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Enhanced Traffic Management Procedures in Transition Areas

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Abstract

In light of the increasing trend towards vehicle connectivity and automation, there will be areas and situations on the roads where high automation can be granted, and others where it is not allowed or not possible. These are termed 'Transition Areas'. Without proper traffic management, such areas may lead to vehicles issuing take-over requests (TORs), which in turn can trigger transitions of control (ToCs), or even minimum-risk manoeuvres (MRMs). In this respect, the TransAID Horizon 2020 project develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, with the goal of avoiding ToCs and MRMs, or at least postponing/accommodating them. Our baseline simulations confirmed that a coordinated distribution of takeover events can prevent a drop in traffic efficiency, which in turn leads to a more performant, safer, and cleaner traffic system, when taking the capabilities of connected and autonomous vehicles into account.

Keywords:

Traffic management, autonomous vehicles, V2X

Introduction

As the introduction of automated vehicles becomes feasible, even in urban areas, it will be necessary to investigate their impacts on traffic safety and efficiency. This is particularly true during the early stages of market introduction, where automated vehicles of all SAE levels, connected vehicles (able to communicate via V2X) and conventional vehicles will share the same roads with varying penetration rates.

There will be areas and situations on the roads where high automation can be granted, and others where it is not allowed or not possible due to missing sensor inputs, highly complex situations, etc. Moving between those areas, there will be areas where many automated vehicles will change their level of automation. We refer to these areas as ‘Transition Areas’.

Without proper traffic management, such areas may lead to vehicles issuing take-over requests (TORs) to their drivers, which in turn can trigger transitions of control (ToCs) towards these drivers, or even minimum-risk manoeuvres (MRMs) by the vehicles themselves. In this respect, the TransAID Horizon 2020 project (‘Transition Areas for Infrastructure-Assisted Driving’) develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, with the goal of avoiding ToCs and MRMs, or at least postponing/accommodating them.

Outline of the traffic management framework

Traffic Management as a Service

In first instance, TransAID compiled an outline of the state-of-the-art of traffic management, putting the focus first on general approaches, including coordinated network-wide traffic management, using KPIs, layered architectures spanning the range from top-down regulation over self-organisation to full bottom-up regulation, and Traffic Management-as-a-Service. We also looked at the trend towards more cooperative systems which is well-suited for enhanced traffic management, making the systems smarter by targeting (cooperative/connected) vehicles individually. Moreover, we looked at the expected impacts that machine learning techniques and artificial intelligence in general would have on traffic management.

In itself, all these solutions are very fine and usable. However, there are no (readily available) integrated traffic management experiments or setups, taking higher degrees of vehicle automation into account. Nor do they allow the interplay between all the various solutions to lead to a better system performance. This is where TransAID makes the difference by creating a traffic management framework. Fleet managers of connected and/or autonomous vehicles (CAVs), as well as road authorities, both operate backend centres to manage their fleets and traffic networks, respectively. To effectively and systematically manage transition areas on a large scale and for multiple AV fleets and multiple road authorities, TransAID positions itself as an intermediary service provider, acting as a trusted (and possibly mandated) third party. It will then represent the single-point-of-contact for road authorities and traffic participants (or indirectly, via their OEMs).

TransAID in the role of an intermediary service provider

Automated vehicles of different makes with different levels of automation will each be designed to operate in a particular domain. Such a domain is characterised by static and dynamic attributes which range from road type and layout to traffic conditions, weather and many attributes in between. In general, we call these domains ‘operational design domains’ (ODD), which are defined by Czarnecki (2018) as the operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. An ODD may put limitations on (i) the road environment, (ii) the behaviour of the automated driving systems (ADS)-equipped subject vehicle, and (iii) the state of the vehicle. Furthermore, an operational road environment model (OREM) is a representation of the relevant assumptions about the road environment in which an ADS will operate the ADS-equipped vehicle (e.g., a two-lane rural road). An ODD of an ADS implies a set of operational environments in which the ADS can operate the ADS-equipped vehicle. These environments can be specified using a set of OREMs, which can be in- or out-of-scope of the ODD.

