SMART TRAFFIC IN A NETWORK

UNIVERSITY OF TWENTE.

SWECO

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Preface

Here you are at the beginning of the thesis "Smart Traffic in a Network", a research about what it takes to change Smart Traffic from a local to a network level based on Dutch Rule-based approach and the vision of two Dutch municipalities Almelo and Amsterdam. This thesis is written in the context of my graduation of the bachelor Civil Engineering at the University of Twente and commissioned by internship company Sweco. I have been researching and writing this thesis from April 2020 until June 2020.

For my thesis, I was interested in the transitions taking place in the field of traffic management. Initially, I would focus on the self-driving car, but after a conversation in February with my supervisor at Sweco, Sandra Kamphuis, this subject shifted. Smart Traffic is a viable variant that also anticipates to future developments. After this conversation, I came in contact with my supervisor at the University, Eric van Berkum. Together, we eventually came to this investigation. When the investigation could finally begin, the world was confronted with the coronavirus. Therefore I ended up doing the complete thesis from home in Ootmarsum and Enschede.

I am grateful to both supervisors for their help and positive attitude despite these difficult times. Because of this, I have kept faith in completing this research. After meetings, I always had the motivation to continue, and I am ultimately satisfied with the result. By studying from home, writing the thesis went differently than expected, but I think we all made the most of it.

I would also like to thank the clients of Sweco, Rob Hulleman from the municipality of Almelo and Koen van Sleeuwen from the municipality of Amsterdam for their contribution to this thesis. Because of the coronavirus, I have not actually met these people, but by making appointments online, I was able to express the interests of the municipalities as well as possible. It was occasionally difficult to make an appointment in these tumultuous times, but that is why I appreciate it more that when I had an appointment, they took the time for me. The same applies to Bert van Velzen, who helped me with discussions about the Rule-based approach and the possibilities of Smart Traffic. Thanks to the enthusiasm of these people, I enjoyed writing this thesis despite studying at home.

I hope you enjoy your reading.

Oscar Hoogeslag

Enschede, June 29, 2020

Abstract

Smart Traffic is an intelligent Traffic Control System that focuses on the local performance of an intersection. Due to predicting and taking into account traffic volumes, Smart Traffic can be seen as a more dynamic software compared to the current vehicle actuated controls. However, at this moment, Smart Traffic is not able to take into account the performance of the rest of the network. Cities would like to see that the dynamic characteristic can also be used to manage traffic on a network level. This transition means other parameters, perspectives and interests. In this thesis, there is looked at what is needed to transform Smart Traffic to a network level. In addition to the Dutch Rule-based approach (Landelijke Regelaanpak), the interests of the municipalities of Almelo and Amsterdam are considered. Two main points came up: Drawing up a Rule-based approach is labour intensive and complicated because different scenarios have to be written for all situations. With Smart Traffic, it would be more efficient to ease the work of the road manager. Next to this, they indicated that the spaces in the network could be utilized more efficiently. Designating buffer locations in a busy network is almost impossible, and a thing of the past. The Rule-based approach is a handbook, and sometimes the vision of the municipalities could differ from this handbook. Ultimately the municipality is the client of Sweco, the company with which this thesis was carried out. Therefore the vision of the municipalities of Almelo and Amsterdam is the main focus, which could help Sweco to make their product more in line with future demand.

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Translations

English	Dutch
Backlash	Terugslag
Blockage	Blokkade
Boundary conditions	Randvoorwaarden
Buffer length	Bufferlengte
Circuit diagrams	Schakelschema
Control objective	Regeldoel
Control point	Regelpunt
Control scenarios	Regelscenario’s
Control space	Regelruimte
Corridor	Invalsweg
Decision point	Keuzepunt
Decision rules	Beslisregel
Divert traffic	Verkeer omleiden
Drive-off capacity	Afrij capaciteit
Drive-off intensity	Afrij intensiteit
Frame of reference	Referentiekader
Green times	Groentijden
Highway	Snelweg
Inner ring	Binnenring
Intelligent Traffic Control System (iTCS)	Intelligente Verkeersregelinstallatie (iVRI)
Leeway	Speelruimte / bewegingsruimte
Limit inflow	Instroom beperken
Mode of transport	Verkeerdmodaliteit
Overload	Overbelasting
Promote outflow	Uitstroom bevorderen
Rat running	Sluipverkeer
Resolving power	Oplossend vermogen
Road authority	Wegbeheerder
Road manager	Wegverkeersleider
Rule-based approach	Regelaanpak (LRA=Landelijke Regelaanpak)
Rule-based strategy	Regelstrategie
Saturation	Verzadiging
Setup space	Opstelruimte
Space utilization	Ruimte benutten
Strip length	Strooklengte
Subnetwork	Deelnetwerk
Switch-off conditions	Uitschakelvoorwaarden
Switch-on conditions	Inschakelvoorwaarden
Target value	Streefwaarde
The Directorate-General for Public Works and Water Management	Rijkswaterstaat
Through traffic	Doorgaand verkeer
Traffic Control System (TCS)	Verkeersregelinstallatie (VRI)
Traffic network	Verkeersnetwerk
Turning direction	Afslaande richting
Underlying road network	Onderliggend wegennet
Urban road network	Stedelijk wegennet

1 Introduction

The population in cities is growing. The prediction is that municipalities of Amsterdam and Utrecht will increase with respectively 17,8 and 22,5% in 2035 (CBS, 2019). This population growth creates a lot of new issues, for example, the increased demand for transportation. Municipalities, provinces and other government bodies are constantly working on these type of traffic issues. The increasing demand makes it challenging to realise traffic flows as good and as safe as possible. Also taking into account the developments in the field of self-driving cars, Floating Car Data and road-vehicle communication systems, there are significant changes in the area of traffic going on. This transition is reported under the name of Smart Mobility.

An essential element of Smart Mobility is the intelligent Traffic Control System (iTCS). The successor of the Vehicle-Actuated Control is not pre-programmed with maximum green times or standard sequences, and therefore even better suited to the current traffic situation. Sweco has developed software which optimizes control schedules. This product is called Smart Traffic and is an example of an intelligent Traffic Control System. At this moment, the software focusses on the local performance of an intersection, with primarily the number of stops and total delay at an intersection as parameters. The model can make predictions when traffic arrives, but the optimization is still on a local level. This local optimization is not always the most favourable when zooming out to a network level.

For example, when traffic has been redirected to a downstream intersection, where already a lot of traffic is waiting, problems could occur. You would like to include the performance of the network in the optimization of your control schedule, especially when the traffic flow gets in trouble. That has not been done yet and will be the main focus of this thesis. What is, in case of an incident, needed for Smart Traffic to act on a network level?

An incident means that the target value of a link has been exceeded. All non-regular situations are covered by this concept. How you could intervene when there are problems in the network is explained in the Rule-based approach. This national handbook indicates which measures can be used and what should be considered in case of these traffic problems. The procedure will be used as the foundation for the analysis of Smart Traffic on a network level. Except for the theoretical aspect, it is also important to see what this will mean in practice. Therefore, Almelo and Amsterdam will be used as a case study.

Almelo is a city with ambition and implemented already 27 traffic lights supported by the software of Smart Traffic. These traffic lights are not connected with each other, and Almelo is interested to see how this could look like in a network. They do not have a clear network vision elaborated in documents, so this will also be a part that has to be done before the possibilities of Smart Traffic can be analysed. Furthermore, Almelo has a lot of space in the network, which makes it relatively easy to manage traffic in case of an incident. Amsterdam, on the other hand, has less space available in the network. Traffic jams are part of the daily picture there, and the municipality is looking for a way to fix this. They have a clear network vision of how traffic should be managed, but the transition to the iTCS did not take place yet. Therefore, they are also interested in the possibilities of Smart Traffic on a network level. Amsterdam can contribute to this thesis because they have a different view on traffic management.

With the perspectives of Almelo and Amsterdam, I hope to give a good idea of what Sweco could change to prepare their product better for future demands. At the end of this thesis, I will conclude and recommend where less focus needs to be placed and what the points of attention are.

2 Research structure

The research structure was also worked out for the proposal of the bachelor thesis. Due to other insights on the development of Smart Traffic and the network vision in Almelo, the structure has changed a bit. The main focus has remained the same. In this chapter, the research questions are formulated and how these questions could be addressed in the thesis.

2.1 Problem description

When the traffic intensity is higher than the capacity, there is a bottleneck, that we also call ‘incident’ in this thesis. Causes for this could be an increase in intensity (e.g. morning rush hour) or a decrease in capacity (e.g. accident). The bottleneck has to be solved, which will not happen by itself. Actions are required, and these actions that could be taken to solve a problem are discussed in the Dutch Rule-based approach (Dutch: Landelijke Regelaanpak – LRA). In summary, a service is requested that can be performed at a traffic light. For example, to give less green time to a signal group where a lot of traffic is waiting downstream. When we return to Smart Traffic, it must be concluded that they can not yet comply with the way of traffic management described in the LRA. But is this a problem? No, it does not have to be that Smart Traffic adheres exactly to the prescribed LRA. The LRA is sometimes described as static, and maybe with Smart Traffic, it is possible to solve this more dynamically.

However, the way Smart Traffic is currently not taking the performance of the network into account is for most networks insufficient. When Smart Traffic is now being installed on a larger scale in Amsterdam, it could not handle the problematic traffic situations in the city. And yes, this is a problem. In a city like Amsterdam, actions are needed to solve problems in their network. You can not handle all peaks and troughs in the traffic intensity with the same regular control schedule. In a wider network as Almelo, it is maybe not required, but it could also help when the performance of the network is used in the optimization process. In this thesis, the focus will be on how Smart Traffic could act on a network level in case of an incident. The Rule-based approach and also the perspective of the clients Almelo and Amsterdam are used for this analysis.

Main question

What is, in case of an incident, needed for Smart Traffic to act on a network level?

2.2 Research questions

As already mentioned, the Rule-based approach is a national handbook with how traffic could be managed in a network. This document needs to be studied, to see what is necessary to control traffic in a network. Furthermore, it could be used as a guideline to work out a traffic situation, which will be done in a later stage of the research.

Sub question 1

How is traffic managed in case of an incident according to the current LRA?

Smart Traffic is not taking into account the consequences for the network at all, by now only processing the number of stops and the total delay in the optimization process. The development to make the switch to network-level was not yet as far as expected. Therefore the structure of the thesis slightly changed. Chapter 5 describes the concept of Smart Traffic and how it could currently function in a network. The following question is answered in this section:

Sub question 2

How is traffic currently managed in case of an incident with the use of Smart Traffic?

After the theoretical concepts of the Rule-based approach and Smart Traffic, there will be looked from a practical perspective to two different cities: Almelo and Amsterdam. As already mentioned in the introduction, these cities differ in space and vision on how traffic should be managed. The main focus will be on Almelo because here, next to the fact they implemented Smart Traffic, they have the ambition to use these Traffic Control Systems on a network level. Almelo has previously also been used to test Smart Traffic in practice, and they are open to testing further developments. Furthermore, the contacts between the municipality of Almelo and the University of Twente and Sweco are good due to previous collaborations.

But before Smart Traffic can be worked out at a network level, there is a network vision needed that can be built on. This network vision was not clearly described in documents and has, therefore, been elaborated based on the Rule-based approach in Chapter 6.

Sub question 3
How does the situation in Almelo look when the current Rule-based approach is applied?

Now that the network vision is known, it is possible to continue with how Smart Traffic could act within this vision. Specific examples are used to get a clear picture of what the municipality of Almelo wants to see within Smart Traffic. This picture is mentioned as the vision of Almelo. Other interests that may not have been included in the Rule-based approach may also come to the fore here. The interests of the client, in this case the municipality of Almelo, are central to Chapter 7. In addition to Almelo's perspective, there is looked at Amsterdam. The circumstances are completely different, and Amsterdam has also indicated that it is open to looking at the possibilities of the iTCS. Sweco started with the installation of four traffic lights at the IJTunnel. Amsterdam has already a Rule-based approach for the northeastern part of Amsterdam. The network of Amsterdam is, together with the vision of the municipality, explained in Chapter 8. The vision of the municipalities of Almelo and Amsterdam ensures that sub question 4 can be answered.

Sub question 4
What does the client want to see in Smart Traffic to manage traffic in a network?

Sweco has expressed its ambition to provide Smart Traffic at the network level. They have already some ideas about how to realise the transition, which is explained in Section 5.4. For the future, Sweco would like to know what is needed for the change to the network level. This demand is also reflected in the main question. However, I also wanted to look at how the ideas from the municipalities could look in Smart Traffic, without using Sweco's train of thought. The discussed plans should be realistic, to prevent that it is difficult to use. The possibilities within Smart Traffic have arisen from the discussions with the municipalities and Sweco, among other things. The results of this, the opportunities within Smart Traffic, are suggestive and could be interesting for Sweco to see the approach from a different light. But it is good to emphasize that this is not the main focus of the thesis. The suggestions made in Chapter 9 will be discussed with Sweco to analyse the feasibility of it.

Sub question 5
How could the vision of Almelo and Amsterdam look like in Smart Traffic?

The sub questions will be mentioned separately in the report. It could be possible that the answer to the question is given in one specific paragraph. In this case, the rest of the chapter is used to provide supportive information.

2.3 Method

The first part of the thesis that is linked to sub question 1 and 2 is an introduction to the concepts of the Rule-based approach and Smart Traffic (Chapter 4 and 5). It mainly consists of theory. The information can be obtained from the LRA drawn up by the CROW. Information about Smart Traffic is less easy to find. The reason for this is that documents within Sweco speak with particular internal knowledge. There is hardly any explanation in a simple way to the outside world. Therefore employee knowledge will be used to get a better idea of how Smart Traffic works now. This first part of the thesis can be seen as a literature study.

After this, the theory will be applied to Almelo and Amsterdam (Chapter 7 and 8). The different situations will be studied, and the possibilities will be analysed. Interviews with the municipalities could map out the vision and demand of the clients of Sweco. Especially for Almelo, the only way to get information about the network vision is by direct contact because the information is not on paper at this moment. The Rule-based approach of Almelo is worked out in Chapter 6. In the meantime, it is possible to use internal knowledge from Sweco to decide whether the theory has been used correctly. This part is a case study with interviews. It is the main focus of this thesis.

The fifth sub question will be answered by designing a new approach for Smart Traffic to act on a network level (Chapter 9). As already mentioned, this can be based on ideas from the two municipalities, but also, on my own input. After drawing up the design, it is useful to analyse the feasibility of it within Sweco. The feedback from the municipalities is also requested, but because Sweco has to realise it, their opinion is more relevant. For example, Almelo does care less about how optimal schedules could be found, but more about how this optimal schedule will look like to solve the problems in their network.

With these five sub questions, enough information has been collected to answer the main question. This answer will be a conclusion of how Smart Traffic could act on a network level. The information is mostly coming from Chapter 7 and 8. Further, a recommendation is given on what may be relevant for Sweco to investigate in the future.

3 Background

For the terminology of this report, definitions from the Dutch Rule-based approach to traffic management are used. This handbook is abbreviated with LRA. The Rule-based approach module is primarily designed for professionals at road authorities and can be interpreted and used in its own way. The LRA is not a regulation that road authorities must comply with. In the next chapters, approaches of the municipalities of Almelo and Amsterdam will be discussed and are mentioned as their Rule-based approach.

In this thesis, the terminology from the LRA will be used, which describes how traffic could be managed on a network level. The network vision and description of the traffic network are fundamental elements of the LRA. Besides this, the definition of an incident has also been adopted and is explained in Section 3.3. The terms and distinctions are also used in the explanation of the concept of Smart Traffic. Most of the sources that are used for the theory of Smart Traffic or the Rule-based approach are Dutch. The translations from English to Dutch can be found at the beginning of this thesis on page 5.

3.1 Network vision

Before you could manage traffic in a city, it is good to have an idea about how the network should look like. These ideas consist among others of the layout, function and use of the road network and are an alignment between cooperating road authorities. This policy is also called the network vision and could be elaborated according to the GGB+ method (Dutch: Gebiedsgericht Benutten Plus). In other words, the network vision is the main idea about how traffic could be managed in a network. It consists of two parts: the Rule-based strategy and the frame of reference. The Rule-based strategy represents the available road network. Locations of decision points, priorities and functions of roads and preferred routes between different networks belong to this part of the network vision. The other part, the frame of reference, determines when a traffic problem should be seen as a bottleneck. Within the Rule-based approach, a bottleneck should have real and verifiable target values. This quantitative characteristic is also used to determine when there is an incident, the term used in this thesis.

3.2 Traffic network

It is also essential for the cooperation between road authorities that the same terminology is used for the elements in the network. In this section, the various terms, that are used in the LRA to describe a traffic network, are elaborated. From this frame of reference, the terms 'decision point' and 'control point' are taken over. At a decision point (Dutch: 'Keuzepunt), traffic can choose between routes in an available road network. Most of the time, a *dynamic routing information panel* is installed to give information to the drivers about the different routes. A control point (Dutch: 'Regelpunt') is where the traffic capacity can be affected, for example, by traffic lights.

The road between two decision points is called a route section (Dutch: 'Routedeel'), where the route between two control points is defined as a 'link'. An overview of the mentioned terms is given in Figure 1. With these concepts, it is easier to discuss plans and apply the LRA.

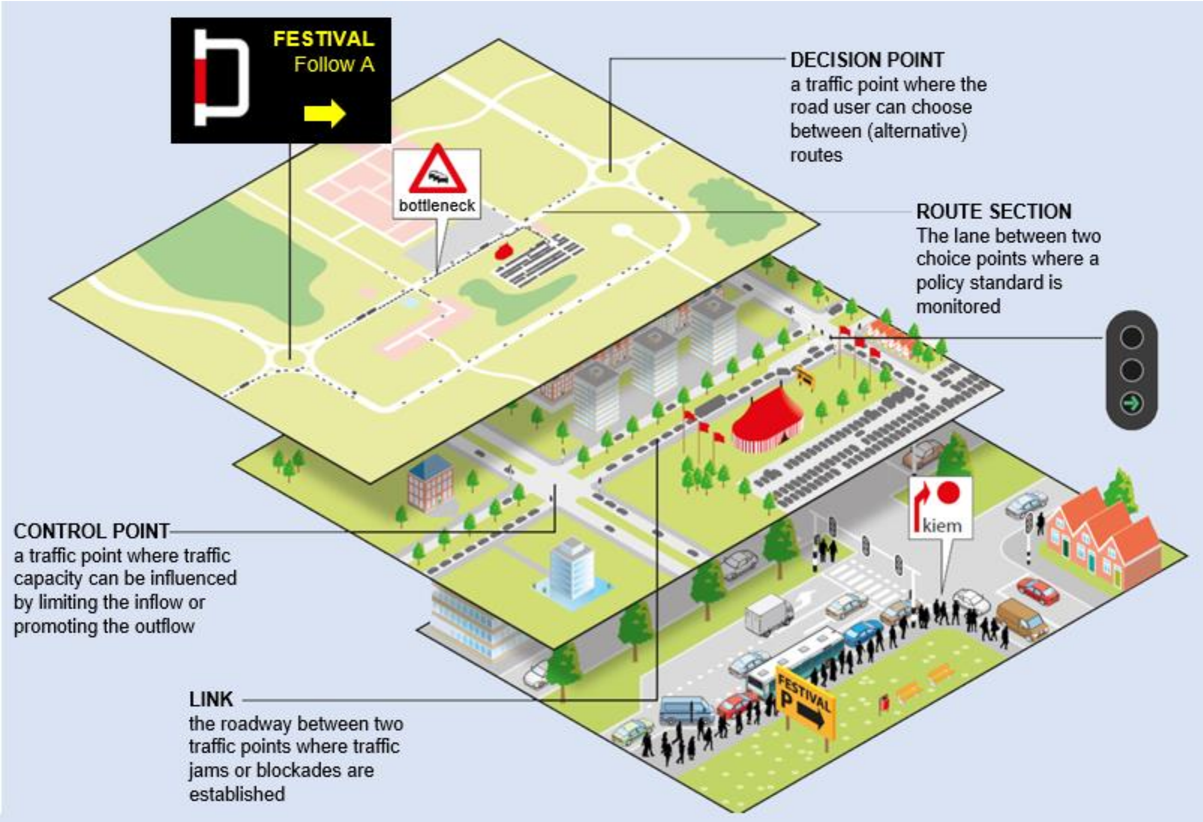

Figure 1 – Concepts in the LRA.

