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The road to networkwide traffic management in Utrecht

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Abstract

Several traffic management pilots around the city of Utrecht in the Netherlands have led to the successful implementation of integrated networkwide traffic management. The proof-of-concept program used a step by step approach to develop and test innovative traffic management. The first phase in 2016 focussed on controlling individual road sections; this was extended to arterials and highway ramp metering in the next step. Currently, a networkwide approach that combines traffic signal control with route guidance is being tested. For the development of the control principles, a detailed analysis of the network was required. For this purpose, a multimodal network analysis methodology has been set up. Experiments with bicycle detection, and traffic monitoring with radar sensors show how the control principles can be improved. This explanatory video also provides the results https://youtu.be/_kPnRVXluPM (English version available soon).

Keywords: Dynamic traffic management, network analysis, ramp metering, traffic signal control, route guidance, bicycle detection, radar sensors

Introduction

Road authorities at several levels (city, province, national) collaborate in the 'Proof of Concept Utrecht-Zuid' to improve the accessibility around Utrecht (see Figure 1). The considered network contains four highways and an urban road network with eleven controlled intersections. Several automated and networkwide traffic management approaches have been tested in practice. This has provided useful lessons and insights in network control and ultimately lead to the implementation of an innovative control system. Congestion on the highway is reduced, and queues on the urban network are better controlled, i.e., they are distributed more smoothly and do not exceed (policy-based) maximum queue lengths. Furthermore, the impact on other modes, buses and bicycles, are minimized. The Proof of Concept consists of five phases, where each step builds upon the previous results. The first phase considered a road section, and the last phase considers the complete network. This paper presents the results from phases 2 till 4, which are executed in the years 2017-2019. Arane cooperates with road authorities, Technolution and Fileradar to implement the Proof of Concept.