When the ODD of an AV ends, it will handover the control of the vehicle to the human driver or in case the driver does not respond, initiate a minimum risk manoeuvre (MRM). The location of such an event is referred to as the Transition Area (TA). However, due to the stochastic nature of traffic (take the occurrence and impacts of incidents for example) and the diversity of automated vehicle makes and their capabilities, it is impossible to perfectly predict where, when, and why the ODD ends and consequently TAs are located. Nonetheless, the existence of TAs affects both AV-fleet managers and road authorities due to reduced performance of the vehicle and the traffic network respectively. Here, TransAID develops infrastructure support measures for situations which normally would imply the end of the ODD. However, as part of these support measures, AVs receive additional information and/or guidance needed to enable them to proceed in automation mode.

AV-fleet managers and road authorities both operate backend centres to manage their fleets and traffic networks, respectively. To effectively and systematically manage TAs on a large scale and for multiple AV fleets and multiple road authorities, we propose a trusted third party (and where possible mandated) intermediary service. This will then act as the single-point-of-contact for road authorities and traffic participants (or indirectly, via their OEMs). Based on status and disengagement information from AV fleet managers and traffic management plans from road authorities, this intermediary service acts as a delegated traffic manager who digitally implements the TransAID infrastructure support measures. With support of the right tools, an operator continuously monitors in real-time the traffic system and disengagement reports, based on triggers and scenarios, identifies TAs, and finally selects the appropriate measure. An advantage of this service is that measures taken by AV-fleet managers and road authorities can be coordinated and harmonised across multiple AV fleets and geographical areas (managed by different road authorities). Moreover, smaller and/or rural road authorities, which may not have backend centres or not a suitable operational overview of the road and traffic flow dynamics, can benefit from an intermediary service that can perform this task for them. The concept of the intermediary service approach adopted within TransAID's traffic management scheme is depicted in Figure 1.

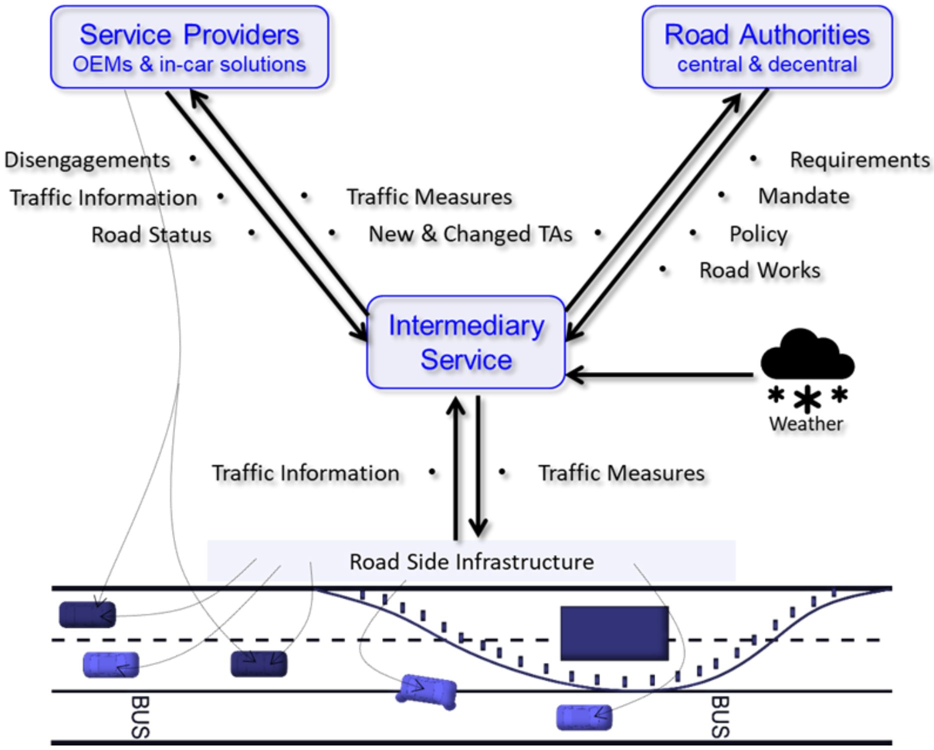

Figure 1: Schematic overview of TransAID's intermediary service approach.

High- and low-level traffic management operations

Within the framework of traffic management (TM) in TransAID, we also assume there are a number of road-side units (RSU) that each look at traffic in their immediate vicinity (their finite range stems – among other reasons – from the assumption of realistic communication capabilities). The traffic management centre (TMC) is then a logical entity that uses and communicates with these RSUs, as illustrated in Figure 2. In that sense, the RSUs aspire to have an as-good-as-possible view on their local situation (either through communication with connected vehicles, such as CV and CAV, or through information obtained from road-side detectors such as loop detectors, camera's, …), whereas the TMC – as a smart infrastructure – combines these in order to get the global picture. Or TransAID, the TMC is to be considered as the intermediary service.