3.3 Incident

So, the frame of reference states how much traffic is allowed on a particular link in a network. When these values are exceeded, there is an incident. So, the frame of reference determines when a traffic problem should be seen as a bottleneck. Regular traffic management is unable to resolve this bottleneck, and action is required.

How these values are exceeded can have different causes. In the Rule-based approach, incidents can be divided into overload or blockage. An overload is when the traffic supply exceeds the traffic capacity. There is too much traffic to deal with, resulting in a traffic jam. This increase in demand could be due to regular circumstances, for example, every workday you have a certain traffic intensity in the morning. Or an event that ensures that the demand for a specific road section is higher.

With a blockage, the traffic capacity has decreased, and this has created a bottleneck. A complete blockage is when there is no possibility to use the link anymore. With a partial blockage, it is still possible to use a part of the road. For example, one of the two lanes is closed: half of the original traffic can continue on its way. Most of the blockades are caused by accidents, but it is also possible that blockades are planned, for example, with road work or a bridge opening.

Furthermore, a distinction is made between the phases in which a problem can arise. Not every overload requires the same measures. First, saturation occurs, which means that the traffic can not drive freely. An example is that traffic for the left turning direction is blocked by the queue with cars that would like to go straight ahead. When this queue becomes bigger, it can lash back to a control point (phase 2) or a decision point (phase 3). More about the phases in the LRA is discussed in Section 4.3.

4 Rule-based Approach

Before the Rule-based approach was written, traffic management in case of an incident consists of pre-programmed scenarios (Dutch: Regelscenario's). For every type of incident, a different scenario was written. This type of traffic management was assessed as labour-intensive and complex. Reuse of scenarios was hardly possible and should be activated by a road manager. This changed with the introduction of the Rule-based approach. In this chapter, the concept of the Rule-based approach will be explained and also applied to a subnetwork. A starting point of the Rule-based approach is that the operational part is controlled completely or partly automatically. This automatization makes the task for the road manager more organized. In Section 4.3, the function of the Traffic Control System in the LRA is explained. The reason that there is zoomed in at the TCS on a local level is that Smart Traffic acts on the same level. This makes it easier to compare both concepts. This section answers sub question 1.

4.1 Concept

The Rule-based approach is based on three so-called building blocks.

1) *Policy* – The policy consists of the network vision and frame of reference. These are explained in the previous chapter. It is crucial to keep the function of the road in mind to decide which measures are possible. How this network vision is documented is prepared in the GGB+ method (CROW, 2017).
2) *Traffic network* – How to describe a traffic network is also explained in the previous chapter. Links, route sections, control points and decision points are essential elements that should be recorded clearly, to prevent misunderstandings between different governing bodies.
3) *DVM-services* – The measures that could be taken are divided into three services. These are the promotion of outflow, limitation of inflow and the diversion of traffic. Services could be requested automatically, and because scenarios are not entirely elaborated for a single situation, it is easier to use the services in a different environment.

When a problem occurs at a route section or link, the decision rules determine when a DVM service is requested. This request depends on the traffic situation and the phase of the traffic problem. In general, the sequence looks like this:

- Phase 1: Saturation — Promote outflow
- Phase 2: Backlash of the queue to a control point — Limit inflow
- Phase 3: Backlash of the queue to a decision point — Divert Traffic

A summary of which services can be requested in which situation is shown in Table 1.

Table 1 – Decision rules DVM services (CROW, 2017).

Phase	Overload	Overload	Overload	Blockage	Blockage
Network element	Control point	Link	Route section	Link	Route section
Promote outflow	*Request*	*Request*	*Request*	-	-
Limit inflow	-	*Request*	*Request*	*Request*	-
Divert traffic	-	-	*Request*	*Request*	*Request*

A DVM-service is requested when the switch-on conditions have been met. It is not desired that the values that are stated in the frame of reference are exceeded so most of the time, the switch-on conditions are lower. The services could be requested before the actual problem occurs.

The same applies when a DVM service should be deactivated. The switch-off conditions are not only lower than the frame of reference but also lower than the switch-on conditions. The latter to prevent that switch-on and switch-off conditions are too close and the request of the belonging service is continually changing.

By requesting a DVM service, the consequences of the corresponding service are also taken into account. It is not desired that the output is promoted to a link where also problems with the traffic capacity take place. In Table 2, the availability of the services is shown for different situations. When there is no capacity in a conflicting direction, it is not possible to promote the outflow, because conflicting directions will get less green time. When a service is requested, the consequences must be within the boundary conditions.

Table 2 – Availability of DVM services (CROW, 2017).

	Promote outflow	Limit inflow	Divert traffic
No capacity on the conflicting direction	*Not available*	-	-
No capacity on the upstream link	-	*Not available*	-
No capacity on the downstream link	*Not available*	-	-
No capacity on the diversion route	-	-	*Not available*

4.2 Different types of Traffic Control Systems

Traffic Control Systems play a significant role in the management of traffic in a network. In the current Rule-based approach, these Traffic Control Systems make use of pre-programmed sequences and green times and can be divided into the following:

- *Fixed Time Schedule (FTS)*. The cycle length, green times for each phase and sequences are all fixed. A constant cycle is repeated, and the current traffic situation is not taken into account, which can lead to inefficient traffic management when traffic has to wait for another lane where no traffic is presented.
- *Vehicle Actuated Control (VAC)*. The problem described before can be mainly solved by a vehicle actuated control. Here, the current traffic situation is taken into account. Green phases will be activated by the presence of vehicles or pedestrians at the intersection. If there is no traffic detected, the green period will end or skipped. The green times for each phase and cycle length are now variable (Mathew, 2019). The sequence of the green phases is still pre-programmed. In low complex traffic situations, the improvement over the FTS is vast. In cases with more traffic, the VAC will tend back towards a Fixed Time Schedule. A minimum and maximum green time are determined, and when all detection loops are activated, the variability of the traffic light parameters will decrease, and the system becomes static.

A dynamic traffic control system as Smart Traffic is not discussed in the Rule-based approach.

4.3 The function of Traffic Control Systems in the LRA

In this section, the functions of Traffic Control Systems are explained for the three different DVM-services that can be requested. A small subnetwork with an overloaded situation is chosen, with the assumption that all three services can be requested. As mentioned in Table 2, not all services can be used for a blockage, but the process will look similar.

Sub question 1

How is traffic managed in case of an incident according to the current LRA?

An example from the Rule-based approach is used, and the functions of the Traffic Control Systems in this situation will be compared with the functions of Smart Traffic in Section 5.3. The actual situation is shown in Figure 2, where through traffic is blocked by the turning direction. On this turning lane, saturation occurs.

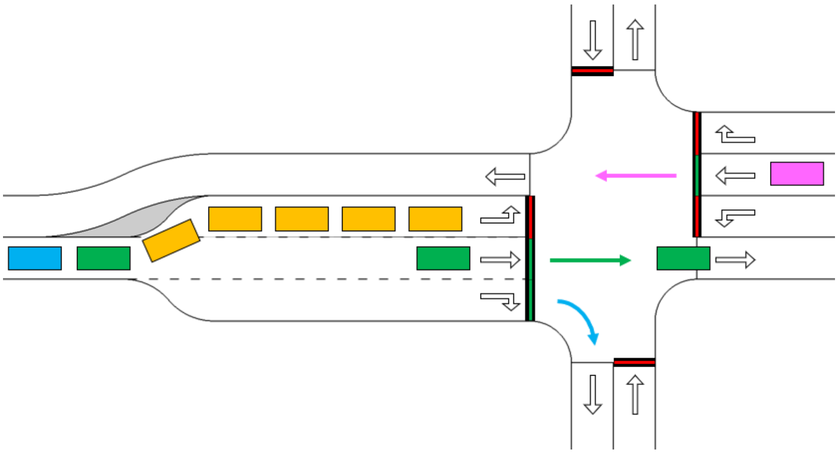

Figure 2 – Through traffic is blocked by the turning direction (saturation).

Phase 1 – When saturation arises, measures have to be taken to prevent further development of congestion. First of all, the service “promote outflow” will be requested. The cycles from the FTS and VAC should contain more green time for the left turning direction. The scenario is deployed because the road manager intervened or a specific boundary condition is reached.

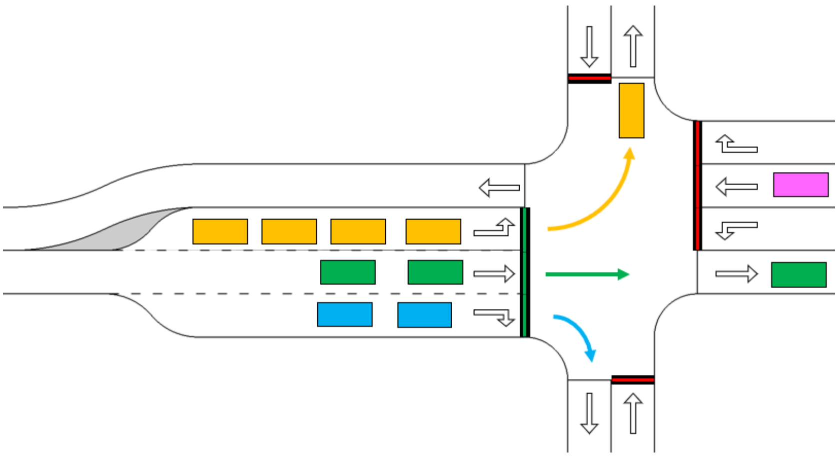

Figure 3 – Promote outflow by giving TCS more green time for the outgoing directions.

Phase 2 – Figure 3 shows a situation, where the outflow is promoted. There was not a lot of traffic in the other directions. If it is not possible to give enough green time to the outgoing direction because the conflicting directions also need green time, a queue will hit back on a previous control point. This phase is also called congestion. In this case, further measures are needed, and the inflow will be limited, which is done in Figure 4. Traffic control systems will give ingoing directions less green time at the upstream intersection B. The traffic problem will be spread because a queue will arise on the upstream link. Here the inflow should also be limited.

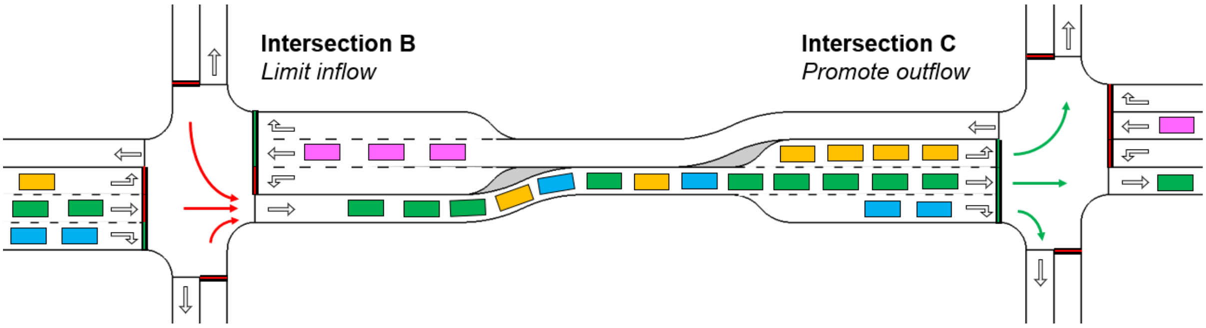

Figure 4 – The inflow will be limited to previous intersection B.

Phase 3 – When the queue reaches a decision point because the previously mentioned DVM services are unable to solve the problem, the traffic could be rerouted. This situation is described as a gridlock. Traffic can laboriously continue its route. Traffic diversion is a drastic measure that has influences for the complete subnetwork. Therefore, other intersections must be aware of the increased traffic flow. However, this also depends on how the diversion is used. It is possible to inform, advise or force a signal group to chose an alternative route.

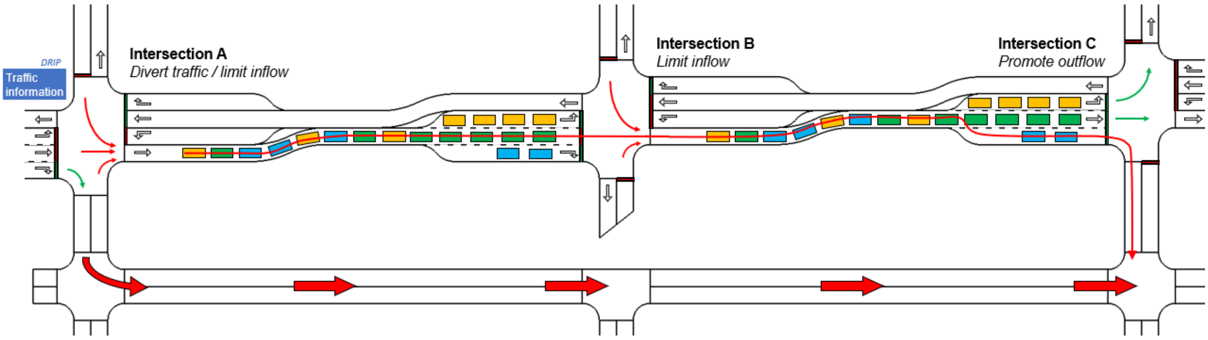

Figure 5 – Backlash at a control point, traffic will be diverted by an alternative route.

Remember, intersections B and C are control points. At intersection A, traffic could choose between two routes. The presence of an information instrument is needed: in this case, a *Dynamic Routing Information Panel* (DRIP). The role of the traffic control system is that the direction for the alternative route will be promoted, and that green times towards the main route are limited.

5 Smart Traffic in theory

The previous chapter discussed how Traffic Control Systems would look like executing the services from the LRA. In this chapter, Smart Traffic is analysed in the operation of this Rule-based approach. Sub question 2 is answered in Section 5.2. Despite not taking into account the rest of the network, the Smart Traffic controlled traffic lights could already be used. Shortcomings will emerge. In Section 5.3, the pros and cons of Smart Traffic compared to the Rule-based approach are considered. Before the analysis of how Smart Traffic works in the LRA, it is good to have more knowledge about the concept.

5.1 Concept

Smart Traffic is a software that optimizes traffic for an intersection. It is an iTCS, that takes the current traffic situation into account. One of the differences with the *Vehicle Actuated Control* is that with Smart Traffic also the traffic volume is used for assessing the situation. Smart Traffic takes into account how many cars are waiting and for how long these cars have to wait. With Smart Traffic, there are no cycles, sequences or maximum green times pre-programmed. All possible sequences and green times are simulated, and after the calculations, the optimal solution is chosen.

Cars are detected by detection loops, and it is also possible to receive information about the number of vehicles from upstream intersections. The software can predict when this traffic will arrive at the intersection and take it into account for the simulations. In Figure 6, you can see a by Smart Traffic controlled intersection. When there is a high demand for in this case (orange) direction to the left, compared with conflicting directions, Smart Traffic will give this signal group the green light. How long this green time will take, depend on how the situation develops. A new situation is simulated continuously for the next 20 or 30 seconds.

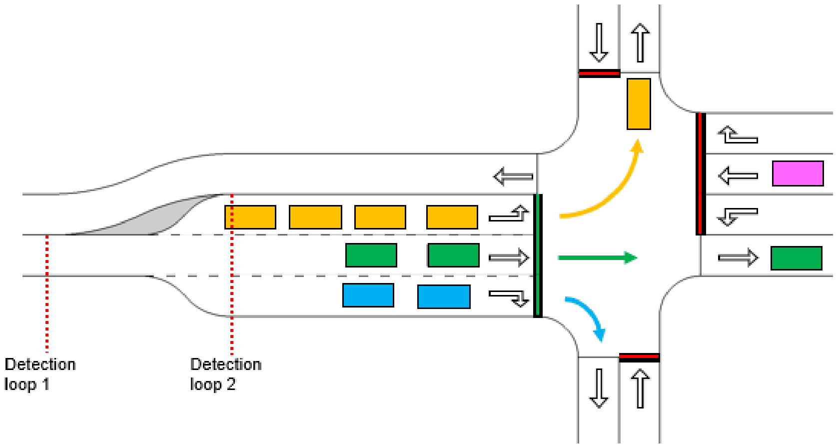

Figure 6 – Smart Traffic predicts when traffic will arrive and finds the optimal schedule.

However, at this moment, the optimal schedule will be chosen for one individual intersection. Smart Traffic intersections cannot communicate with each other to find a common optimum, which is not always favourable for the network performance. For example, when at the downstream intersection, a lot of traffic is already waiting.

In reality, when the downstream intersection is also controlled by Smart Traffic, it can use the information from the upstream intersection, that there will arrive a certain amount of traffic. The software will simulate what would be the consequences to stop this platoon of traffic, and in most cases, it is inefficient to stop this. Therefore the signal group will probably receive a green light, and a long queue is prevented.

5.1.1 Objective function

The optimization strategy is to minimize an *objective function*, which is related to the preferences of the road manager. The most used objective function is to decrease the total delay at the intersection. As already mentioned, Smart traffic takes into account how long a vehicle is waiting. Another objective can be to minimize the stops at an intersection. Traffic that has to stop causes noise nuisance and CO2 emissions. With an objective function, it is also possible to take different objectives into account. However, it could be challenging to combine the number of stops and the total delay.

5.1.2 Weights

Weights could be used to express different interests at an intersection. The priorities that are mentioned in Section 3.1 could lead to giving a particular signal group a higher weight. For example, a car that is waiting in the direction of the main route has the same weight as three cars waiting for a turning direction. The reason for this is that, in the opinion of the road manager, the traffic flow on the main route has higher importance. In addition to giving weight to a specific signal group, it is also possible to give preference to certain vehicle categories. Examples of this are freight traffic, cyclists/pedestrians or public transport.

5.1.3 Data

For the simulations, data is needed. An advantage of Smart Traffic is that it is also possible to use not only data from detection loops, but also from GPS systems, Floating Car Data, or cameras. However, the use of this type of data is still at the beginning. The expectation is that in the coming years, the use of FCD will increase. At this moment, Smart Traffic is only using the data that is coming from detection loops. These loops are located in the lanes directed to the intersection and, together with data from upstream intersections, predictions about traffic volumes in the future can be made.

5.2 The function of Smart Traffic in the LRA

Sub question 2

How is traffic managed in case of an incident with the use of Smart Traffic?

So, Smart Traffic is software that focusses on the local performance of an intersection, where the Rule-based approach concentrates on a network level. A quick misconception is that these two do not go together, but it is also possible to analyse Smart Traffic in the context of the current Rule-based approach. How this could look like is discussed in this section.

At this moment, there are no services that can be requested in Smart Traffic as the Rule-based approach does. This lack will also uncover shortcomings. Sweco started with the implementation of scenarios in Smart Traffic. How these scenarios could look like in Smart Traffic is explained in Section 5.4.

Phase 1 – With Smart Traffic, it is not needed to activate a scenario where the outflow is promoted. The reason for this is that Smart Traffic is always trying to promote the outflow. Saturation on, for example, the turning direction from Figure 3, will be prevented because this signal group will get a green light when there is enough traffic waiting or arriving. This traffic will be detected by the detection loops and will get a green light. The only reason that this signal group would not get a green light is that there is traffic at another signal group with a higher impact on the objective function. In this case, the second problem phase is reached.