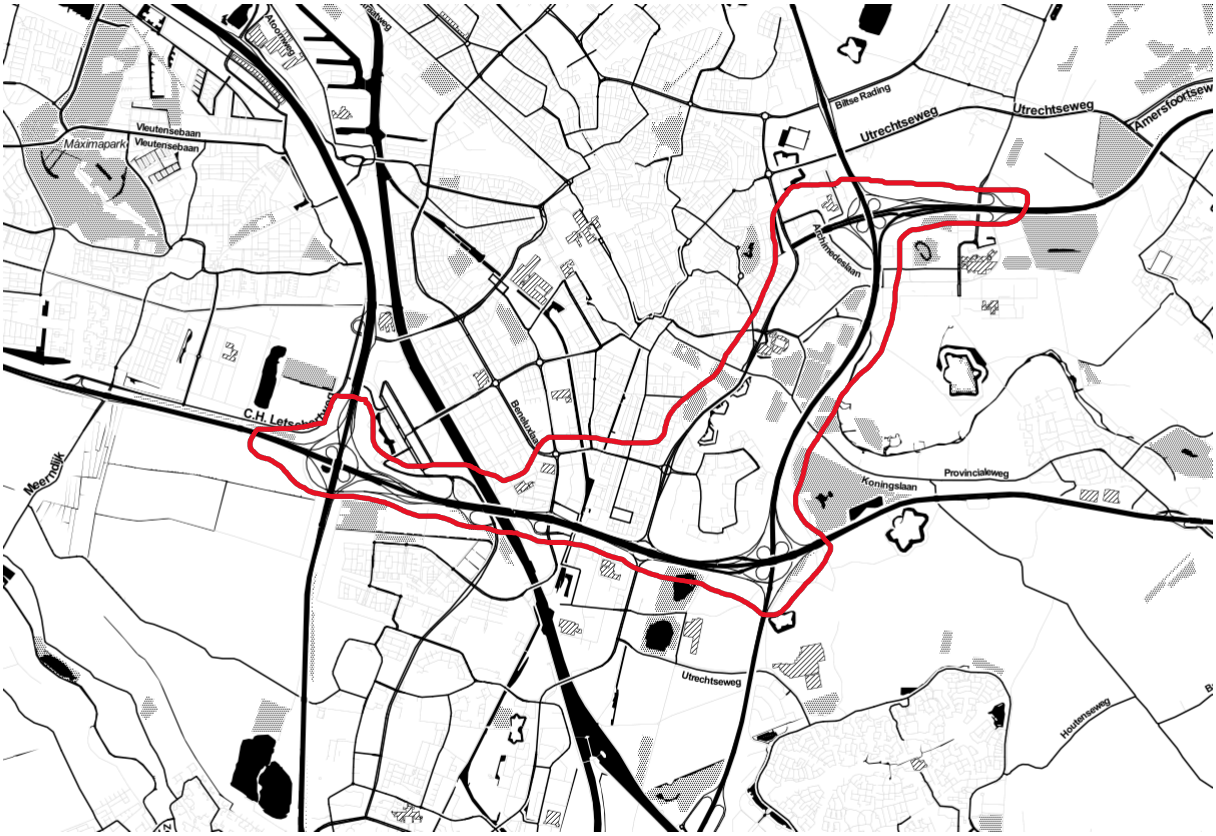

Figure 1 – Utrecht Zuid, study area in red

One key aspect to effective control is to address and understand bottlenecks with their causes and effects. Understanding the dynamics of traffic in the surrounding of the bottleneck is the basis to design efficient control systems. Bottlenecks in the road networks are identified with loop detector and floating car data. Beside cars, the transport network around Utrecht facilitates buses, trams, and bicycles. To analyse accessibility, not only the performance of the car network should be addressed. However, sensing techniques for other modes than car lack availability. Several experiments within the Proof of Concept with new sensing techniques have helped to understand multi-modal transport networks.

The control system uses real-time monitoring of the bottlenecks to determine the control strategy. Other project in the Netherlands have helped to design the system. The system uses control principles that were piloted in Amsterdam [1,2]. Important results from the project in Amsterdam are (1) a generic method to monitor highway bottlenecks, (2) detailed trigger conditions for system activation, and (3) insight in the gains, in terms of travel time, over the whole peak period when congestion is postponed at the start of the peak. In Rotterdam, the Adaptive Flow Management Maastunnel project, used these results to implement a tunnel safety traffic management system [3,4,5]. Tests in a simulation environment as well as in practice has helped to further fine-tune the system.

Methodology for network analysis

To obtain more information about the functioning and quality of the network a network analysis methodology was developed and executed. The network analysis provides the following goals:

- It allows to analyse the performance of the network and shows the location and size of all existing bottlenecks.
- It allows ex-ante and ex-post analysis of the impact of measures.
- It shows the impact on multiple modes (car, public transport, active modes) and on different scales (network, subnetwerk, origin-destination relation, route, arterial, road section, intersection)

The methodology consists of four steps, which are briefly described below.

Step 1: Identification and monitoring of bottlenecks in the network based on current policy.

A bottleneck is defined as a part of the network where the performance is below an a priori determined reference. The references are chosen by policy makers. Key performance indicators (KPI) are used to express goals from policy. Usually these KPI's are defined on road sections or subnetworks. They are calculated based on multimodal data.

Step 2: Diagnosis and analysis of bottlecks' causes.

Analysis of the traffic upstream, downstream and on alternative routes of bottlenecks, usually provides insight in the traffic flow phenomena that cause the bottleneck. If a KPI is defined on (sub)network level, the analysis should zoom in on the road section within the network. The result is a list of traffic phenomena that lead to the bottleneck. Based on this list, the *task* to resolve the bottleneck can be determined.

Step 3: Identification of potential solutions in space and time.

Based on the physical space in the network and the KPI's (that define available space from a policy point of view), potential solutions for each bottleneck can be found. Space downstream of the bottleneck indicate if it is efficient to increase the outflow of a bottleneck. Space upstream of the bottleneck indicate if it is efficient to buffer vehicles and to reduce the inflow. Space on alternative routes indicate if rerouting is an efficient measure. Time is an important factor when space is considered. Space is particularly useful at the time bottlenecks originate. When available space is better used at that time, bottlenecks can be postponed, or even completely averted. Figure 2 shows an example of a bottleneck analysis tool.