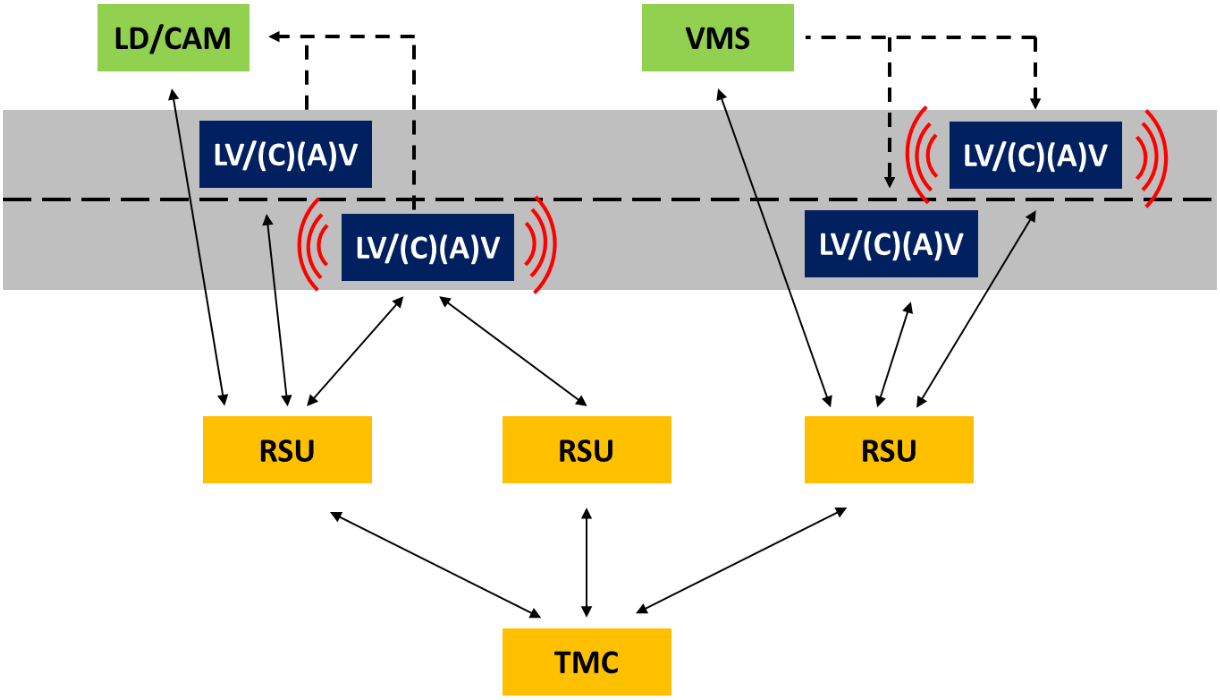

Figure 2: High-level overview of how the traffic management centre (TMC) interacts with the road-side units (RSU), in order to obtain information on the traffic stream as well as broadcasting measures.

TransAID's services and use cases

General overview

Within TransAID we defined five different use cases where disruptions of traffic flow are expected to be most severe as a result of transition between automation levels. The initially selected use cases were:

- Service 1 (Use case 1.1): Prevent ToC/MRM by providing vehicle path information
- Service 2 (Use case 2.1): Prevent ToC/MRM by providing speed, headway and/or lane advice
- Service 3 (Use case 3.1): Prevent ToC/MRM by traffic separation
- Service 4 (Use case 4.2): Manage MRM by guidance to safe spot (urban & motorway)
- Service 5 (Use case 5.1): Distribute ToC/MRM by scheduling ToCs

In addition, we elaborated all use cases with general descriptions, timelines, road networks, and requirements on the vehicle capabilities, vehicle numbers, and traffic compositions. For each of these use cases, we listed when (i.e. which Level of Service), where (spatial locations), and how (traffic management recipes) traffic management measures should be applied. The measures are implemented in the iTETRIS simulation platform (using SUMO as a microscopic representation of traffic flows and ns-3 to achieve realistic communication capabilities and collective sensing). They are calibrated and validated using predefined sets of KPIs/metrics.