Phase 2 – This point has already been mentioned before, but when Smart Traffic is not able to manage the traffic at an intersection by promoting the outflow, for example when there is a lot of traffic in conflicting directions, the Rule-based approach will limit the inflow. Smart Traffic cannot limit the inflow when the backlash of a queue reaches a control point, because there is not a scenario which can execute this service.

*** For the outcome of intersection B, there is also data coming from the remaining directions.*

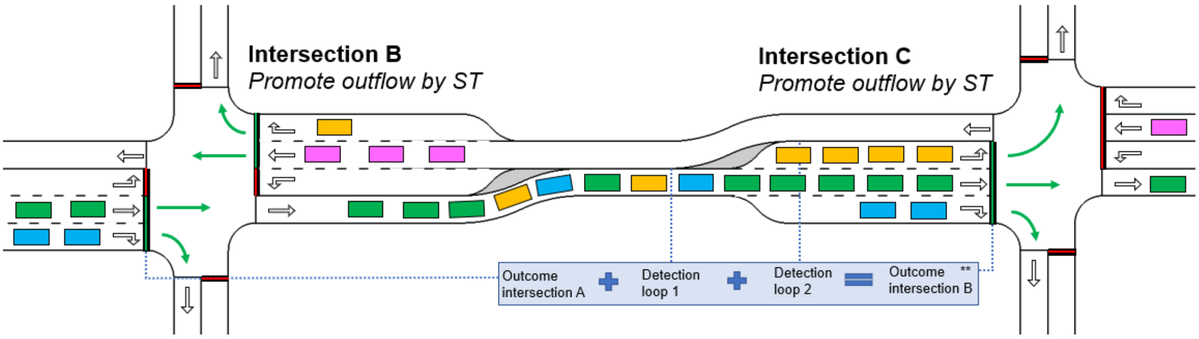

Figure 7 – Limit the inflow is not possible with Smart Traffic at this moment.

Phase 3 – When the backlash of a queue reaches a decision point, the dynamic characteristic of Smart Traffic comes in. The function of a Traffic Control System in diverting traffic is only *facilitating*. The direction of the alternative route should get more green to promote this route. When the driver receives the advice to take an alternative route, he or she will choose for this direction, and there is less demand for the through direction. Smart traffic will automatically give the alternative route more green time, and the through direction less green time.

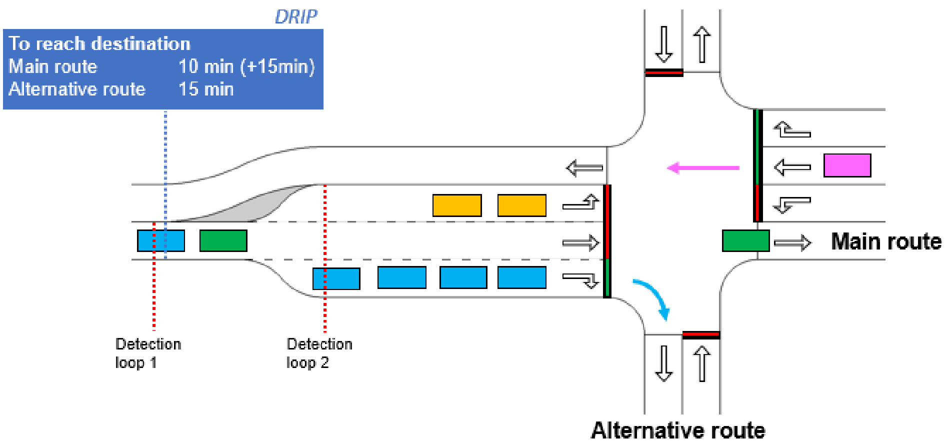

Figure 8 – Diversion with Smart Traffic.

5.3 Conclusion

+ The advantage of Smart Traffic is, that at the beginning phase of an overload, it is not needed to recognize an incident and activate a scenario. The software can appropriately take care of the problem in an early stage. It is not necessary to determine specific conditions when the outflow should be promoted, because this has already been done. These soft conditions also give an advantage when the incident is solved because the services do not have to be turned off. With the VAC and FTS, a specific switch-off condition has to be reached to fall back to the original situation.

+ The same applies to the scenario of how a TCS should adapt to a new situation to divert traffic. When the diversion is not needed anymore, the system will fluently change back to the original situation.

- In most cases, the response to the new situation is already too late and can be seen as *reactive*. Road managers would like to have a *proactive* way of traffic management to prevent these problematic situations.

- The priorities of roads change when alternative routes become more important. The relation between a car that is waiting in the main direction and for example, three cars waiting in an alternative direction should, in this case, change with it. This change of priorities is at this moment not possible.

- There is a point where Smart Traffic cannot manage the traffic without getting backlash at a control point. When this point is reached can be seen as abstract and asks research to the resolving power of Smart Traffic. When this point is reached, measures should be taken as limiting the inflow. How scenarios could look like in Smart Traffic will be explained in the next section.

5.4 Scenarios in Smart Traffic

At this moment, it is not possible to run a scenario with Smart Traffic. However, there are already some thoughts within Sweco how this could look like in the future. Software developers are working on this. The scenarios are aimed at enabling Smart Traffic to act on a network level. The current idea is set out in this section.

There could be different parameter-sets stored in the network supervisor. These parameter-sets can be seen as scenarios. One of the parameter-sets will be selected by the 'Network Supervisor'. This supervisor sends the parameter values for the schedule composer and the objective function. There is always one scenario active, which is selected by simple logic (e.g. time-based), or by an external system (NMS). An overview of the network supervisor is given in Figure 9 and is coming from internal documents of Sweco. Especially the activation from an external system, in this case, the Network Management System, would fit in with the thoughts of the Rule-based approach. In this approach, switch-on conditions are used to request services.

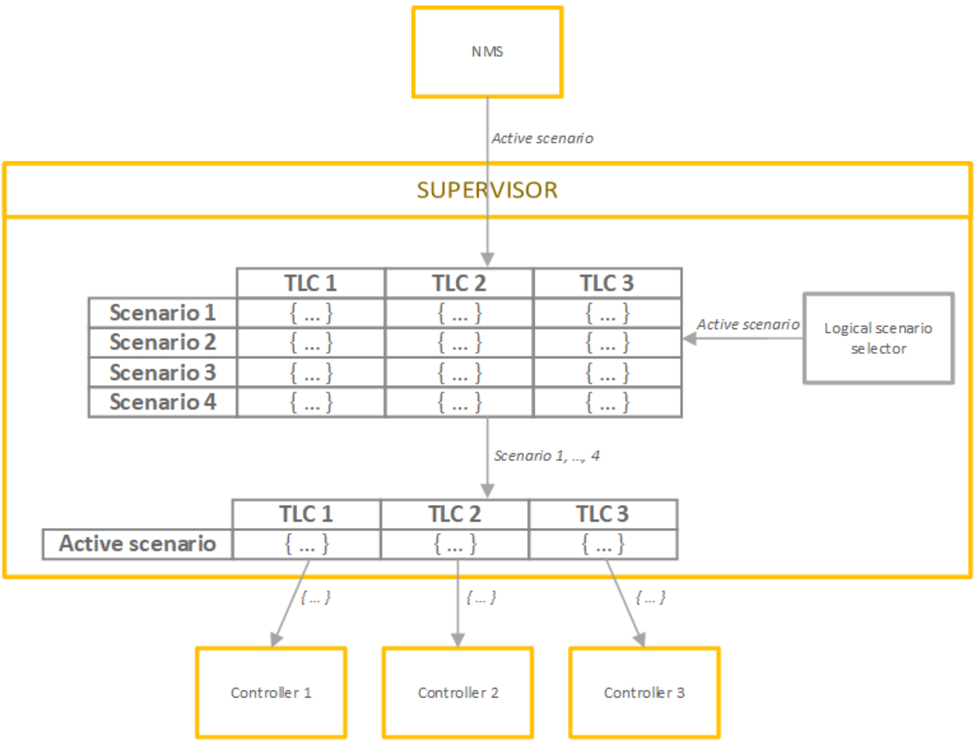

Figure 9 - The network supervisor contains parameter values for the traffic light controllers.

For example, the weight of a signal group could be changed, or a signal group could be blocked. It is possible to process multiple services in one scenario. How a scenario looks like depends of course on the belonging services.

5.4.1 Promoting outflow

You could have some doubts about if this is a separated service. As already mentioned, Smart Traffic is always trying to promote outflow. When there is more traffic (saturation), this signal group will have a significant impact on the objective function, because there are so many vehicles. The chance that this signal group will get a green light is high. Therefore, it is not always needed to activate a scenario. With a scenario, a parameter set could be activated that gives the signal group that needs to be promoted, a higher value.

5.4.2 Limiting inflow

For limiting the inflow, a trigger is needed, because limiting the inflow is not wanted if it is not required. The NMS would activate a scenario, which is a difference with promoting the outflow.

1) For example, when more than five cars are waiting at the downstream intersection, this signal group can be dosed.
2) When ten cars are waiting at the downstream intersection, the signal group will be blocked, until there is enough space.

For this example, the queue length was used as a parameter for the NMS. Instead of queue length, it could also be done with vehicle speed, but this is less reliable to estimate the available space. The dynamic characteristic of Smart Traffic should not be lost. When a signal group is blocked, the optimal schedule should still be chosen for the remaining directions.

If the inflow will be limited depends on the function of the road. Is this a road with a high priority, then you do not prefer to spread the traffic jam over this road. Here, inflow should only be limited when there are no other options. First, the input from lower prioritized roads should be limited.

5.4.3 Divert Traffic

Traffic is diverted by DRIPs, and the primary function of a Traffic Control System in diverting is facilitating. As discussed in Section 5.2, Smart Traffic will automatically give the alternative route more green time when there is a higher demand. It is doubtful whether this automatic adjustment is made on time. The adaptation to the new situation is reactive, and it could be more efficient to do this proactively. A scenario with a higher value for the signal group of the alternative route could help with this. The alternative route gets in case of a diversion, most of the time, a higher priority. More use is being made of it, and therefore the realisation of traffic flow has become more critical. Weights should be adjusted to ensure that the network adapts proactively.

6 Rule-based Approach in Almelo

Almelo has a vision about how traffic could be managed in case of an incident. This vision is not worked out in documents, because their primary focus is on the application of Smart Traffic, and next to this, incidents are not that common in the traffic network of Almelo. The ambition to work this vision out has been expressed. Therefore this chapter consists of two proposed situations: the Roland Holstlaan and the Van Rechteren Limpurgsingel. The municipality of Almelo indicated that problems are sometimes experienced here.

Sub question 3:
How does the situation in Almelo look when the current Rule-based approach is applied?

The proposals show how the Rule-based approach could look like in Almelo. At this moment, the services: promotion of outflow and limitation of inflow, are not used. In 2013, a project named TINA-2 was executed to see how traffic could be diverted over the ring road. This project is also used for the elaboration of the Rule-based approach. After all, the proposals were reviewed by R. Hulleman (senior traffic consultant at the municipality). Because there was also no quantitative frame of reference available, the proposals are not supported by numerical data. To determine these allowed values is out of the context of this thesis.

6.1 Almelo

As described in the GGB+ methodology, before the Rule-based approach can be worked out, it is necessary to map out the network vision of Almelo. For this, the network vision of Regio Twente is used. However, this priority map, which is shown in **Fout! Verwijzingsbron niet gevonden.**, can not be used directly. The map represents not all interests of the municipality because it covers a larger area than just Almelo. Next to this, the map is prepared in 2010 and is not entirely up to date. After discussing the priorities and roads in the network of Almelo, two main policy principles came out: The traffic flow at the A35 and the ring road should in all circumstances be realized. Further, the six corridors are important to take into account where the Plesmanweg coming from Aadorp has a lower priority. An overview of the priority map, which is used for the Rule-based approach is given in Figure 10.

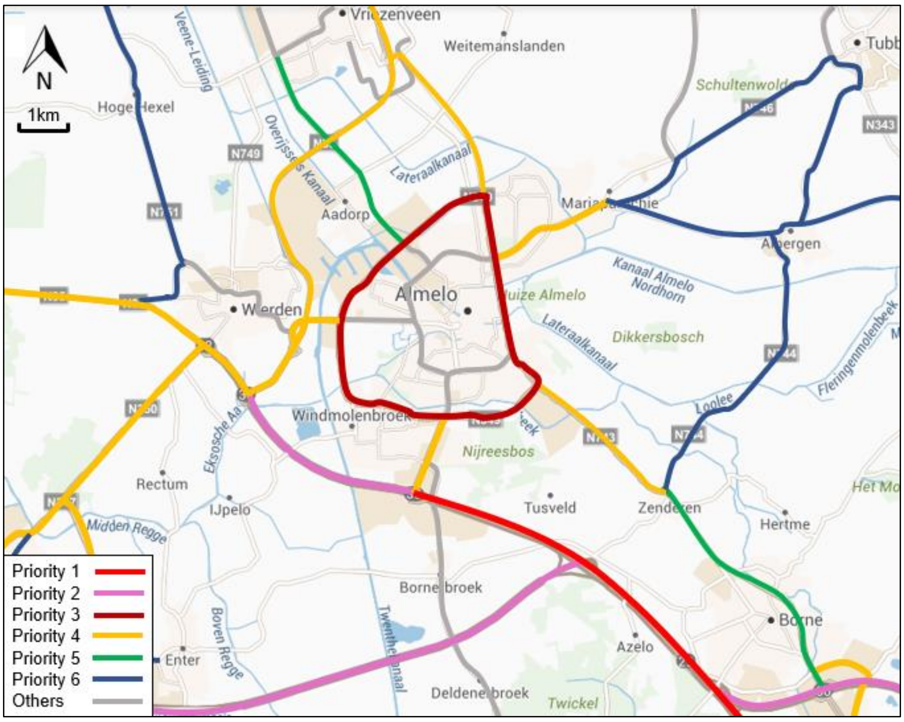

Figure 10 – Priority map of Almelo, including the surroundings.

The third priority that is given for the ring road around Almelo is added because otherwise, it would have the same priority as the corridors, which is not desired with working on a scenario. Choices have to be made, and in this case, traffic flow on the ring road is more important, according to the municipality.

6.2 Henriette Roland Holstlaan

The Henriette Roland Holstlaan is the connection between the ring road and the highway A35. Therefore, it is a vital connection where traffic jams will have a significant impact. For the Rule-based approach, the network from Figure 10 is zoomed in to get a subnetwork with affected roads. The existing numbers of the traffic control installations are used for the designation in the subnetwork. For the naming of the links, abbreviations of the street names are used. RK62 is an intersection of the Nijreessingel (NS), Weezebeeksingel (WS) and the Roland Holstlaan (RH). The number of a link increases along the orientation direction: from West to East and from North to South (CROW, 2017).

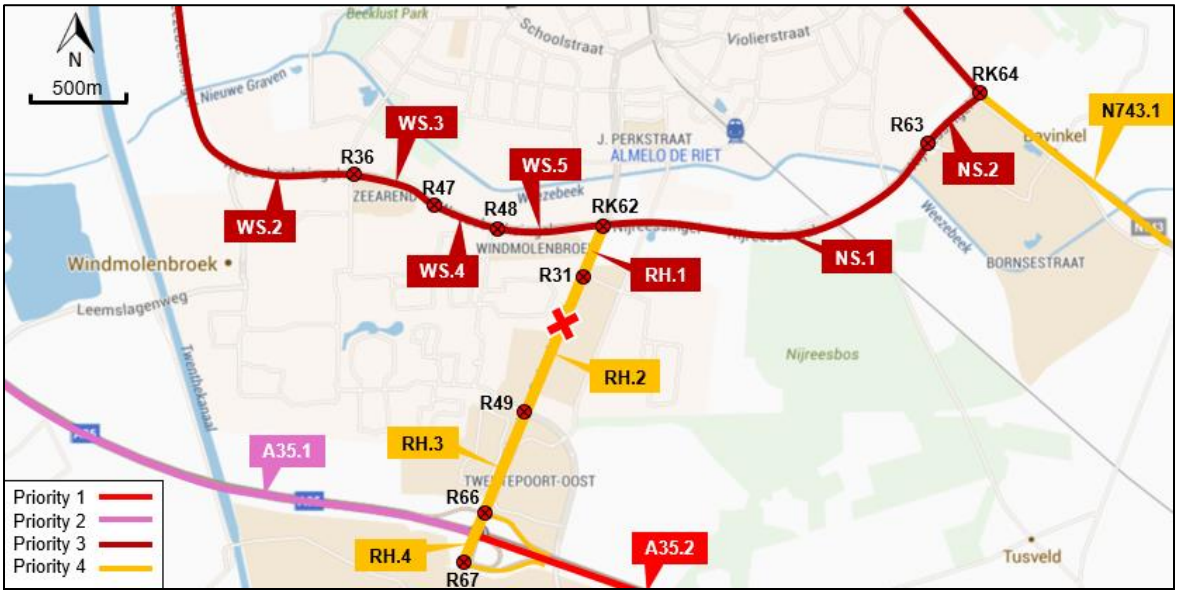

Figure 11 – Subnetwork of the Henriette Roland Holstlaan.

The Rule-based approach for the situation at the Roland Holstlaan can be set up by the following steps:

1) Determine the required control space.
2) Define the circuit diagrams for each involved link.
3) Define the services used in the circuit diagrams.

6.2.1 Control space

The two most relevant links on the Roland Holstlaan are the RH-2 and the RH-3. If one of these links is overloaded, the chance that this will also be noticeable on the other link is high.

First, a specific bottleneck located at link RH-2.L will be discussed. This bottleneck is indicated in Figure 11 with a red cross. The ‘L’ means the direction on the road, which goes against the orientation direction. The R goes along the orientation direction. Long queues for R31 could be a problem. It is crucial to prevent these queues from becoming too large and moving to R49 as this could affect the traffic flow on the A35.

6.2.1.1 Control space upstream

RH-3.L could be used to limit the inflow, subject to strict conditions. The use alleviates the problem on RH-2.L. But when the queue also becomes too long on RH-3.L, the outflow has to be promoted. So, limiting the inflow at R49 can mainly be used in the beginning phase of the problem. At R66 and R67, it is not possible to restrict the inflow. Traffic flow at the highway A35 has the highest priority.

The control space is currently only being expanded with link RH-3.L.

6.2.1.2 Control space downstream

The direct downstream link is RH-1.L. An estimation is made that on this link, there is not enough capacity to promote the total outflow from RH-3.L. Therefore, the outflow must also be promoted to the route sections downstream WS-5.L and NS-1.R. A consequence of this service is that the links WS-5.R and NS-1.L get less green time, and problems could arise.

Just like the upstream control space, it is essential to establish clear conditions when the services can be deployed. The priority and the amount of traffic on the ring road should be monitored in all situations. In the case of a low prioritized road section, also called buffer location, saturation would not be a problem. That would namely mean that traffic flow on a highly prioritized road is achieved by using a buffer location. However, this is not the case with the ring road in Almelo. When outflow is promoted from RH-1.L, the traffic flow on the ring road is not entirely blocked. But to prevent problems on the WS-5.R and NS-1.L, it can be useful to limit the inflow at further upstream control points. On the NS-1.L, there is enough space to buffer, so it would not be necessary to limit inflow further upstream. In contrast to WS-5.R, where inflow could be limited at WS-4.R and WS-3.R. These services could be deployed when traffic on the ring road experiences problems, but are not taken into account in the elaboration of the Roland Holstlaan.