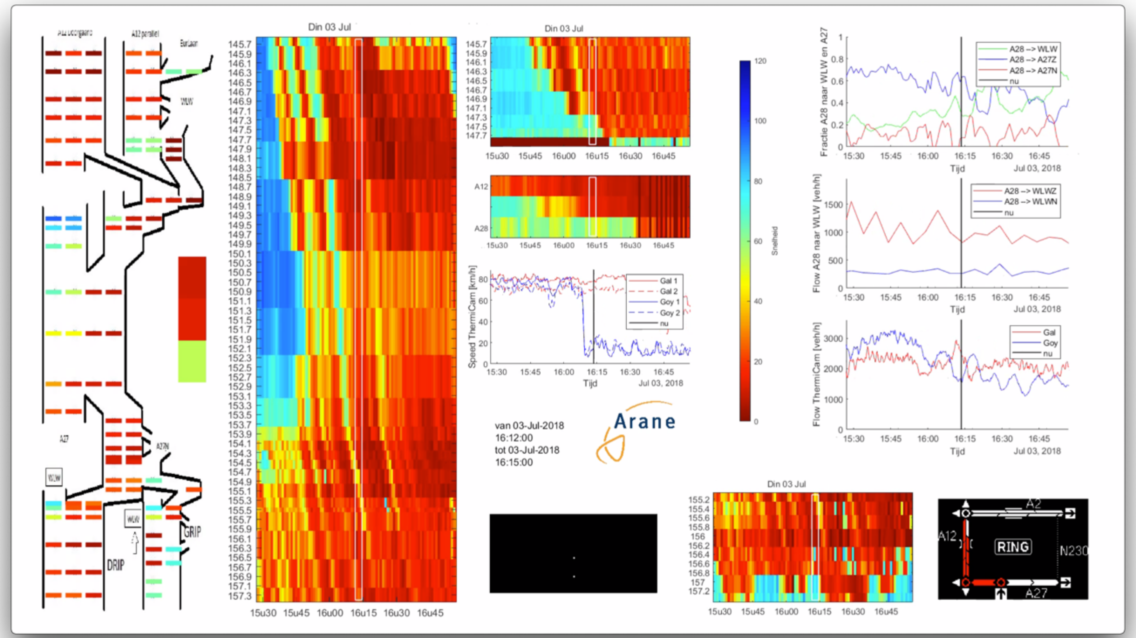

Figure 2 – Bottleneck analysis tool. This is a screenshot of a 'movie' that contains speeds, travel times, space-time diagrams, flows, turn fraction, dynamic information panels. It allows for an analysis in space and time of route alternatives.

Step 4: Selection and evaluation of measures

The final step connects possible measures with the solution potential. By doing this, the impact of measures is determined in terms of KPI's. Examples of considered measures are traffic control and small infrastructural measures. It is important not only to determine the direct effects of the measure on the bottleneck, but also to consider secondary effects on other modes, upstream and downstream networks, and alternative routes. For example, changing signal timings to improve car flows at bottlenecks, can worsen bicycle throughput at intersections.

The network analysis methodology was applied on several use cases. In one use case KPI's on the urban network are analyzed with floating car data from TomTom. This provided insight in the performance of local roads, where no information was available in the past. The use case formed the basis for the control principles that are described below.

Control principles

The control system tested in the Proof of Concept differs significantly from ordinary traffic management. The control target is the cause of the congestion (the bottleneck), instead of the resulting congestion. Also, measures (e.g., ramp metering and real-time signal control) are deployed in coordination (instead of stand-alone). Finally, the system works completely automatically.

Example of highway bottleneck mitigation with urban roads

Ramp meters in the Netherlands normally activate when *local* congestion occurs on the highway. However, in many situations the bottleneck lies further downstream of the ramp meter, for example a lane drop. The new approach monitors the bottleneck and when it foresees soon build-up of congestion, the ramp meter will be activated. This allows us to postpone or prevent the initiation of congestion.

The effect of ramp metering can be improved by adding supporting measures in a coordinated manner. The effectiveness of ramp meters are determined by the length of the ramp. If the queue exceeds the available space, blockages occur. To prevent this the signal controllers upstream of the on-ramp control the inflow to the ramp and keeps the queue length on the ramp steady. In turn, more upstream signal controllers can be used to control queues at downstream intersections; again to prevent blockages.

A second coordination principle allows more upstream on-ramps to support the first ramp meter. These on-ramps are controlled by intersection controllers because no ramp meter exists at these locations. This means that we have made it possible to perform active ramp metering without ramp meter installations. These signal controllers are also supported by signal controllers further upstream to add buffer space. These two coordination principles increase the control power of the system.

