8,50	29,43	5,87	9,49
2006	8,57	29,67	5,92	9,57
2010	8,85	30,63	6,11	9,88
2020	9,58	33,17	6,62	10,69
2040	11,70	40,51	8,08	13,06

Strong Europe (SE)

Jaar	VoT woon-werk in Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	8,50	29,43	5,87	9,49
2006	8,59	29,76	5,93	9,59
2010	8,98	31,09	6,20	10,03
2020	10,02	34,70	6,92	11,19
2040	12,64	43,75	8,73	14,11

Transatlantic Market (TM)

Jaar	VoT woon-werk In Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	8,50	29,43	5,87	9,49
2006	8,59	29,75	5,93	9,59
2010	8,97	31,07	6,20	10,02
2020	10,00	34,63	6,91	11,17
2040	12,72	44,04	8,78	14,20

Cost value for buses per traveller:

Bron:
AVV, 1998, "Advies inzake reistijdwaarderingen van personen", Rotterdam.
Ministerie van Verkeer en Waterstaat en Ministerie van Economische Zaken, 2004, "Aanvulling leidraad OEI-directe effecten", Den Haag.
CPB, 2006, "Centraal economisch plan 2006", Den Haag.
CPB, 2004, “Vier vergezichten op Nederland; productie, arbeid en sectorstructuur in vier scenario's tot 2040”, Den Haag.

Regional Communities (RC)

Jaar	VoT woon-werk in Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	7,97	13,89	5,04	5,92
2006	8,03	14,00	5,08	5,97
2010	8,29	14,45	5,24	6,16
2020	8,98	15,65	5,68	6,67
2040	10,97	19,12	6,94	8,15

Strong Europe (SE)

Jaar	VoT woon-werk in Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	7,97	13,89	5,04	5,92
2006	8,06	14,04	5,10	5,99
2010	8,42	14,67	5,32	6,25
2020	9,40	16,38	5,94	6,98
2040	11,85	20,65	7,49	8,80

Transatlantic Market (TM)

Jaar	VoT woon-werk in Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	7,97	13,89	5,04	5,92
2006	8,06	14,04	5,09	5,98
2010	8,41	14,66	5,32	6,25
2020	9,38	16,34	5,93	6,97
2040	11,93	20,79	7,54	8,86

Global Economy (GE)

Jaar	VoT woon-werk in Euro per uur	VoT zakelijk in Euro per uur	VoT overig personen in Euro per uur	VoT alle motieven in Euro per uur
2005	7,97	13,89	5,04	5,92
2006	8,08	14,08	5,11	6,00
2010	8,54	14,89	5,40	6,35
2020	9,82	17,11	6,21	7,29
2040	13,26	23,11	8,39	9,85

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