6.2.1.3 Diversion route

Traffic that would like to go from the highway A35 to Almelo could be diverted via A35-1 and N36-4 to reach the ring road. The diversion ensures that there will be less traffic on the Roland Holstlaan. The alternative route is shown in Figure 12. The A1 and the N36 are already high prioritized roads, so it seems not necessary to adjust the priorities of these roads. The Directorate-General for Public Works and Water Management (Dutch: Rijkswaterstaat) can activate this diversion route when the incident causes a certain amount of nuisance. The exit of the A35 to the Roland Holstlaan will be closed, when there is not enough space available downstream on the RH-2.L and RH-3.L. No scenario has been worked out for it.

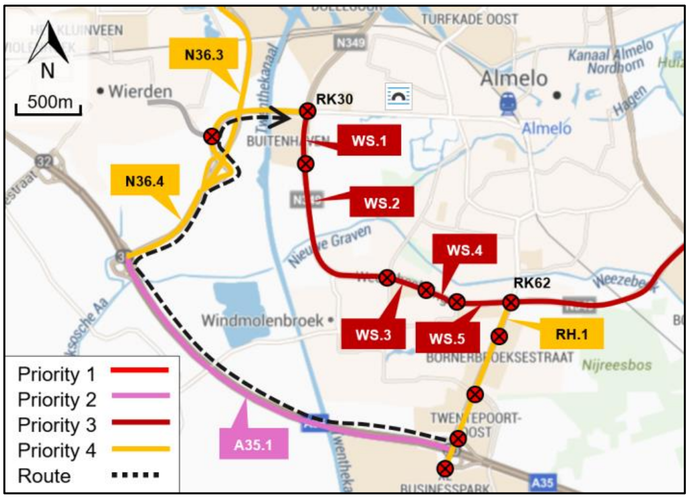

Figure 12 – Diversion route Roland Holstlaan.

6.2.1.4 Available services

Now, the control space that can be used for the Rule-based approach is defined, and as you may already notice, not all services can be implemented. With limiting the inflow, you have to deal with the A35, and for diverting traffic, DRIPs are needed. These dynamic route information panels are located on the corridors to the ring road of Almelo. An overview of the available services is given in Table 3. It is important to remember that the services can only be deployed when the conditions are met. More about these conditions will be explained in Section 6.2.3.

Table 3 – Available service in the subnetwork of the Henriette Roland Holstlaan.

	Traffic control system	Promote outflow	Limit inflow	Divert traffic	Explanation
Weezebeeksingel (WS)	R47	X	X		
	R48	X	X		
	RK62	X	X	X	
Henriette Roland Holstlaan (RH)	RK62	X	X	X	
	R31	X	X		
	R49	X	X		Limit inflow is possible, but pay close attention to preconditions.
	R66	X			Prevent backlash on A35
	R67	X			Prevent backlash on A35
Nijreessingel (NS)	RK62	X	X	X	
	R63	X	X		
	RK64	X	X	X	

6.2.2 Circuit diagrams

When traffic control systems are still used in Almelo that work with pre-programmed green times (VAC or FTS), the services that are requested determine how these green times change. The outflow can be promoted by giving a particular direction more green. The green times differ with the degree of intervention. In a circuit diagram, a distinction is made between the different directions. The numbers of these directions are retrieved from the LRA and are shown in Figure 13. For other intersections, the same numbering is used. The terminology of the different elements that are used in the circuit diagrams can be found in Appendix A.2.

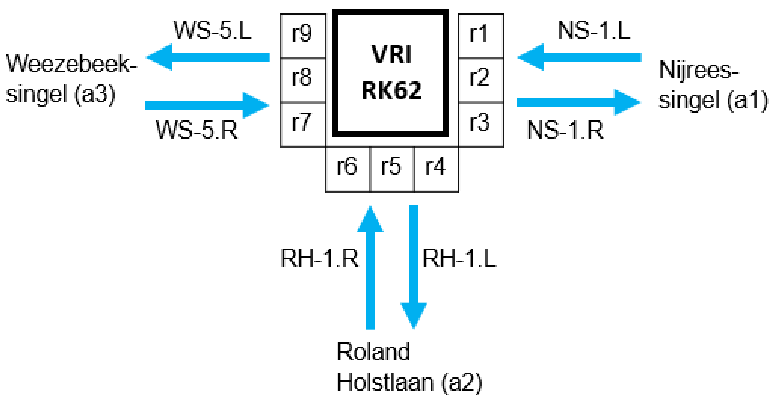

Figure 13 – Numbering of directions.

6.2.2.1 Bottleneck

The bottleneck is at link RH-2.L, and for this link, the circuit diagram is given in Table 4. The buffer length is the maximum queue standard as defined in the frame of reference. Services can be deployed with different strengths. For the promotion of outflow and limitation of inflow, this is displayed with pre-programmed green times. These green times are assumed and shown in Table 6.

Table 4 – Circuit diagram RH-2.L.

Route section:	RH-2	Link:		L	Rolland Holstlaan
Circuit diagram		**Problem phase**			**Explanation**
Traffic data	**Services**	**Saturation**	**Backlash control point**	**Backlash decision point**	
VRI31.a2.sg4. queue		80% strip length	>strip length <buffer length	>buffer length	
	R31.a2.r4.UB	Strength 1	Strength 2	Strength 3	Promote outflow to all directions
	R31.a2.r5.UB	Strength 1	Strength 2	Strength 3	
	R49.a2.r5.IB	-	Strength 2	Strength 3	Limit inflow upstream.
	A35.a1.RK30.OL1			Strength 3*	Divert traffic from A35 to RK30 at Wierdensestraat.

6.2.2.2 Downstream

In Table 5, the circuit diagram of the downstream link RH-1.L can be found. There are only services mentioned that promote the outflow because it is exclusively aimed to fix the bottleneck on the RH-2.L.

Table 5 – Circuit diagram RH-1.L.

Route section:	RH-1	Link:		L	Rolland Holstlaan
Circuit diagram		**Problem phase**			**Explanation**
Traffic data	**Services**	**Saturation**	**Backlash control point**	**Backlash decision point**	
VRI62.a2.sg4. queue		80% strip length	>strip length <buffer length	>buffer length	
	RK62.a2.r4.UB	Strength 1	-	-	Promote outflow to the right turning direction
VRI61.a2.sg5. queue		80% strip length	>strip length <buffer length	>buffer length	
	RK62.a2.r5.UB	Strength 1	-	-	Promote outflow to the straight direction
VRI61.a2.sg6. queue		80% strip length	>strip length <buffer length	>buffer length	
	RK62.a2.r6.UB	Strength 1	-	-	Promote outflow to the left turning direction
VRI61.a2. queue		80% strip length	>strip length <buffer length	>buffer length	
	RK62.a2.r5.UB	-	Strength 2	Strength 3	Promote outflow to all direction
	RK62.a2.r6.UB	-	Strength 2	Strength 3	
					No limitation of inflow
					No diversion

6.2.3 Service catalogue

When the services that are mentioned in the previous section can be deployed is stated in the service catalogue. A service can only be used when the conditions are met. This service catalogue is a proposal with assumed values obtained from the example of Central Netherlands in the Rule-based approach (CROW, 2017). The diversion route to Almelo-West can be deployed when the travel time of the alternative route is lower than the original main route. Due to the massive difference between the travel times of these routes, the traffic jam has to be significant to activate the diversion. However, traffic with their destination between RK30 and RK62 can already profit in an earlier stage. For this traffic, the diversion route could, in this case, be advised.

Table 6 – Service catalogue.

Service	**Strength**			**Conditions**	**Explanation**
	1	2	3		
R31.a2.r5.UB	40s	50s	60s	VRI.62.a2.queue<bufferlength && VRI.31.a1.queue<bufferlength	Space downstream Traffic from the right direction
R49.a2.r5.IB	10s	15s	20s	VRI.49.a2.queue<bufferlength || VRI.49.a2.sg.drive-off-intensity < 50% drive-off capacity	
RK62.a2.r4.UB	40s	50s	60s	VRI.63.a3.queue<bufferlength & VRI.62.a1.queue<bufferlength & (VRI.62.a3.queue<bufferlength || VRI.62.a3.sg8.drive-off intensity < 50% drive-off capacity) & (VRI.62.a4.queue<bufferlength || VRI.62.a4.sg11.drive-off intensity < 50% drive-off capacity)	Space downstream Traffic from the right direction Traffic from the left direction Traffic from the opposite direction
RK62.a2.r5.UB	30s	50s	50s	VRI.12.a3.queue<bufferlength & VRI.62.a1.queue<bufferlength & (VRI.62.a3.queue<buffer length || VRI.62.a3.sg8.drive-off intensity < drive-off capacity) & (VRI.62.a4.queue < buffer length || VRI.62.a3.sg12.drive-off intensity < 50% drive-off capacity)	Space downstream Traffic from the right direction Traffic from the left direction
RK62.a2.r6.UB	40s	50s	60s	VRI.48.a1.queue<bufferlength & VRI.62.a1.queue<bufferlength & (VRI.62.a3.queue<bufferlength || VRI62.a1.sg2.drive-off intensity < drive-off capacity) & (VRI.62.a4.queue<bufferlength || VRI.62.a1.sg11.drive-off intensity < 50% drive-off capacity	Space downstream Traffic from the right direction Traffic from the left direction Traffic from the opposite direction
A35.a2.RK30.OL1	Inform	Advise	Force	RH.traveltime > WS.traveltime + A35-1.traveltime + N36-4.traveltime	Diversion to Almelo-West by N36.

6.3 Van Rechteren Limpurgsingel

The following situation is on the Van Rechteren Limpurgsingel (RL). At the intersection with the Violierstraat (R12), there is a lot of bike traffic. In some cases, this can lead to a traffic jam on RL-4.L and may also spread over other links on the ring road of Almelo. In Figure 14, an overview of the subnetwork is given.

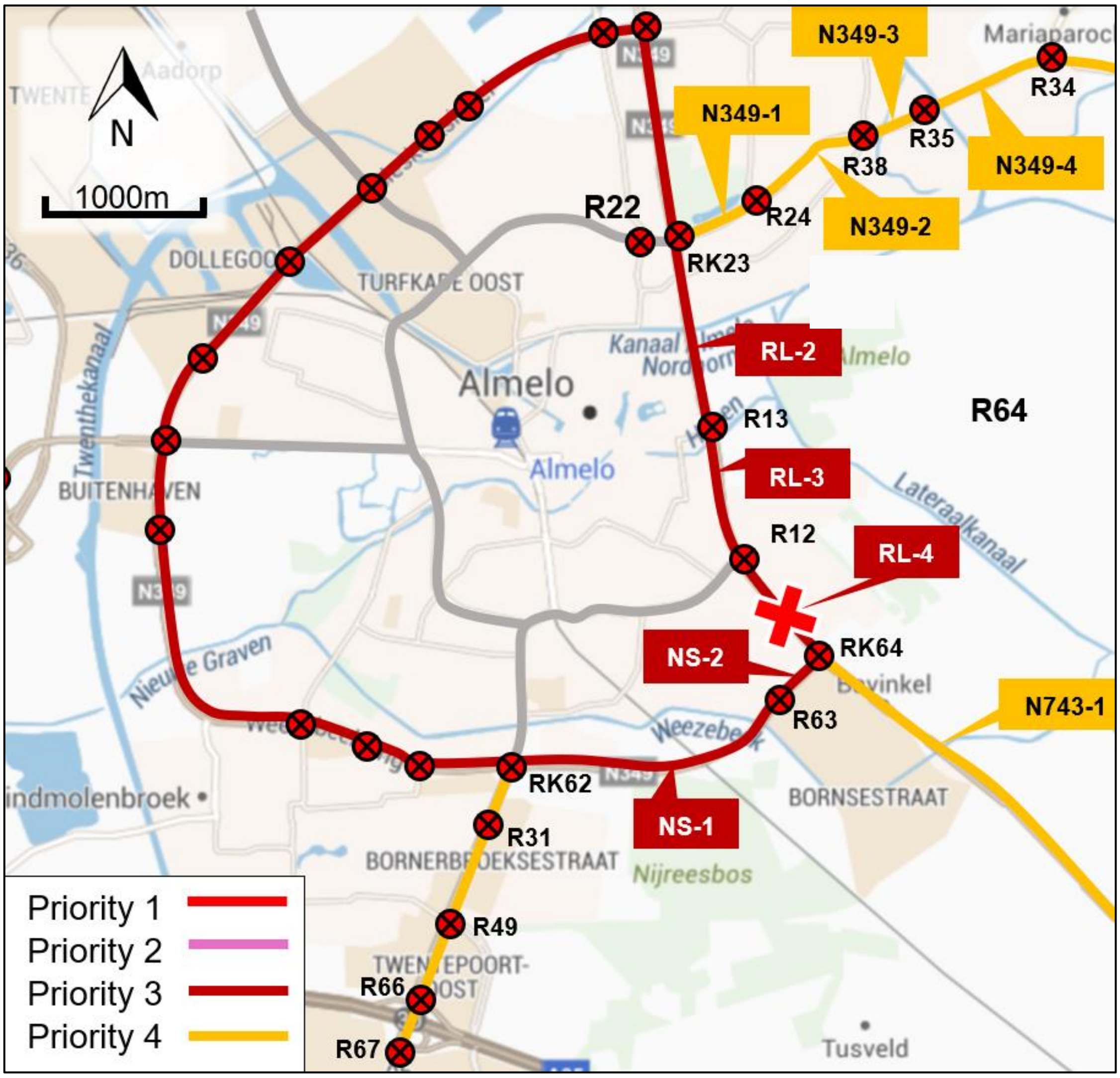

Figure 14 – Subnetwork of the Van Rechteren Limpurgsingel.

The Rule-based approach of the Van Rechteren Limpurgsingel is not supported with a circuit diagram and a service catalogue. These tables have the same format as at the Roland Holstlaan and are assumed. As already mentioned, this is out of the context of this thesis. In this section, the control space will be discussed. This control space is also used for Chapter 7 by analysing the possibilities of Smart Traffic.

6.3.1 Control space

6.3.1.1 Control space upstream

Traffic comes from two different directions upstream. The Nijreessingel (NS) is an element of the ring road. The other is the N743, the connection between Hengelo and Almelo that crosses the villages Borne and Zenderen. The N743 has a lower priority than the Nijreessingel because traffic flow on the ring road should always be realized. So, when there is a choice, the N743 is preferred as a buffer location.

6.3.1.2 Control space downstream

The downstream links are the RL-2.L and the RL-3.L. These Traffic Control Systems are located relatively far away from each other, but because these links have no significant intersections, problems are easily spread downstream. Therefore, it could be possible to use the N349, coming from Albergen, as a buffer location. It is not the intention to start immediately with buffering on this corridor, but it belongs to the possibilities.

6.3.1.3 Diversion route

The diversion routes on the ring road of Almelo have been established in the project called "TINA-2" (Vialis, 2013). DRIPs are located where the corridors and the ring road converge. This project determined the trigger values when a particular direction on the ring road should be advised based on travel times. For example, for RK62, when the travel time via the Van Rechteren Limpurgsingel to RK23 exceeds the trigger value of 540 seconds, the alternative route via Weezebeeksingel will be advised.

When an incident on RL-1.L happens, two alternative routes can be activated. When and how these diversions will be deployed, depends on the size of the incident. At RK64 traffic with destination business park (Northwest Almelo) can be advised to take the ring road counterclockwise. In a normal situation, the travel time of this route is not inferior with the alternative clockwise direction. So, this diversion can be deployed in an early stage.

At RK62 it is also possible to divert traffic. Traffic that would like to go to Northwest Almelo, Plesmanweg, already takes the ring road anticlockwise, because this travel time is way shorter than taking the ring road clockwise. Traffic that needs to go to RK44 could now be advised to take the ring road anticlockwise at RK62 because the difference with the clockwise alternative is smaller. The two diversion routes that can be performed are viewed in Figure 15.

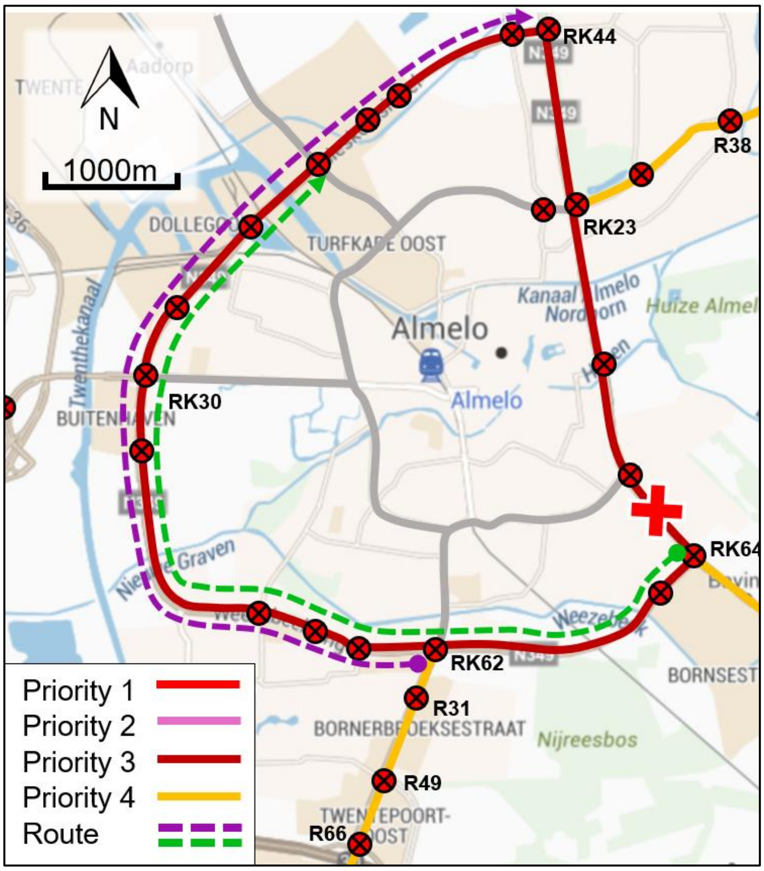

Figure 15 - Diversion routes Van Rechteren Limpurgsingel.

7 Vision of Almelo

In the previous chapter is discussed how traffic management in Almelo would look like when the current Rule-based approach is used. However, this does not mean that every road manager would like to manage the traffic in this way. The Rule-based approach can be interpreted differently, and the road manager also has a vision about how traffic could be handled in the future. In this chapter, the view of the municipality of Almelo on traffic management will be discussed, and how Smart Traffic can play a role in this.

Sub question 4

What does the client want to see in Smart Traffic to manage traffic in a network?

The vision of Almelo can be described as ambitious. It is located at an intersection of the highways A1 and A35 and connected to the waterway 'Twentekanaal'. With this excellent location, the municipality of Almelo has the ambition to grow to a logistics hotspot. With Smart Traffic, the Municipality of Almelo would like to among others reduce the CO2 emission, manage traffic safely and improve the traffic flow in the network. The latter is what this report focusses on in particular.

7.1 Space utilization

The first criticized point of the Rule-based approach is the lack of space utilization in the network, according to the municipality. When the target values are exceeded, the order in which measures are taken is most of the time the same. First, the outflow will be promoted, then the inflow limited, and after this, the traffic could be diverted. The services can only be requested when the conditions are met, but it could be that there is more space upstream than downstream. In this case, it is not efficient to promote the outflow, because the chance that there will arise a problem here is higher. A schematic image is given in Figure 16.