Example urban arterials

At routes with multiple controlled intersections where bottlenecks occur, similar control strategies can be applied. The difference lies in the fact that the outflow can also be increased at intersections. The control system monitors the bottlenecks; for example, it determines if the combined queue length on a route does not exceed a threshold to prevent intersection blockages. When the bottleneck activates, the first signal controller increases the outflow of the bottleneck. If this measure is insufficient, the inflow of the bottleneck can be reduced (similar to the highway approach). Not only ‘traffic’ bottlenecks can be addressed, it is also possible to control traffic safety (see [3,4,5]) and livability. For these purposes different KPI’s should be used.

Example re-routing with dynamic signing

When multiple alternatives (routes or modes) exist for a relation in the network (i.e., origin-destination), traveler choose their best alternative based on information and individual preferences. If the information is inaccurate or when the traffic state changes after the decision is made, congestion can concentrate at undesired locations.

Utrecht has an urban arterial that is over-used when small queues build up at the highway. The travel time delay can exceed 20 minutes on the urban arterial, while the travel time delay at the highway is only 5 minutes. The control system predicts travel times on both routes with a prediction horizon of ten minutes. Based on this information the control system determines the appropriate text strategy for the dynamic route information panel above the highway. By informing and advising drivers, long queues on the arterial road are prevented. This measure is currently implemented and the first evaluation results are expected in May 2019.

Results and lessons learnt

Besides the implementation of the control system, local experiments were conducted. They led to the following results and lessons learnt:

Queue estimation with radar: Information about queue lengths on urban roads is key to design efficient control system. Despite several attempts, it was not possible to estimate the queue length based on loop detector data at intersection. Therefore, the study area is equipped with radar sensors that provide reliable queue length estimates.

Radar information for intersection control: By having the radar sensors for queue estimation, it is also interesting to investigate other applications for the data. In the Netherlands, loop detectors are used to extend the green time. If no more vehicles are present, the controller switches to the next phase. Radar sensors can enrich the information available for the controller. For example, the expected number of arrivals at the intersection within *x* seconds can be determined. Figure 3 provides a screenshot of vehicle trajectories from radar sensors

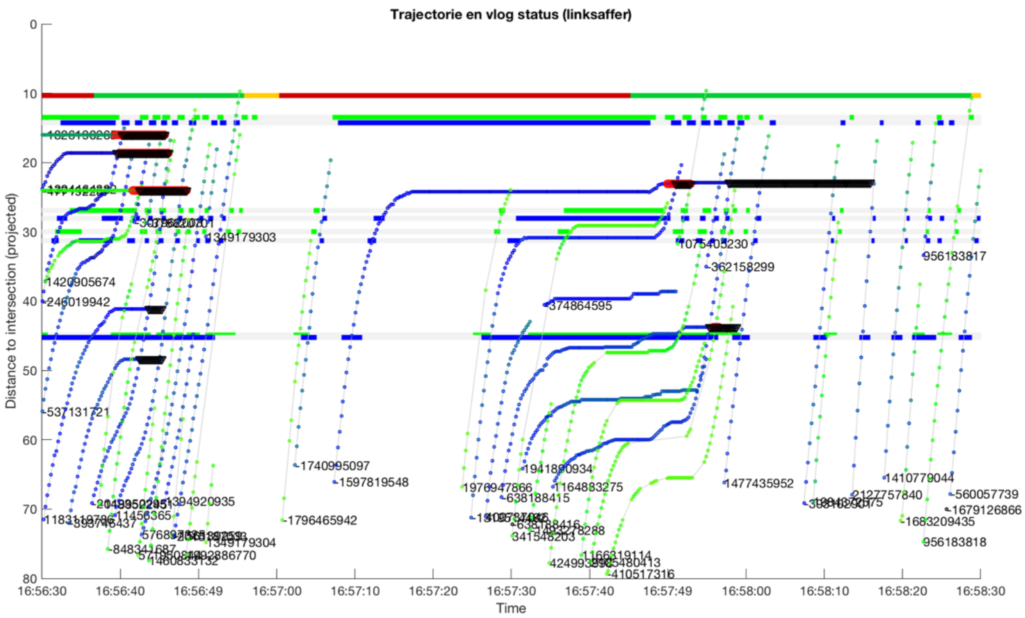

Figure 3 – Vehicle trajectories from radar to enrich information at intersections

The use of feedback control: When inflow is reduced or when outflow is increased, the control action depends on the current state of the bottleneck *and* the effects of earlier control actions. In this manner, the system automatically corrects the settings, by steering towards an optimal point. This allows a smoother control of traffic and provides robustness for accidental oddities.