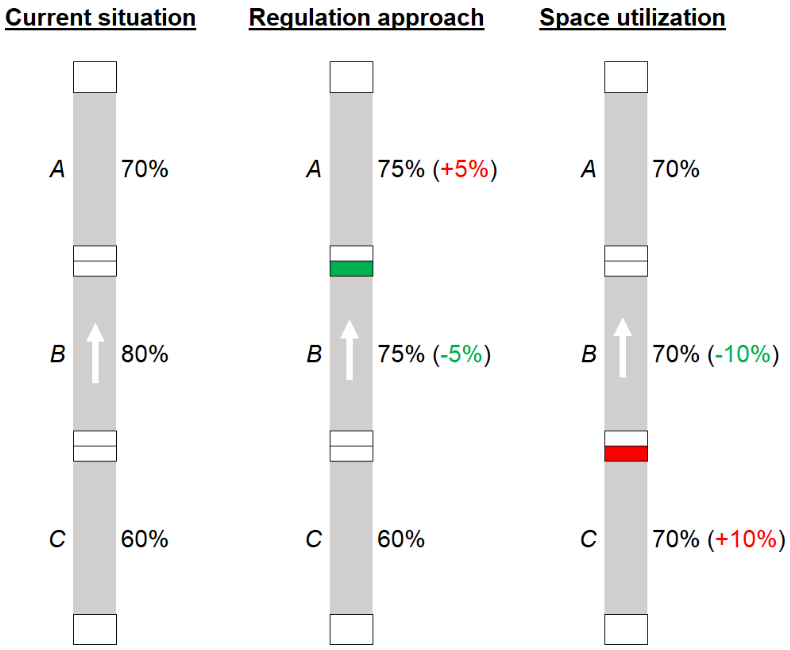

Figure 16 – Space utilization compared with the current Rule-based approach.

The percentages in Figure 16 indicate the space on a link. The most important thing about this number is that it can be compared to another link. So, it is possible to level the traffic intensities in a network. How this number can be determined is explained in Section 9.2 and is called the *space indicator*. These numbers can be seen as an intensity/capacity ratio that indicates how much space is available, provided that the priority and capacity are the same on all links. 80% is taken as a target value, but this value can change with the preferences of the road manager.

In the current situation (*left*) an incident is taking place: the target value of 80% per cent is reached. In the Rule-based approach, this is called “saturation”, and usually, the outflow will be promoted (*middle*). Instead of using link A, the municipality of Almelo would like to see that link C will be used to absorb traffic from link B. Link C could be used as a buffer because there is more space available (*right*).

An interesting question is when these spaces should be utilized. Would you like to keep the spaces available in case an incident happens, or would you level the intensities in an earlier stage to prevent an incident is going to happen? For example, when the intensities are around 60 per cent, the same principle as Figure 16 Figure 16 – Space utilization compared with the current Rule-based approach.could be used.

The answer to this question depends on the preferences of the road manager. R. Hulleman, the senior advisor of the municipality, has a clear answer to this:

“The policy principle is that you would maintain accessibility as long as possible. You will only limit inflow at a time when there is no other way.”

It is not the intention that action is already taken when it is not needed. But a small concession is made that when there arises a ‘potential’ problem, it is possible to take measures to prevent that a target value will be exceeded. This prevention is an essential point for attention because a potential problem could be recognized by predictions: a characteristic of Smart Traffic. In this report, it is necessary to distinguish between a potential incident and a problem that can not be prevented. It could be possible that Smart Traffic may not be able to prevent a problem because there is, for example, too much traffic to handle or an accident has taken place. First, how a problem could be flattened or prevented is discussed in Section 7.2, and after this, how Smart Traffic should act in case of an unavoidable incident in Section 7.3.

7.2 Potential incident

In the previous chapter is discussed how the situation at the Van Rechteren Limpurgsingel would look like when the Rule-based approach is used. Even though this method is not fully elaborated, the municipality has a vision about how traffic should be managed in a network: measures should be taken when a potential incident arises.

7.2.1 Predicted decrease in outflow

For this, the situation with the high amount of bike traffic at R12 is used. Smart Traffic could predict how the network would look like in the next time step. When in this future time step, the target value is exceeded, actions must be taken. The situation is outlined in Figure 17. At the right side of the image, you can see that the inflow is limited upstream at RK64 to prevent that the target value at RL-4.L is exceeded when the cyclists cross the intersection.

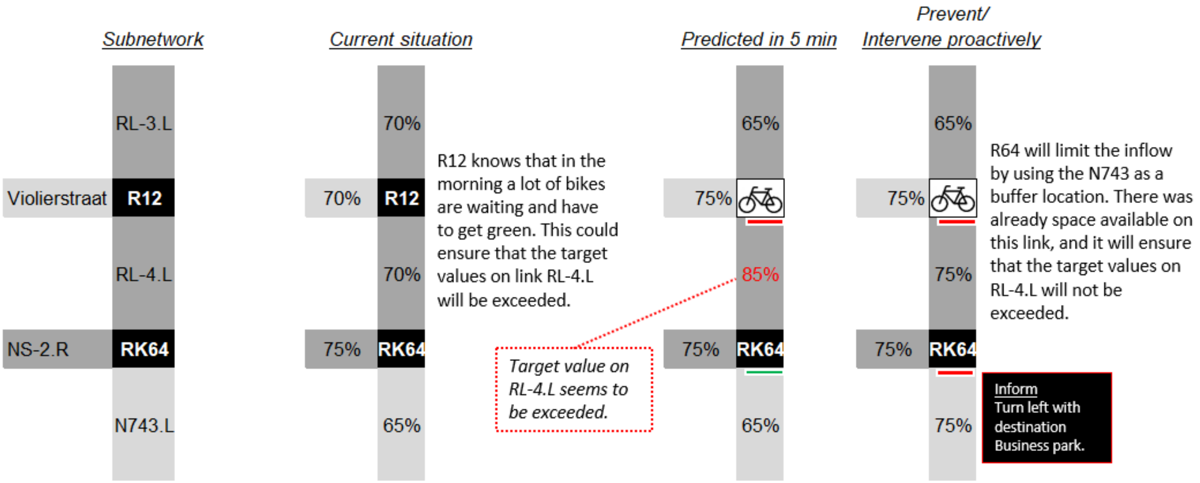

Figure 17 – Intervene proactively to prevent an incident at the Van Rechteren Limpurgsingel.

The same assumption as in Figure 16, is made. There is an incident if the target value of 80% is exceeded. However, now it is essential to keep in mind that the priorities of the roads differ for this specific situation in Almelo. The dark grey line indicates the ring road, which has a higher priority than the corridor N743. The priority is one of the points to be included in the calculation of the 'space indicator'. The strip length and buffer length are large enough to use the corridor N743 as a buffer location. So, the suitability of a link as a buffer location depends also on the setup space.

In Figure 17, a time step of five minutes is mentioned. This time frame would already be a beneficial prediction for the network of Almelo because distance travel times of diversion routes are also around five minutes. Even though the intersections are relatively far apart, in five minutes, it is possible to take adequate measures as limiting inflow or diverting traffic in the network of Almelo. So, the time window of predictability depends on the network it is acting in.

7.2.2 Predicted increase in inflow

With this predictable power of Smart Traffic, it is also possible to create space. Next to buffering upstream, it could also be possible to promote the outflow downstream. In Figure 19, the traffic flow from the Nijreessingel will ensure that the space indicator on RL-4.L will increase by 15% and exceed the target value of 80%. Therefore, it could be possible to create space on this link by promoting the outflow to RL-3.L and limit the inflow on N743-1.L in advance.

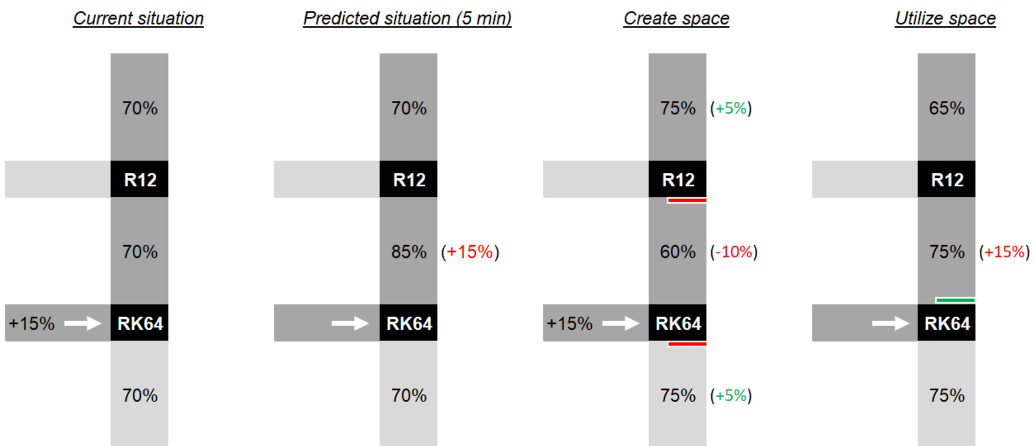

Figure 18 – Create space in advance at the Van Rechteren Limpurgsingel.

The increase in the inflow of 15% does not happen all at once. At the moment, Smart Traffic is already able to handle a platoon. This schematical increase represents a longer period, for example, around five minutes. So, in Figure 18, it is not a platoon, but a longer peak in the traffic flow.

7.3 Unavoidable incidents

In Section 7.2, is discussed how Smart Traffic can prevent an incident. Being able to intervene early can help to regulate traffic more efficiently in a network. However, it is still possible that the target values are exceeded. Reason for this could be that Smart Traffic is not able to handle the increased amount of traffic. Another reason is an event that could not be predicted: in most cases, an accident. The Rule-based approach divided this into overload and blockage for the urban road network and highway. In Almelo, the focus is on the urban road network and therefore, the following situations have to be distinguished:

1) *Overload* – The network can not deal with the current traffic, and the measures taken to prevent an incident are not sufficient. The traffic supply exceeds the regular capacity.
2) *Partial blockade* – The blockade reduces the capacity, but it is still possible for traffic to continue on their route. Usually, this is when one lane is closed, but the other lane is still open. It does not often happen in the urban road network, because mostly, the roads consist of only one lane.
3) *Complete blockade* – When the road can no longer be used, there is a complete blockade. The cause is usually a traffic accident.

In this section, the vision of Almelo about how traffic should be managed in case the target values are exceeded is discussed.

7.3.1 Road manager

From the experience of the municipality of Almelo, it is tough to recognize one of the mentioned traffic situations automatically. Almelo has looked at it but concluded that there has to be someone that can distinguish the mentioned cases. In the vision of Almelo, the road manager checks whether the system is working correctly. The road manager who assesses Almelo is located in Wolfheze at the traffic control centre North and East Netherlands. A point of attention is that this road manager does not know the network of Almelo in detail to deploy the right services. Therefore, traffic management in a network should become as labour-intensive as possible.

7.3.2 Overload

Measures have already been taken to prevent overloading. However, these measures are not strong enough to solve the incident and should be deployed more powerful:

- Promote outflow stronger
- Limit inflow stronger
- Diverse traffic in a more forcing way

How much stronger these measures should be deployed depends on the phase of the problem. For Smart Traffic, the same phases as the Rule-based approach in Section 3.3 can be used. Therefore, there are no numbers given to the measures in the examples.

The available space in the network is still valuable to take into account. However, since measures have already been deployed, there will not be a lot of space available. Otherwise, this space would be used to prevent the incident.

Due to the consequences of the stricter measures, it is possible that at other adjacent links problems arise. With preventing an incident, this was not allowed. The cure should not be worse than the disease. But now there is an incident it is permitted that at another link the target value is exceeded. Of course, this should still be in the proportion of the problem.

In Figure 19, the situation at the Van Rechteren Limpurgsingel is viewed. As you can see, the inflow is limited on the N743. This road is used as a buffer location, in the same way as the Rule-based approach did. The difference is that the available space is taken into account. When this available space is the same for all links (see current situation), choices have to be made, and this is where priorities come in. The priorities were also there before the incident took place, but now they are changed to point out where buffering is allowed, provided that there is no other space available in the network. The N743 is suitable for this and can realise the traffic flow on the ring road.

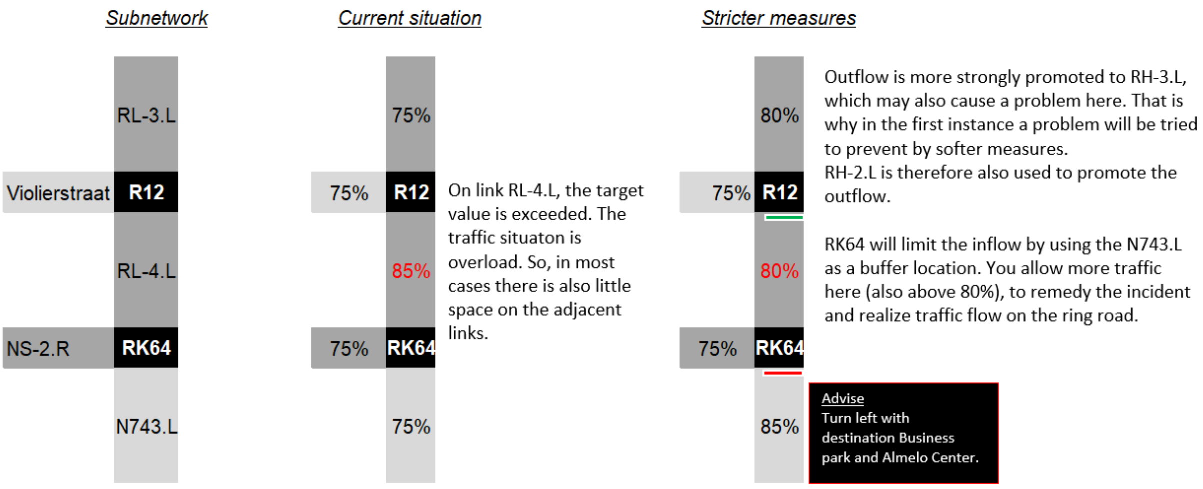

Figure 19 – Overload at the Van Rechteren Limpurgsingel.

When the overload continues to grow, the situation will look more like a blockage. Measures will be scaled up. Instead of advising traffic to turn left with destination Business park and Almelo Center, all traffic will be diverted. Traffic will be forced to turn left. In practice, this can cause problems because when a signal group is blocked, drivers have to experience that it is not possible to continue their route. Otherwise, they would think that a signal group does not work and neglect the red light. Therefore, dosing at an early stage has a preference. When the driver sees at RK64 that traffic is blocked on RL-4.L, the driver will most likely go for the diversion.

The difference with the next two traffic situations is that with a blockage, the capacity of the link decreases, which is not the case with an overloaded situation. In theory, nothing has to be changed, because the next phase (more powerful measures and priority changes) can automatically be activated. A road manager should get a warning when the target values on a link are exceeded. After this, he or she will decide whether the situation is assessed correctly and whether Smart Traffic responds adequately to this.

7.3.3 Complete blockage

If the road is actually blocked, the network must be notified immediately. The capacity on a link should be adjusted. This adjustment could be made by a road manager, that is warned by the exceedance of the target value. Another possibility that does not require the action of the road manager is the direct connection via emergency services. Emergency services are usually the first to know about an accident, and when they could send this information to Smart

Traffic, no time is wasted to deploy the right measures. Smart Traffic will try to handle the problem itself. The road manager will again decide whether the situation is assessed correctly, but with this direct connection, the issue that the road manager has not enough knowledge about the network is mostly resolved.

The measures that are taken with a complete blockage look similar to the ones from the Rule-based approach. Smart Traffic should be able to block the upstream signal group to prevent that new traffic enters the blocked link. Promotion of outflow is not needed, and traffic should be forced to take an alternative route.

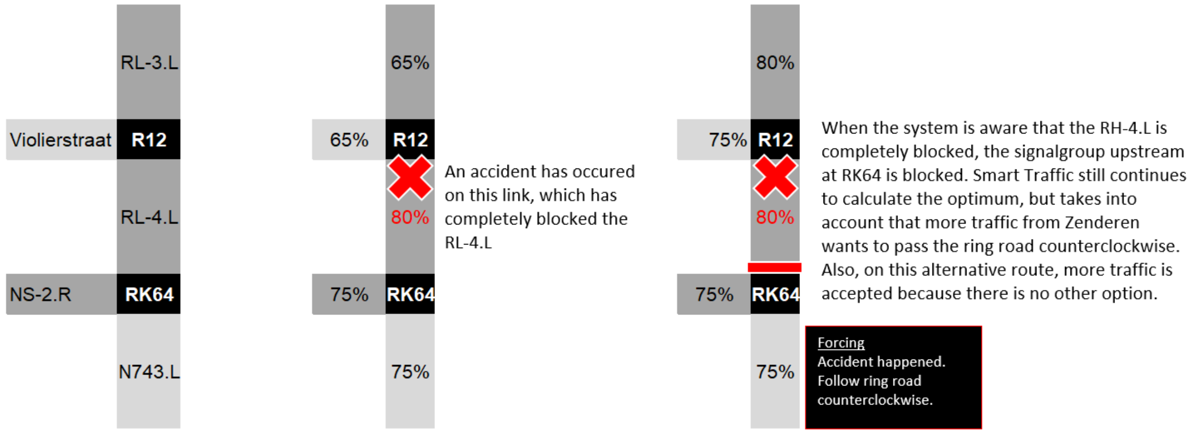

Figure 20 – Complete blockade at Van Rechteren Limpurgsingel.

In Figure 20, a complete blockage at RL-4.L is shown. Due to the diversion at RK64, traffic could be struggling to get off the N743 onto the ring road. All traffic has to turn left, and there is also coming traffic from the opposite direction RL-4.R. In addition to the fact that the ring road will be used more efficiently, the rest of the network can already respond to the blockade. This response will look the same, as explained in Section 7.2, to prevent potential incidents. For example, the inflow from the Roland Holstlaan, to the ring road can be limited at R31 and R49 if there is enough space available. Of course, to do this, there has to be a potential incident.

7.3.4 Partial blockage

In an urban road network, the roads mainly consist of a single lane, whereby partial blockage is not that common. However, it is still possible at entry and exit lanes, and therefore this situation is elaborated for the Van Rechteren Limpurgsingel in Figure 21.

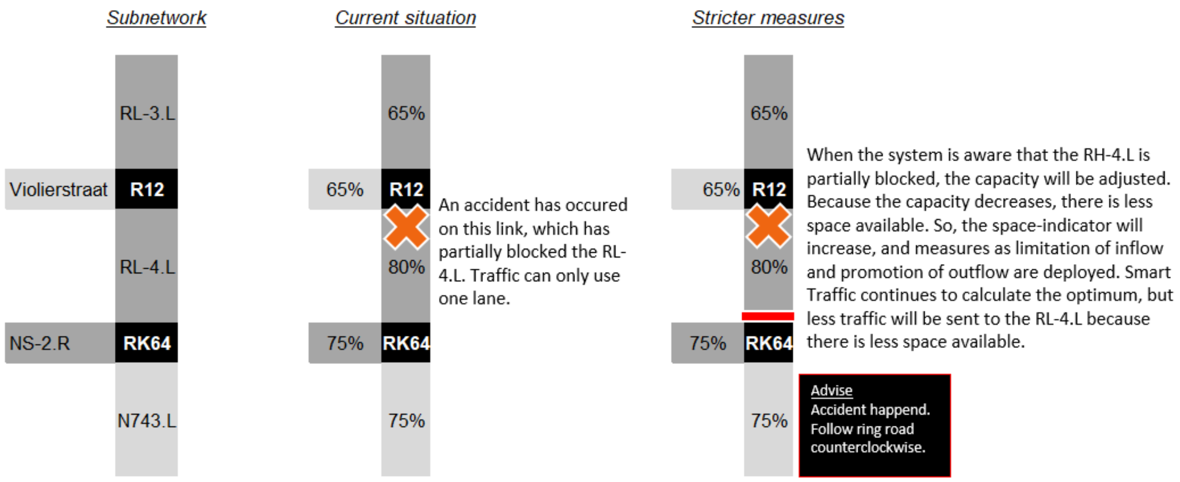

Figure 21 – Partial blockade at Van Rechteren Limpurgsingel.

In Figure 21, there is again a target value exceeded. The regular measures that are also used for an overloaded situation are deployed: promote outflow, limit inflow, and diverse traffic. Again, the extent to which these measures are implemented depends on the problem phase. But it does not necessarily have to be the case that there is a problem in the network. It could be possible that an accident occurred, but there is not enough traffic to cause a real problem. The capacity of the link still needs to be adjusted, to prevent incidents in the future, but the additional measures are not required anymore.

7.4 Diversion

Traffic diversion plays a significant role in the Rule-based approach. It can be done in different ways by informing, advising or forcing the driver to choose for an alternative route. The diversion should be deployed efficiently because it makes no sense to advise or inform if the alternative route is not chosen. The diversion should be understandable, and this is also an aspect that is taken into account for sending information to the driver. At this moment, this information is sent to the driver via DRIPs. The municipality of Almelo expresses its ambition to do this in the future with “Talking Traffic”, a method where the driver gets real-time advice while driving.

7.4.1 Psychological aspect

An aspect that is closer to the reality and the municipality already tested is the psychological choice by the driver. This psychology can be explained by two options for the driver, A and B. The original intention of the driver is to take direction A, but direction B needs to be promoted to increase the network performance. If the promoted direction (B) gets every time a little bit earlier green than the unfavourable direction (A), the driver is inclined to adjust his choice. The driver arrives at the intersection and sees direction B already having green. The chance that he or she will take this direction instead of the original route becomes higher. With this psychological aspect, an alternative route can be informed or advised in an earlier stage more efficiently.

7.4.2 Rat running

Before the Rule-based approach could react to a possible incident, it is essential to take all characteristics of the network into account. To initiate traffic diversion, one of the points of attention is rat-running. Rat-running is the practice of driving through residential side streets to avoid congested main roads. The use of streets in residential areas is something a road manager would like to prevent (Massey, 2014).

In Almelo, in case of an incident at the Roland Holstlaan, people will turn left at R49. They try to find their way through the neighbourhood of Windmolenbroek to the ring road. At the Van Rechteren Limpurgsingel, people will use the Violierstraat or the inner ring road. To use these roads is understandable when the city centre is their destination, but when these people need to travel to, for example, Almelo North, it is not desirable. Policy premise is that for a problem on the ring road, also the ring road is used as a diversion. The inner ring is not intended for this. Both shortcuts are shown in Figure 22.

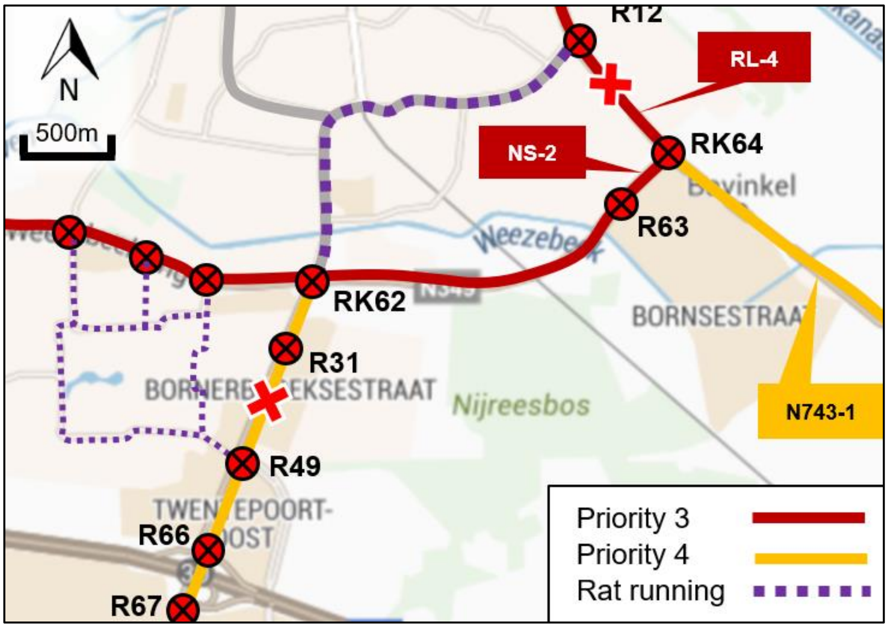

Figure 22 – Rat running in Almelo.

7.4.3 Diversion based on traffic volume

As explained in Section 6.3.1.3, when a traffic diversion will be initiated depends on the travel time of the alternative route compared with the original one. The municipality of Almelo admits that travel times are not always accurate enough. The travel times are a recording from the past. The choice to turn left or right at RK62, to reach RK44 (purple line Figure 15) is based on a vehicle that has already completed the route. It is not guaranteed that this also applies to a new car at RK62. The consequences of the diversion are not taken into account and can be seen as reactive. The municipality would like to see that this changes to proactive.

As a result of the diversion, the alternative route may have become busier, and the travel time increased. Therefore, with the predictive ability of Smart Traffic, the consequences for the network can be included. Maybe, the alternative route is not that attractive anymore, and other measures should be taken. Or measures should be deployed to ensure that the alternative route experiences no problems.

7.4.4 Talking Traffic

With Talking Traffic, Almelo would like to give the driver real-time advice. At this moment, drivers get their route advice also based on delayed information. An example is TomTom that uses actual traffic information, to predict travel times. Almelo would like to see that this advice is connected to Smart Traffic. Vehicles could be controlled individually, and services could eventually be deployed.

The reason why this development of proactive route advice is not that far yet is the lack of Floating Car Data. The predictions that could be made by Smart Traffic can be sent to TomTom, and they could use this information to divert traffic. However, these predictions are not that reliable because there is not enough Floating Car Data available. Measures could only be taken when there is enough data available about the traffic flows. The same applies to send information to navigation companies.

8 Amsterdam

In the previous chapter is mentioned that Almelo is a municipality with ambition in the field of traffic management. They had not worked out a Rule-based approach on how traffic could be managed in a network but had specific ideas about how Smart Traffic could do this. Since there is a lot of space in the network, problems are not often experienced and do not develop that quickly. Therefore the customer's requirements were not that strict, which is different for a city as Amsterdam. Here, a lot more requirements are drawn up, and there is less space available in the network. For these reasons, Amsterdam is also included in this thesis. Amsterdam is a city where the demand for traffic is so high that traffic jams are part of everyday life. The municipality of Amsterdam has different interests, experiences, and opinions about how Traffic Control Systems should manage traffic in a city. The vision of Amsterdam is discussed with K. van Sleeuwen (Advisor Traffic Management Amsterdam).

8.1 Rule-based approach in Amsterdam

For the analysis of Smart Traffic on a network level, a situation in the centre of Amsterdam is used. In the network, the highest priority is for the ring roads: the highway A10 and the inner ring road S100. In Figure 23, an overview of Amsterdam is given with the shaded research area.

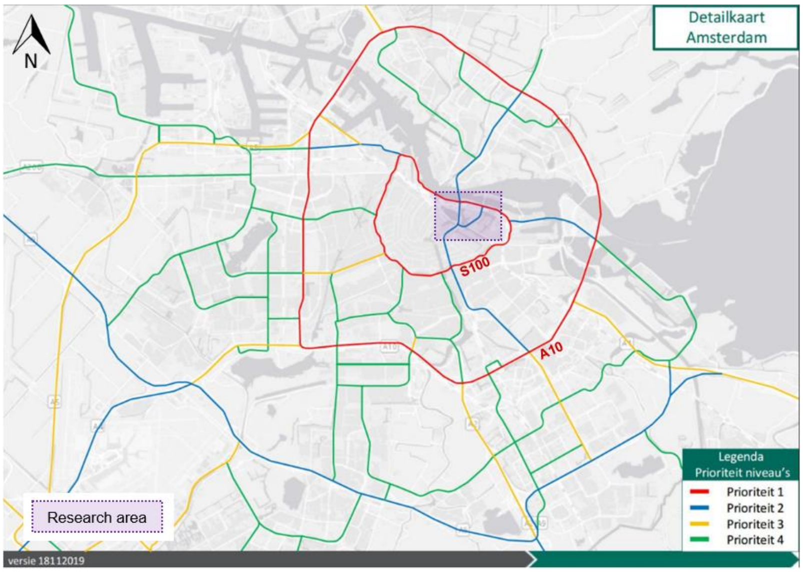

Figure 23 – Priority map Amsterdam (Provincie Noord-Holland, 2019).

Amsterdam has, at this moment, only implemented the Rule-based approach for the Northeastern part of the city. They distinguish the traffic situations into four categories, which are shown in Table 7. Because Amsterdam is currently mainly driven by vehicle actuated control (VAC) systems, there is not enough data for calculating intensities. The average speed is taken to activate one of the four scenarios which are coming from the LRA. This speed should then persist for at least three minutes.

Table 7 – Traffic situations in Amsterdam.

Nr.	Situation	Condition	Promote outflow	Limit inflow	Divert traffic
0	Regular situation	> 70% speed limit	-	-	-
1	Saturation	< 70% speed limit	X	-	-
2	Backlash to control point	< 50% speed limit	X	X	-
3	Blockade	<10 km/h	X	X	X

In the LRA, a distinction is also made with the strength with which a service can be deployed. This distinction is not made in Amsterdam, because Traffic Control Systems are located too close to each other. Next to this, these systems perform almost at their maximum. There is not enough space to save time in other directions.

The research area is given in Figure 24. The numbers of Traffic Control Systems have been taken over from the municipality (Gemeente Amsterdam, 2020). The same has been done for the name of the links, which differs from the naming in the LRA. For example, the link on the Kattenburgerstraat directed from R442 to RK463 gets the number 442_463. The situation in Figure 24 is more complicated than the one in Almelo. The blue dotted line, coming from the North is the IJTunnel, which crosses the Prins Hendrikskade (401_111) below. The exits are indicated with small blue lines at RK401.

Sweco has already started installing Smart Traffic on four traffic lights at the Valkenburgerstraat (403_404). These four traffic lights belong to two different Traffic Control Systems: R403 and R404.

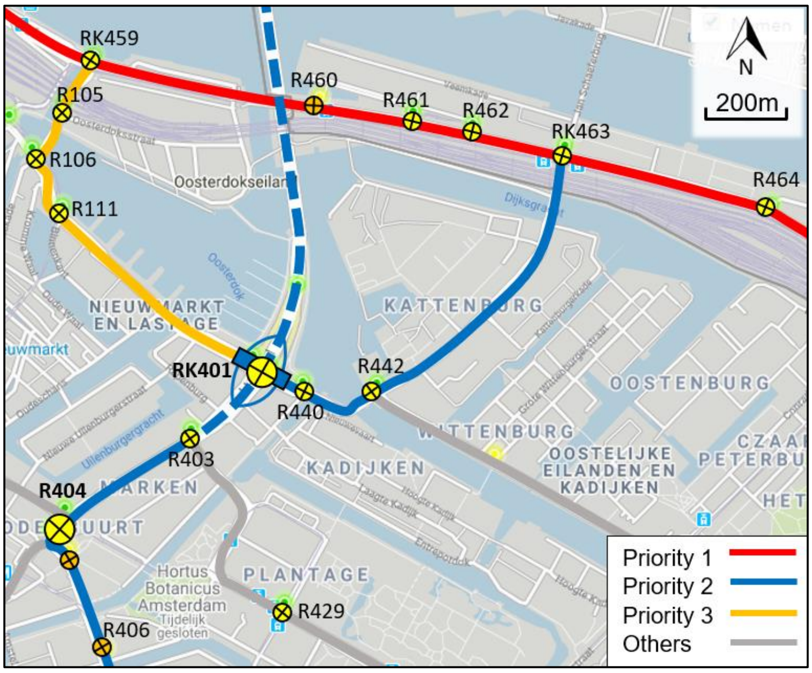

Figure 24 – Subnetwork Kattenburgerstraat in Amsterdam.

How the Rule-based approach acts, is tracked for later analysis. At this moment, Amsterdam is trying to determine the right switch-on and -off conditions to ensure that the network performs well. It is not the intention that services are continually switching between phase 0 and 1. If the Rule-based approach is intervening too often, there is not an incident, but a bigger long-term problem. It is also difficult to estimate how much traffic is on a link when the link is relatively small. The intensities, in this case, can be influenced too much by the green times.

In Table 8, a situation at the Kattenburgerstraat is analysed, where multiple traffic jams are experienced in the network. The orange rows represent the services that are requested for 442_463. Due to these services, other links get into trouble. The relation between these problems can not be 100% guaranteed because other factors could also play a role. But what you can conclude is that services get in conflict with each other, whereby problems become difficult to solve. The system is programmed to prevent that conflicting services will be deployed together. For example, promoting outflow at 440_442 is not possible when the inflow should be limited at 442_463.

Table 8 – Rule-based approach in Amsterdam.

DAG	DATUM	TIJD	IN/UIT	NAAM	NUMMER	BESCHRIJVING	OPMERKING
di	28-jan-20	09:16:56		KATTENB	442_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	**De drukte is grotendeels voorbij.**
di	28-jan-20	09:15:53	Instroom	TUSSEN2	440_442	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	09:14:53	Instroom	IJTUNNEL	201_401	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:13:56	Instroom	TUSSEN1	401_440	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:13:53	Instroom	TUSSEN2	440_442	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:12:53	Instroom	IJTUNNEL	201_401	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	**Zelfs gevolgen voor de IJTunnel!**
di	28-jan-20	09:12:52	Instroom	TUSSEN2	440_442	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	09:12:00	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:11:55		KATTENB	442_463	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	
di	28-jan-20	09:11:01	Uitstroom	S100LINKS	462_463	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	Doordat de uitstroom vanuit Kattenburgerstraat wordt bevorderd, krijgt verkeer op de S100 minder groen. Dit zie je terug in de doorstroming.
di	28-jan-20	09:10:56		KATTENB	442_463	Ingesteld op '3 - Blokkade (< 10 km/u)'	**Kattenburgstraat weer te druk.**
di	28-jan-20	09:10:01	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:09:02	Uitstroom	S100LINKS	462_463	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	09:08:54	Instroom	IJTUNNEL	201_401	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:06:57	Instroom	TUSSEN1	401_440	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	Blijft een probleem om dat de instroom moeilijk kan worden beperkt.
di	28-jan-20	09:05:57	Instroom	TUSSEN1	401_440	Ingesteld op '3 - Blokkade (< 10 km/u)'	
di	28-jan-20	09:05:00	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	09:04:56	Instroom	TUSSEN1	401_440	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	
di	28-jan-20	09:00:56		KATTENB	442_463	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	**Wordt weer rustiger, maar nog steeds IB en UB.**
di	28-jan-20	09:00:00	Uitstroom	S100LINKS	462_463	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:59:55	-	KATTENB	442_463	Ingesteld op '3 - Blokkade (< 10 km/u)'	**De UB en de IB was niet genoeg. De maatregelen moeten worden uitgebreid met ook het verkeer om te leiden.**
di	28-jan-20	08:58:56	Instroom	TUSSEN1	401_440	Ingesteld op '3 - Blokkade (< 10 km/u)'	Gevolg van de instroom beperken op de Kattenburgerstraat.
di	28-jan-20	08:55:53	Instroom	IJTUNNEL	201_401	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:54:53	Uitstroom	S100LINKS	463_462	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:53:52	Uitstroom	S100LINKS	463_462	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:52:56	Instroom	TUSSEN1	401_440	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	
di	28-jan-20	08:52:53	Instroom	TUSSEN2	440_442	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:51:58	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:51:52	Instroom	TUSSEN2	440_442	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:51:13	Instroom	TUSSEN1	401_440	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:47:55	-	KATTENB	442_463	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	**Nu wordt behalve de UB ook de IB.**
di	28-jan-20	08:46:01	Uitstroom	S100LINKS	462_463	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:45:53	Instroom	TUSSEN2	440_442	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:44:56	Instroom	TUSSEN1	401_440	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	Kleine link. Mogelijk minder betrouwbaar
di	28-jan-20	08:44:53	Instroom	TUSSEN2	440_442	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	
di	28-jan-20	08:44:01	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	Kleine veranderingen, maar dit zijn ook de schakelingen die hiervoor ook al plaatsvonden
di	28-jan-20	08:43:57	Instroom	TUSSEN1	401_440	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:43:01	Uitstroom	S100LINKS	462_463	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:42:56	Instroom	TUSSEN1	401_440	Ingesteld op '2 - Verzadiging met terugslag (< 50% V-gem)'	
di	28-jan-20	08:42:53	Instroom	TUSSEN2	440_442	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:41:55	-	KATTENB	442_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	**UB bevorderen**
di	28-jan-20	08:38:53	Instroom	IJTUNNEL	201_401	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	Schakeling tussen nulsituatie en fase 1 gebeurt vaak. Dit heeft ook te maken met het instellen van de juiste triggerwaarden. Dit is niet echt opvallend.
di	28-jan-20	08:35:19	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	
di	28-jan-20	08:33:19	Uitstroom	S100LINKS	462_463	Ingesteld op '0 - Nulsituatie Freeflow (> 70% V-gem)'	
di	28-jan-20	08:32:19	Uitstroom	S100LINKS	462_463	Ingesteld op '1 - Verzadiging (< 70% V-gem)'	

The services are mainly requested for adjacent links. One of the reasons for this is that setting which services can be set, for which conditions, is very labour intensive.

In the traffic management of Amsterdam, one department focusses on the local performance of the Traffic Control Systems. Another department is engaged in the performance of the complete network. These two different interests can clash with each other, and therefore it is vital to decide where this division is. At this moment, it is complicated to manage traffic on a network level, because there are restrictions from a local point. Examples of these are a maximum cycle time of 120 sec, a maximum waiting time for pedestrians of 40 seconds and always the utmost priority for public transport. These restrictions are also the reason that there are no different strengths for the services. They do not have to disappear, but when these restrictions can be lowered is essential to let the network perform better. This moment is also necessary to determine the space in which Smart Traffic may act.

In phase 3, blockade, Smart Traffic would also divert traffic. In reality, this diversion is not operationally deployed yet. In the network of Amsterdam, it is difficult to divert because there are barely alternative routes that can be used for this. The inner ring road S100 can not be used in the same way as the ring road of Almelo, because there are too many interruptions by traffic lights and possibly other events. Therefore, you can not advice one route over another.

8.2 Vision of Amsterdam

The control space also returns when it comes to the vision of Amsterdam. The municipality of Amsterdam has the same opinion as Almelo, where they would like to see that traffic is better distributed over the network. When an incident occurs, it should be spread as well as possible over the network. How space could be utilized in a network is also explained for Almelo in Section 7.1. In this section, the differences in perspective are considered. Amsterdam has to deal with a busier traffic network than Almelo, which brings other interests. The answer to sub question 4 could be different for Amsterdam.

Sub question 4
What does the client want to see in Smart Traffic to manage traffic in a network?

As mentioned in Section 8.1, the Rule-based approach of Amsterdam is mainly using speed as the parameter to assess if services should be requested. Speed is not always that reliable, and therefore the municipality would like to see that intensities are used. They think that with the iTCS, there is enough data to determine and eventually predict how much traffic is driving on specific links. Data from a local intersection will be used at a network level. Therefore, the space indicator is used for the examples in this section.

A clear position of Almelo was that they only want to intervene in the traffic network if there is no other option. When a potential incident could take place, on a next link, measures would be taken. For Amsterdam, they would like to see that a network adapts earlier because only when an incident will happen is too late. For this, the municipality wants to use trends in intensities. These trends could be supported by Floating Car Data, historical data and the data obtained at an iTCS.

Smart Traffic makes predictions for a cycle, how much traffic will arrive and leave in a cycle. This short time prediction could already be enough for Almelo because there is enough space between intersections to receive the traffic. In Amsterdam, you would like to make predictions for 15 minutes or even an hour and proactively respond to that. Then, the measures could be efficient. More about how data will be used is explained in Section 9.2.1.