Innovative bicycle detection: Contrary to car traffic, bicycle traffic is not very well monitored. In order to analyze bottlenecks on bicycle routes, information about delays has been made available. Infrared (thermal) cameras are used to detect cyclist, and to determine their waiting time at intersections. This also provided a ground to investigate if (bicycle) loop detectors can be used to determine delay of cyclists at intersection. The research showed that it is possible to track cyclists; however, the algorithm requires a training-dataset of infrared cameras.

Evaluation results - highway

The control system was evaluated for several months. By switching the system on and off for certain periods, the differences in terms of KPI's were determined. We refer to the *baseline* when the system was turned off and to the *evaluation* when the system was turned on. Effects on both the highway and urban roads are reported. The highway system was tested on the A12 parallel westbound carriagway between junctions Oudenrijn and Lunetten. Three bottlenecks were controlled with one ramp meter and six signal controllers (see Figure 4).

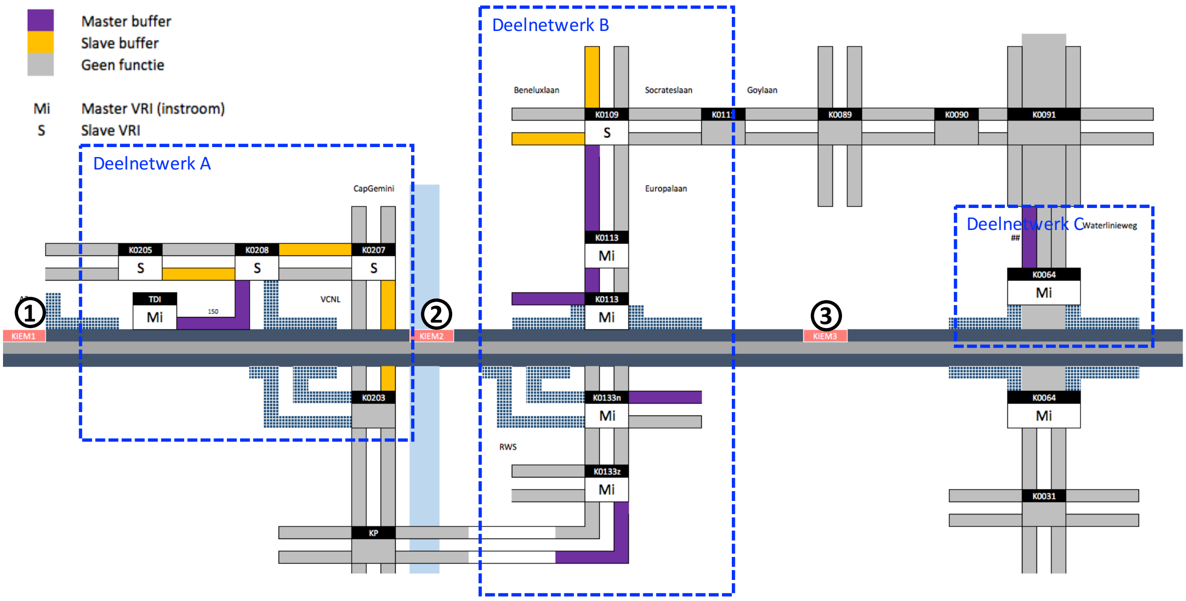

Figure 4 – Highway control area (A12 westbound near Utrecht). Glossary: kiem=bottleneck, deelnetwerk=subnetwork.

The effects are expressed in vehicle loss hours, i.e,, the additional travel time experienced by al vehicles. In the morning peak hour, primarily bottleneck 3 activates. The vehicle loss hours are:

	baseline	evaluation	difference	difference (%)
highway – bottleneck 3	144,6	94,7	-50,0	-35%
urban subnetwork C	50,9	99,7	48,8	96%

The result is that gains on the highway compensate the losses on the urban subnetwork, leading to a total gain of zero. However, the location of the congestion has changed. Instead of the highly prioritized highway, the congestion has been moved to the less important urban network. This makes the system profitable from a policy perspective.

	baseline	evaluation	difference	difference (%)
highway – bottleneck 1	295,2	167,3	-127,8	-43%
highway – bottleneck 2	146,0	98,9	-47,1	-32%
highway – bottleneck 3	2,1	2,8	0,7	33%
urban subnetwork A	24,2	49,5	25,3	104%
urban subnetwork B	142,3	153,8	11,6	8%
urban subnetwork C	366,5	284,6	-81,9	-22%