8.2.1 Control space

With these predictions, Amsterdam would like to see that the Rule-based approach is implemented more abstractly. Smart Traffic should be able to manage the traffic itself. But before Smart Traffic could do this, it is essential to determine the leeway in which Smart Traffic may determine it. This determination is mainly a task of the municipality to make clear where Smart Traffic could act. For a city of Almelo, there is a lot more leeway in the network, compared with Amsterdam. In Amsterdam, there are already so many restrictions for an individual traffic light, that the control space should be created.

An example of this control space is at the Kattenburgerstraat. In Amsterdam, the outflow on the S100 will be promoted as much as possible because traffic flow on this ring road (red line in Figure 24) is essential. As a consequence of this, the conflicting direction from 442_463 gets less green time. A queue of 300 meters is accepted, which indicates the control space. Smart Traffic can do whatever it wants to do, as long as the queue does not exceed the threshold value. If this happens, the chance that the queue will return to the previous control point is too high. Therefore, it could help to stop promoting the outflow on the S100. This threshold differs from link to link, but it is crucial to identify a point where stronger measures can be taken.

In the control space, a control objective can be given to the Traffic Control System that represents the preferences of the road manager. This control objective is something that already exists in the software of Smart Traffic. Examples of this are the number of stops or the traffic flow at an intersection. With these control objectives, it could be possible to find an optimum. A suggestion of the municipality of Amsterdam was to use the production value of traffic, which is the product of the intensity and the average speed. The production value is a parameter that focuses more on network performance instead of the local parameters.

Within the control space, the Rule-based approach can do whatever it wants to do as long as it remains in the control space. When the thresholds are exceeded, measures should be taken more strictly. The intervention could be done by Smart Traffic, but it would also be possible to turn out the Rule-based approach and activate a pre-programmed scenario. These scenarios are not what you would like to see, because it is static, but in reality, it could be useful for handling too complicated situations. It is also something for the beginning when Smart Traffic has not proved it can handle these type of situations. In this case, it can fall back on a pre-set scenario. The scenarios are only written for the conditions that could be relevant for the network to solve with a static script. Here, the starting point of the municipality of Amsterdam differs from that of Almelo, where they give Smart Traffic more space to let it solve the situation by its own.

8.2.2 Route sections

The difference in distance between traffic lights has been mentioned several times. Predictions should be longer, so that action can be taken earlier. But another consequence of this narrow network is that it is risky to compare links with each other. There are traffic lights that are located less than 200 meters apart. The green times of a traffic light have a significant impact on the queues at these intersections. Saturation occurs quickly because the setup space is small. That is why the municipality of Amsterdam proposes to look also at the space on a route section. An example at the Kattenburgerstraat is used where the distance between R440 and R442 is around 150 meters.

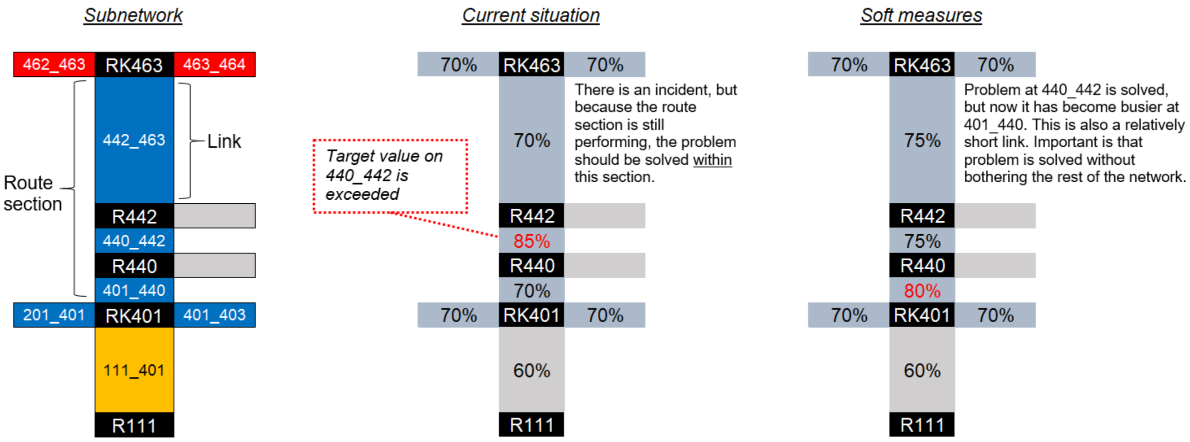

Figure 25 – Levelling between links at S116 (Kattenburgerstraat).

In Figure 25, the "target value" is exceeded at 440_442. This exceedance could happen quickly because a few cars have already a significant impact on the available space. Of course, you could take this into account with determining the space indicator, but the question is if it is even possible to predict the intensities on these small links. There is only one little thing needed to let the target value be exceeded. Therefore, the numbers for these links should not weigh too much. Soft measures could be taken within a route section, but it is not desired that the rest of the network suffers from this. Condition is that there is space on these adjacent links. A few moments later, the problem might be solved or moved to another small link (right side of Figure 25). Levelling between links for Almelo is explained in Section 7.2, but in the context of Amsterdam, it is different than in the situation of Almelo. In Almelo, levelling between links is easier because links are larger.

When there is also not enough space on the adjacent links, the route section will not have enough space and measures should be taken to a larger scale. In the case of the Kattenburgerstraat, it is better to determine the space from RK401 to RK463. If a route section gets in trouble with the available space, it is possible to take measures that are related to other route sections. In Figure 26, an example is given, with the intersection between the S100 and the S116. Amsterdam would like to see that traffic is managed in this way by taking into account the available spaces in the network between route sections.

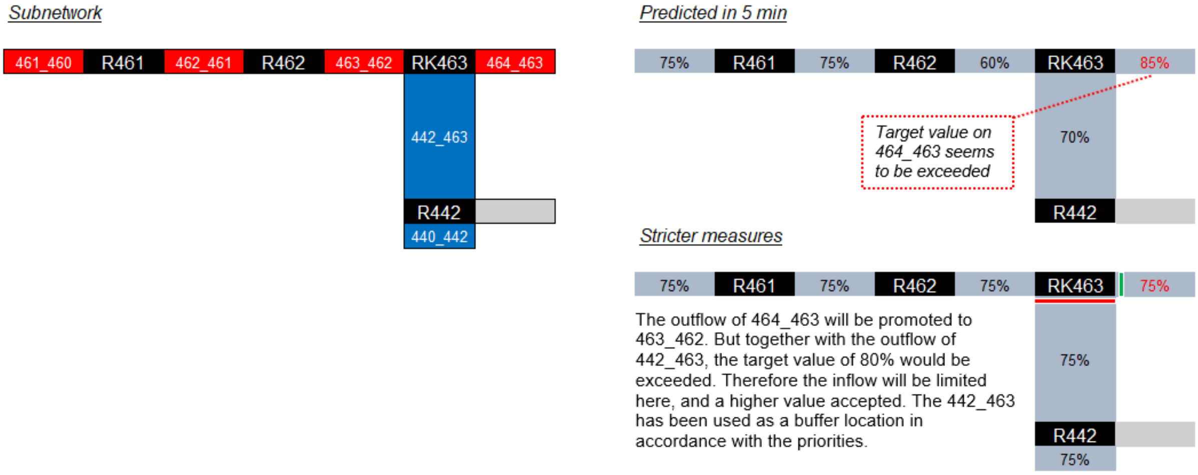

Figure 26 – Levelling between route sections at S100/S116.

So, the order in which traffic problems are addressed is first between links, then route sections, and after all at the network level.

Amsterdam also indicates that it wants to make use of spaces in the network for the service diversion. With the predictive ability, it could take the consequences of the diversion into account. The municipality of Almelo mentioned the same. On the other hand, as already mentioned, there are fewer possibilities to divert traffic, compared with Almelo. Amsterdam shows the ambition to use this service more in the future.

8.2.3 Systems

Amsterdam is a vibrant city, where accidents, traffic jams, road works or other events ensure a complicated network. It is an unfeasible task for a road manager to manage this by hand. Therefore the Rule-based approach has been created, and this should make the tasks of a road manager less labour intensive. At the Rule-based approach, that is explained in 8.1, is no longer any road manager involved. The reason for this is that road managers do not have the knowledge of how to work with this approach yet. In the future, it is the intention that they have to do as little as possible by themself. Their task would be mainly assessing traffic situations and seeing whether the Rule-based approach functions appropriately.

What could help with this is that the Rule-based approach will cooperate with other systems so that the Rule-based approach can handle the problem by itself. An example of this is when an accident happens, and emergency services are on-site, the network should get a notification and immediately respond to the new situation. This principle could also apply to other notifications with a certain reliability number. No time is wasted, and the road manager could assess if the system did this in the right way. At this moment, traffic-related events are reported in MobiMaestro. Smart Traffic should work with a likewise system, to respond directly and appropriately to the new situation.

The road manager could also be asked to assess a traffic situation. In Amsterdam, they are developing a way for the road manager to get the correct camera image on his screen immediately. There are always some events left to be judged by man, especially when it comes to safety. The road manager can decide if the capacity of a road section has to be changed, a signal group should be blocked, or the Rule-based approach could handle the situation. The distinctions between the traffic situations are the same as for Almelo explained in Section 7.3,

Another system that could help the management of traffic in a network is a connection with the tunnels in Amsterdam. There are scenarios written, for tunnels that if traffic is driving too slow, the influx will be blocked. An example is the IJtunnel, where in case of an incident, RK401 will block all signal groups directed to the tunnel. However, at this moment only one Traffic Control System will block the signal group, which will cause a movement of the traffic jam in the tunnel to the front. The municipality would like to see that problems in front of the tunnel are prevented by limiting the inflow at further upstream intersections and promoting the outflow at downstream intersections. This prevention could be done very efficient if the Rule-based approach is directly informed and knows where the space in the network could be utilised.

8.2.4 Future

Further relevant comments that Amsterdam made were the ambition to use the Rule-based approach for different modes of transport and the cooperation with traffic software from other companies.

Not only the cars but also information about pedestrians, cyclists and public transport could be interesting to handle with the Rule-based approach. The idea of giving public transport always the highest priority is maybe not that wanted. If a bus gets a green light because it has the highest priority, but at the next intersection it has to wait, is it right to give priority in advance? Amsterdam is already struggling with these issues and comparing priorities of different modes of transport. Is a tram that is almost empty important enough to stop a busy road with cars?

Of course, Amsterdam should first have this clear to ask an engineering company to implement this on an iTCS, but there could be opportunities to work together with other modes of transport and make this connection dynamic. This connection can be seen as a system where Smart Traffic could work with. For example, there is a lot of bike traffic arriving at R404 it could be better to give these cyclists green instead of stopping them. Especially in a city with so many cyclists, this mode of transport can not be neglected in the management of traffic.

In Amsterdam, there are currently several companies trying to sell their intelligent Traffic Control System software to the municipality of Amsterdam. Because there are more than 400 Traffic Control Systems installed the chance is high that Amsterdam will not choose for one company. Therefore, an essential feature of Smart Traffic could be to work together with other intelligent Traffic Control Systems, for example, from Vialis or Royal HaskoningDHV. This does not mean that the systems should work the same, but that the information from other Traffic Control Systems can be used. The same applies to data from vehicle actuated controls. In this thesis, the assumption is made that there is information available from other traffic lights. In reality, the transition to intelligent vehicle actuated controls will not happen in one go.

9 Smart Traffic in practice

In the previous two chapters, the ideas about how Smart Traffic could act on a network level were explained for the cities of Almelo and Amsterdam. The municipalities of Almelo and Amsterdam are listed as clients of Smart Traffic. Their view largely agrees with one another, but there are also different perspectives. In this chapter, the visions are translated into what they may look like in Smart Traffic. This is not the main aim of the research, but after the interviews and ideas that came up, it could give another insight into how Smart Traffic could act on a network level. Sweco also indicated that it was interested in looking at a different view. They are mainly concerned with ideas that arise from their own way of thinking. In the first instance, Almelo has been the main subject of this analysis. In addition to Almelo, Amsterdam has also been used for a different perspective.

Sub question 5
How could the vision of Almelo and Amsterdam look like in Smart Traffic?

9.1 Network performance parameter

Smart Traffic works with an objective function to determine which is the optimal schedule. The two current control objectives, see also Section 5.1.1, are to minimize the delay at an intersection and the number of stops. These two goals focus on the local performance of the intersection. Clients would like to see that the performance of the network is also included. The spaces in a network are very dynamic, and therefore it would still be labour-intensive to write out complete scenarios with different weights for all these situations.

A third parameter that represents the network performance could help this problem. The *network performance parameter* stimulates directions that are good for the network and discourage the directions that have a bad influence on the network. It is in connection with an information system that compares the predicted *space indicator* of a link with other links or route sections. This system decides whether the outflow should be promoted or the inflow limited and is monitoring the policy framework. It can be seen as a Rule-based approach, but it is different from the current LRA because there are no individual services requested. The system is only providing information. What is ultimately done with this information depends on the value of the network performance parameter.

For this, the example of the Van Rechteren Limpurgsingel in Almelo is used (Figure 14). At RK64, the inflow to the RL-4.L should be limited from the N743. The N743 is used as buffer location, so RK64 should give less green time to this signal group. This type of service is from a longer timeframe than the simulated control schedules. At the network level, the time frame is about minutes, where at a local level, control schedules are calculated for tens of seconds. The more green time directed from N743 to RL-4.L in the simulated control schedule, the higher the costs in the objective function. Ultimately you want to minimize the outcome for the objective function.

How heavily these network costs weigh in the final objective function depends on the preferences of the road manager. Both clients discussed that they would not like to intervene when it is not needed. In a tranquil situation, the network performance parameter could even not be included. The relationship between the other control objectives has now been assumed, but could again be different per road manager.

Table 9 – Objective function phase 0.

Number of stops at the intersection	0.4
Total delay at the intersection	0.6
Network performance	0.0
	1.0

When it is quiet, it is not necessary to stop traffic. Traffic flow on an intersection is vital in a calm network because it is first of all pleasant for the driver. Secondly, because there is still little information available about the routes of individual vehicles, you better let as much traffic through as possible.

For the next phase, there is a potential incident, and there could be taken measures to prevent that target values are exceeded. However, these measures should still be soft. In this phase, the proactive management of traffic is central. It is not the intention that other links in the network suffer from this and an incident occurs. The exact moment that the objectives change values is drawn up in the frame of reference and is based on the predictions in the information system.

Table 10 – Objective function phase 1.

Number of stops at the intersection	0.3
Total delay at the intersection	0.5
Network performance	0.2
	1.0

It is essential to start thinking more about the interest of the network. This shift is most of the time at the expense of the traffic flow at the intersection. However, this does not always have to be the case. When giving green in a particular direction is improving for the network (promoting outflow), and for the traffic flow (there is a lot of traffic). This signal group will, in practice “always” get green.

When the soft measures are not efficient enough to solve an incident, or there is another reason that the target values are exceeded, Smart Traffic should deploy stricter measures. This switching point is an essential element for Amsterdam to solve a traffic problem in the city.

Table 11 – Objective function phase 2.

Number of stops at the intersection	0.0
Total delay at the intersection	0.1
Network performance	0.9
	1.0

For now, there are three different phases shown in this section. Of course, it is possible to create more categories with other values.

9.2 Space indicator

In this thesis, there is used a number to compare the space on links with each other. Assessing the space can be done in different ways. The LRA cites examples as speed, gap times or drive-off capacities among others. But all these traffic data are based on the actual situation. There are no estimations or predictions made, so it will be difficult to manage traffic proactively. When the predictable ability of Smart Traffic is used, there are still different possibilities to assess the space. One example that is shortly mentioned in the LRA is the estimation of the queue at an intersection. The counter-argument here is that you assume that the traffic will stop, which should be decided based on the outcoming control schedule. It is also challenging to let the queue lengths not be influenced too much by the green times of a traffic light.

9.2.1 Prediction

Therefore the space indicator is mentioned, which uses traffic predictions about how much traffic will arrive and leave on a link. The space indicator should be a representation of the space on the road for the long term and not fluctuate with every time this direction gets green. The predictions are based on the actual data coming from adjacent traffic lights, but also on the assumptions how a traffic light will act in the future. A simple example is when five cars are coming from direction X, and at the other directions Y and Z two vehicles are arriving, the assumption will be made that direction X gets a green light. This example is simplified, and in reality, there are much more complex situations.

For these more complex situations, making predictions will also be more difficult. But if a situation arises that has happened before, the predictions could be supported by what the Traffic Control System decided then. The longer Smart Traffic is running, the better the spaces on links can be predicted. Every time a hypothesis is made about how much traffic will arrive and leave. The hypothesis is evaluated afterwards and as a consequence accepted or adjusted. This feedback-loop could be an essential element to use historical data. Primarily, triggers must focus on abnormalities, and as a consequence, change the hypothesis. It could be that there is, for example, more traffic that turns off earlier.

In Amsterdam, this data is called V-log data. All relevant traffic history is registered and could be used for the analysis of the Traffic Control Systems. In Figure 27, a schematical representation of how the space indicator can be determined is given. The situation at the Van Rechteren Limpurgsingel is used where at R12 bike traffic can ensure problems on the link at RL-4.L. By also taking this bike traffic into account, the prediction of how much traffic is at RL-4.L will be appropriately calculated.

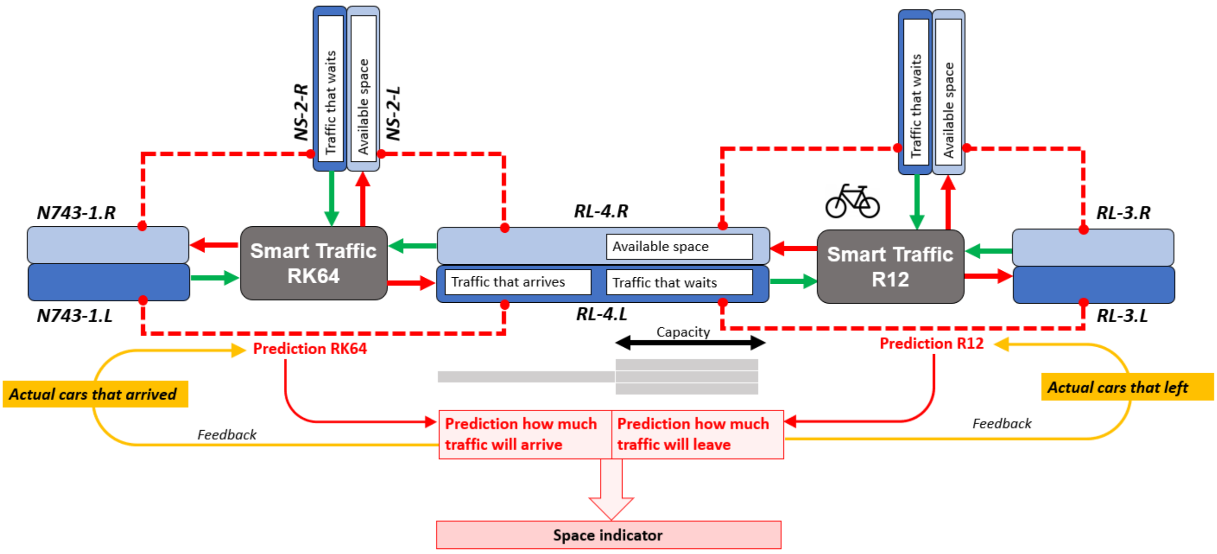

Figure 27 – Estimate space indicator at Van Rechteren Limpurgsingel.

In the future, these predictions could also be supported by Floating Car Data. This type of data is directly collected by moving vehicles as opposed to traditional traffic data collected at a fixed location. It is not yet used so intensively to make predictions based on this type of data. But when in the future, there is more data about individual vehicles and their routes, the quality of the predictions will only get better. In Amsterdam, FCD could be used to gain data about the speed of individual cars. The services of the Rule-based approach are based on this data, but what Amsterdam commented is that they also would like to see the intensities in their network. Only speed is not reliable enough to estimate the spaces in their network.

9.2.2 Factors

In Figure 27, the number of vehicles on a link is determined, but this value can not be used directly to compare with other links. For one link, ten cars that are waiting could be a lot, where another link has no problem with twenty cars waiting. Therefore, some factors needed to be taken into account before links could be compared.

- The first one is already mentioned: *The ratio between the intensity and the capacity on a link*. Especially where cars have to wait, problems could occur. So, the capacity is more related to the strip length than the length of the link.

Weight of a queue. The relationship between the number of cars in the queue and the weight for the space indicator is nonlinear. The difference between position 2 and 4 in a line is different than position 10 and 12. An estimation of this relationship is made by Sweco and can be found in

- Appendix B.1. The relationship is indicated with an S-curve.
- *Priority*. The last factor is the function of the road. On some streets, a road manager accepts that traffic can wait longer where at other roads the traffic flow should be realised in all situations. This priority should also be included to compare different links with each other.

In Figure 28, an overview of how the space indicator can be used in the network performance parameter is shown.

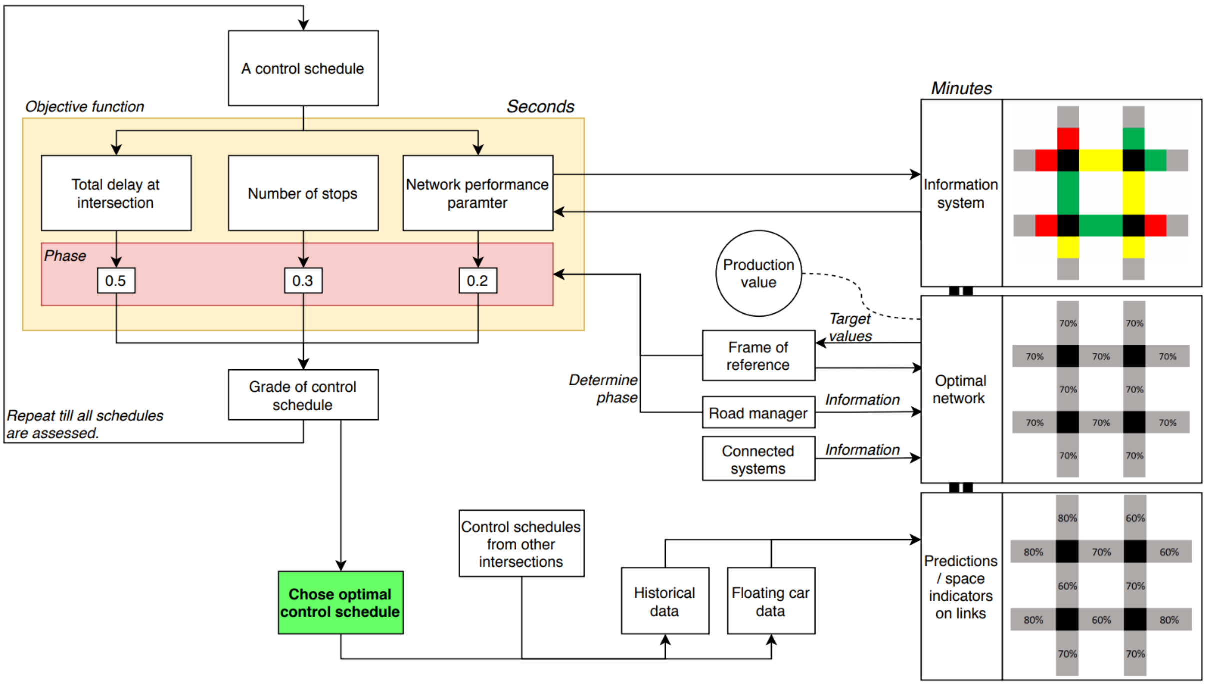

Figure 28 – Overview of how the space indicator can look operational.

With the predictions, an optimal network could be found. This optimization could depend on, among others, the preferences of the road manager or the frame of reference. Amsterdam mentioned that the performance of their network could be measured with the production value. In this step of optimization, it is also important to take new information from outside into account. If there is an accident that caused a partial blockade, the capacity of the link should be adapted, and the optimal network could look different. For the next situation, this partial blockade will automatically be taken into account for the next simulation.

Now, links and route sections can be compared as is done in the vision of Amsterdam and Almelo. It must be mentioned here that how these space indicators are used depend on the network. For Amsterdam, some links could be too small to give a good indication. Therefore, their preference would also go to levelling between route sections.

In Almelo, there is enough space between links that it is possible to decide at an upstream intersection whether it could run in the original way or has to adapt because otherwise, problems could occur. This is explained in the next section.

9.3 Space indicator in Almelo

In Almelo at the Van Rechteren Limpurgsingel, predictions could be made about link RL-4.L. If in the forecast these target values are exceeded, measures could be taken dependent on the available space in the network. A decision tree for the situation at RL-1.L is given in Figure 29.

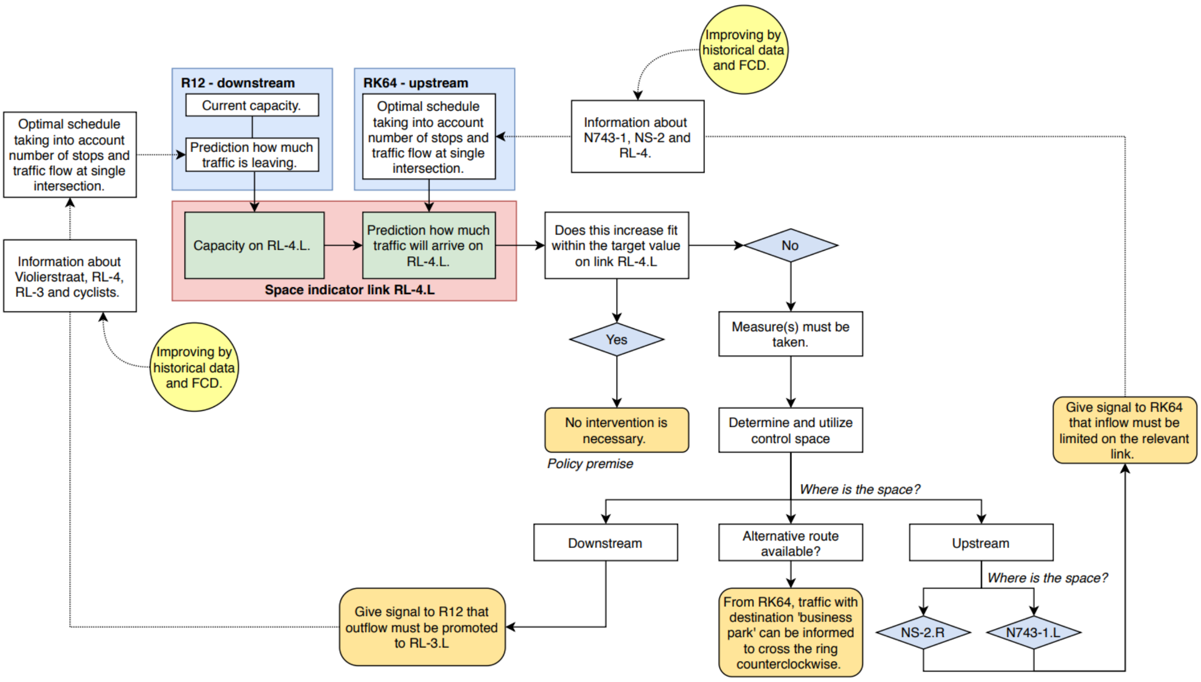

Figure 29 – Decision tree at Van Rechteren Limpurgsingel RL-1.R.

9.4 Road manager

Ultimately, the road manager will have the responsibility that the traffic network is working correctly. As mentioned by the municipality of Almelo, it is difficult to distinguish the three traffic situations automatically. But it would be possible to let the Rule-based approach already act on the situation, whereby it could be checked by the road manager if this is done correctly. In the case, when a target value is exceeded, it can be assumed that there is an overloaded situation. If this is not the case, the road manager will change the capacity of the relevant link.

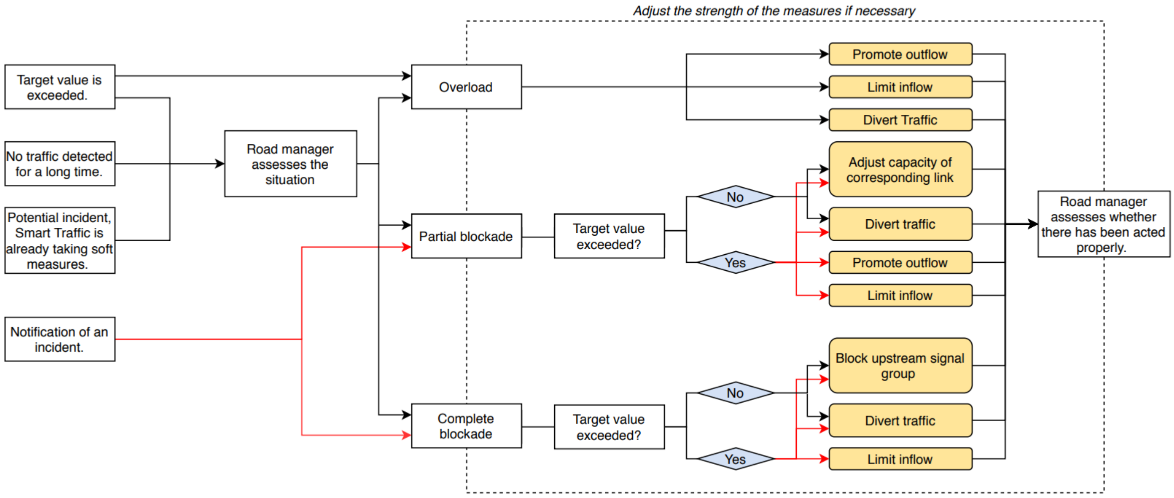

Figure 30 – Function of the road manager.

In Figure 30, the interest of Amsterdam is included with the direct connection between the Rule-based approach and the notification centre. When an incident causes a blockage and is reported with a certain reliability number, the Rule-based approach could already adapt to the new situation. In case the Rule-based approach does not react strongly enough, the road manager could strengthen the measures by hand. In principle, this should not be possible because then the target values are already exceeded, and the Rule-based approach would do this itself.

9.5 Conclusion

The role of the network performance parameter, space indicator and road manager, are discussed with the municipality of Almelo and Amsterdam. However, it should be noted that this was not the focus of the interviews. As a client, they are more interested in what could be done with Smart Traffic rather than the way it is done. S. Kamphuis indicated that this approach is interesting because it is different than their own strategy.

10 Conclusion

In this research, an answer was sought for the question: What is, in case of an incident, needed for Smart Traffic to act on a network level?' For this, the Rule-based approach and the interests of the municipality of Almelo and Amsterdam were examined.

After conversations with the municipality of Almelo and Amsterdam, it was immediately clear that not taking the space in the network into account was a point of criticism. Utilizing space could be done by levelling the amount of traffic between links or route sections. When a particular link has an intensity/capacity ratio of 70% and at the downstream link 80%, it would be more beneficial for the network performance to limit the inflow than to promote the outflow to the downstream link. The moment the road authorities want to use these spaces could differ but are mainly based on predicting. When a potential incident could arise, action may be taken to maintain the network's performance.

At this moment, Smart Traffic can use data from an upstream intersection to predict how much traffic will arrive in the coming period. Platoons are inefficient to stop and therefore most likely get a green light. But if the peak in traffic flow lasts longer, measures on network-level could be taken to prevent an incident arises, for example, by creating space. The data coming from a local level should be used to make predictions over a longer-term. When there is a peak at location A, and in 5 minutes this can cause problems at location B, measures should be taken. The target values could be exceeded in the future.

This proactive way of traffic management is how road authorities would like to see the dynamic characteristic of the iTCS is used. The local data, which is available with Smart Traffic, is used on a higher level. But the predictions that are now made with Smart Traffic are about a shorter period than desired. In the future, more information about individual vehicles could be obtained from Floating Car Data. For now, the predictions could be improved by using historical data. By recognizing patterns and deviations, it is easier to estimate how traffic is moving and when a problem may arise.

However, not all problems can be prevented. For example, it could be possible that Smart Traffic is not able to handle the traffic or an accident has occurred. In this situation, it is still important to look at the currently available spaces. But, just as the Rule-based approach does, measures will have to be applied more strictly. For unavoidable incidents, a distinction is made between overload, partial and complete blockage. In practice, it is difficult to make this distinction automatically. The municipalities of Amsterdam and Almelo would like to see that Smart Traffic is connected with the actual systems in the city. The direct connection between notifications of emergency services, bridge openings, or slow-moving traffic in tunnels, makes the work of the road manager less complicated. In some cases, the road manager will be asked to assess a traffic situation, but he or she will primarily determine whether Smart Traffic acted correctly.

This research has shown that for the transition from a local to a network level, it is necessary to predict further ahead so that traffic can be managed proactively. These predictions can be improved by using historical data and in the future, Floating Car Data. Measures could be implemented more fluently when a problem may arise. If the target values are actually exceeded, Smart Traffic will automatically intervene more strictly. The road manager assesses whether Smart Traffic has acted correctly. Ultimately, Smart Traffic should be in contact with the notification systems that exist in a city. The connection makes the work of the road manager as easy as possible.

11 Discussion

My image of the LRA changed during the research period. At first, I thought that Smart Traffic had to comply with the LRA to act at a network level. It was also indicated by Sweco that the interests of the customer might deviate from this handbook. During the interviews with the municipality of Almelo and Amsterdam, I quickly discovered that this was also the case. The promptings that came from the clients were interesting for the answer to my research question. The LRA has been used to support the interviews and the elaboration of traffic situations. It was useful to study the LRA before having the conversations because I created knowledge about what is needed for traffic management on a network level. After all, utilizing space became a more important part of my thesis. The reason for this is because I think it is an essential aspect of traffic management in the future. The dynamic use of space fits in well with the dynamic characteristic of Smart Traffic.

Further, I also had difficulties in the beginning that the developments of Smart Traffic and the network vision of Almelo were not as far as I had thought. Perhaps I should have figured this out better when writing my research proposal. However, it was also part of the research to find out the definition and progress of these concepts. An example is that in Almelo, traffic is not yet managed at the network level or that Smart Traffic is not taking any network aspect into account. Therefore, various assumptions have been made so that discussions can be held with Almelo and Amsterdam about what they think is important. An example is the space indicator or the assumption that there is enough data available in the network. In the end, I am satisfied with the result, and I hope that this also applies to Sweco.

Moreover, I quickly learned that managing traffic in a network is a broad field. It was sometimes challenging to keep the focus on my research goal because there are so many aspects of traffic management. It was important to define what Sweco wants to see because this thesis only lasts ten weeks. I think this worked out well in the end. For Sweco, I have some recommendations to continue with the transition of Smart Traffic. I did not have enough time to go deeper into these subjects.

In the conclusion is mentioned that when Smart Traffic wants to manage traffic proactively on a network level, it needs to predict over a longer time frame. Only data from an upstream intersection is not enough. The local data must be used on a network level. For the future, it could be interesting to do this with Floating Car Data, but for now, I would really focus on how predictions could be improved by historical data. Intersections that are controlled by Smart Traffic have so much information, that has to be used, to predict further in the future.

Further, a crucial element to the implementation of Smart Traffic is to discuss with clients the control space they have in their network. This seems easier than it actually is. The control space that is incorporated in the network vision is, in reality, not always clearly defined. Smart Traffic can mainly improve the network performance if there is control space available in the network. In Almelo, there is enough leeway to let Smart Traffic manage traffic by itself. It can take proactive measures to improve the management of the network. In busier cities with less space, this is more challenging.

An example is Amsterdam, where the leeway has to be created. There are so many requirements that a local TCS must meet, that it is impossible to let Smart Traffic act in the control space. If a client like this comes to Sweco, with the question what the possibilities of Smart Traffic are, a question Sweco could ask is: “What is the control space in your network?” Are you able to distance yourself from the restrictions that are in your network at this moment? The control space refers to the space in which Smart Traffic may determine itself: the Rule-based approach implemented more abstractly.

The final point of attention is that cities as Amsterdam may not choose one company to implement their iTCS. It could, therefore, be interesting to look at what kind of data you would like to receive from another iTCS to run Smart Traffic as well as possible.

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13 Appendix

Appendix A.1

Figure 31 – Regionaal wegennet 2020, prioriteitenkaart wegennet conform Twente Mobiel (Regio Twente, 2010).

Appendix A.2

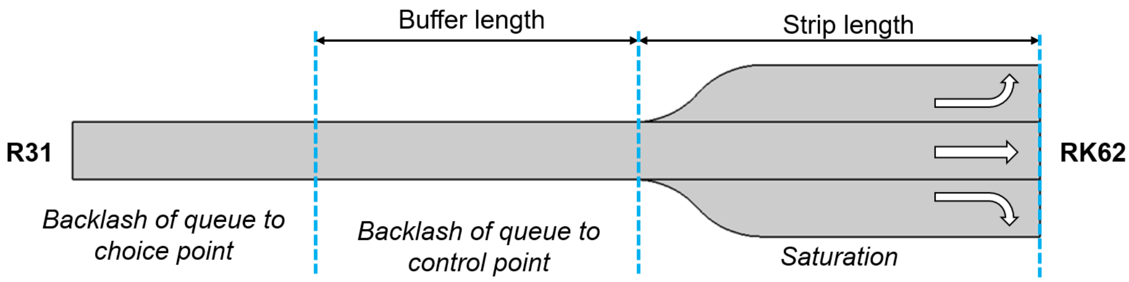

Figure 32 – Elements in the Rule-based approach.

Appendix B.1

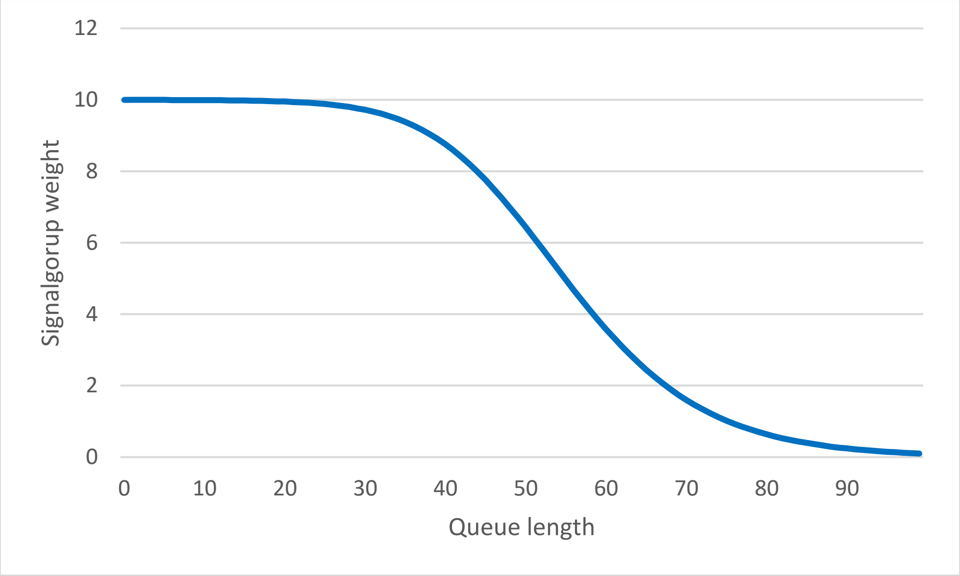

Figure 33 – Relationship between signal group weight and queue length.

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