In the evening peak, an impressive reduction of 175 vehicle loss hours is achieved on the highway; this is an improvement of 40%. This compensates the 37 vehicle loss hours on the urban network by far. It is interesting to see that subnetwork C improves; since the queues behind bottlenecks 1 and 2 are smaller, there is less spillback towards subnetwork C. In the evening peak, 18 % of the total delays are mitigated with the control system. In addition, traffic remains longer on the highway, because it is less congested.

Evaluation results – urban network

Urban traffic control has been applied on ’t Goylaan in Utrecht. A route with five signalized intersections (see Figure 5). The goal was to maintain high performance of het critical routes.

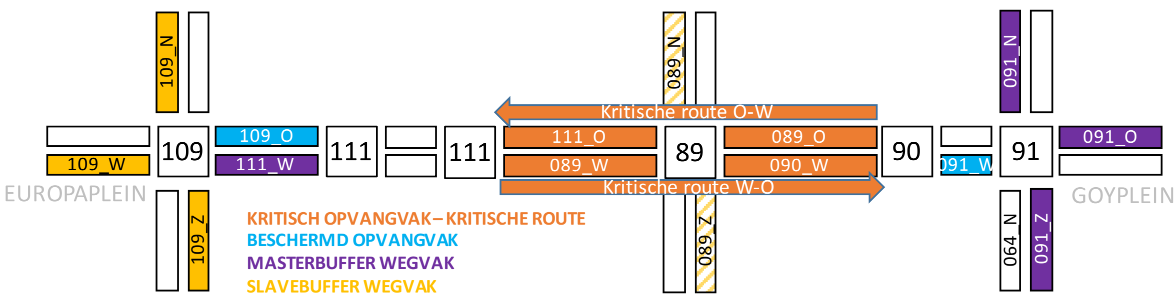

Figure 5 – Highway control area (A12 westbound near Utrecht). Glossary: kritische route=bottleneck=critical route

In the morning peak, little congestion occurs in the area. Therefore, the control system did not have an effect on the performance of the critical routes in the morning peak. In the evening peak, the system controlled the queues within the critical routes. This led to less blockages of intersections and less unsafe situations. The maximum queue length that was imposed from policy, was exceeded less. This system is now always active. The results in terms of blockages are provided below:

	Minutes of excess maximum queue length					
	Morning peak			Evening peak		
route	baseline	evaluation	difference	baseline	evaluation	difference
East - West	15,5	13,8	-11%	37,5	26,0	-31%
West - East	18,2	21,4	+18%	34,8	21,7	-38%

Conclusions

The control system for Utrecht has been successfully tested and implemented. The phase by phase development of the system in practice has led to gradual improvements of the system. The evaluations have shown positive effects of the system on KPI's on highways as well as urban roads. Currently the system is permanently active on the urban network, and permanent activation of the highway system is expected in February 2019. In the current final phase of the Proof of Concept re-routing is trialed; results are expected in May 2019.

References

1. Hoogendoorn, S.P., Van Kooten, J., & Adams, R. (2016). Lessons Learnt from Field Operational Test Integrated Network Management in Amsterdam. In *Transportation Research Board* 95th Annual Meeting (No. 16-2888).
2. Smits, E.-S., van Kooten, J. & Hoogendoorn, S.P. (2016), Towards efficient mitigation of freeway congestion by integrated network management, *Extended abstract for hEART 2016*.
3. City of Rotterdam (2016), *Instruction AFM system Maastunnel*, online explanation video, https://youtu.be/gaOg62WwPnA.
4. Smits, E.-S., Kooijman, R., de Groot, T., van Kooten, J. & Hoogendoorn, S. (2018). *Adaptive Flow Management, where tunnel safety and network-wide traffic management go hand in hand*, 25th ITS World Congress, Copenhagen, Denmark.
5. Hoogendoorn, S.P., Smits, E.-S., Van Kooten, J., van Erp, P. & Kooijman, R. (2019). Adaptive Integrated Traffic Management in Rotterdam: Towards Safe and Efficient Urban Network Operations with AFM. In *Transportation Research Board* 98th Annual Meeting (No. 19-01705).