Used traffic conditions and vehicle mixes

The ‘right’ traffic management measures are dependent on traffic conditions and the vehicle mix. The following tables give an overview of their values:

- Definition of the levels of service (LOS) A through C
- Distribution of passenger vehicles versus LGV and HGV
- Overview of the different vehicle types, aggregated into classes of actors
- Artificial vehicle mixes for baseline simulations

Table 1: Vehicles/hour/lane for Level of Service A, B and C in urban, rural, and motorway conditions.

	LOS A	**LOS B**	**LOS C**
Urban (50km/h) – 1500 veh/h/l	525	825	1155
Rural (80 km/h) – 1900 veh/h/l	665	1045	1463
Motorway (120 km/h) – 2100 veh/h/l	735	1155	1617
Intensity / Capacity (IC) ratio	0.35	0.55	0.77

Table 2: Classification of actors (vehicle types).

Class Name	**Class Type**	**Vehicle Capabilities**
Class 1	Manual Driving	– Legacy Vehicles – (C)AVs/CVs (any level) with deactivated automation systems
Class 2	Partial Automation	– AVs/CVs capable of Level 1 and 2 automation – Instant TOC (uncontrolled driving in case of distracted driving) – No MRM capability
Class 3	Conditional Automation	– (C)AVs capable of Level 3 automation (level 3 systems activated) – Basic ToC (normal duration) – MRM capability (in the ego lane depending on speed and a predetermined desired MRM deceleration level)
Class 4	High Automation	– (C)AVs capable of Level 4 automation (automation activated) – Proactive ToC (prolonged duration) – MRM capability (in the rightmost lane depending on speed and a predetermined desired MRM deceleration level)

Table 3: Artificial vehicle mixes for baseline simulations during 1st project iteration.

Vehicle Mix	Class 1	Class 1 (Conn.)	Class 2	Class 2 (Conn.)	Class 3	Class 3 (Conn.)	Class 4	Class 4 (Conn.)
1	60%	10%	-	15%	-	15%	-	-
2	40%	10%	-	25%	-	25%	-	-
3	10%	10%	-	40%	-	40%	-	-

Example service 5 / use case 5.1

Introduction

As an example, we look at service 5 / use case 5.1, i.e. Distribute ToC/MRM by scheduling ToCs. Here, external reasons might determine if automated driving will be forbidden in certain traffic areas (which we call 'no automated driving' (NAD) zones). Service 5 aims to inform approaching C(A)Vs in order to initiate transitions to manual driving in a coordinated manner. In absence of additional guidance and coordination we expected to have an accumulated occurrence of transitions at specific locations, which can lead to adverse effects regarding traffic safety and efficiency. Thus, Service 5 implements a scheme for the distribution of TORs sent to C(A)Vs ahead of the NAD zone within a dedicated TOR area (as shown in Figure 3).

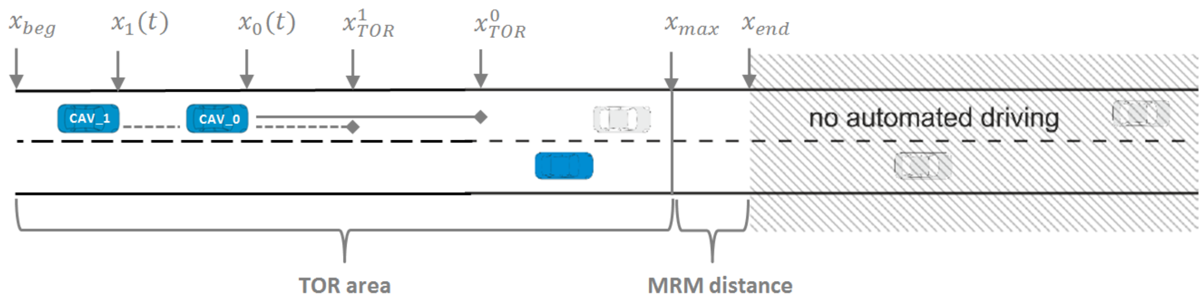

Figure 3: Schematic distribution area for TORs within a transition area.

Traffic management setup

In Figure 4 the principle control logic of Service 5 is presented as a flow chart. The TMC monitors the area upstream of the NAD zone and regularly obtains positions and speeds from each C(A)V. Furthermore, information about the traffic distribution in the monitored area is derived from collective perception and road side detectors.

Consecutive C(A)Vs are pooled into groups at the entrance to the monitored area, and their transitions are supervised and coordinated algorithmically. The traffic management algorithm assigns a TOR schedule for every vehicle depending on the estimated density within the TOR area, the current position, and speed of the vehicle, and its position within the corresponding vehicle group.

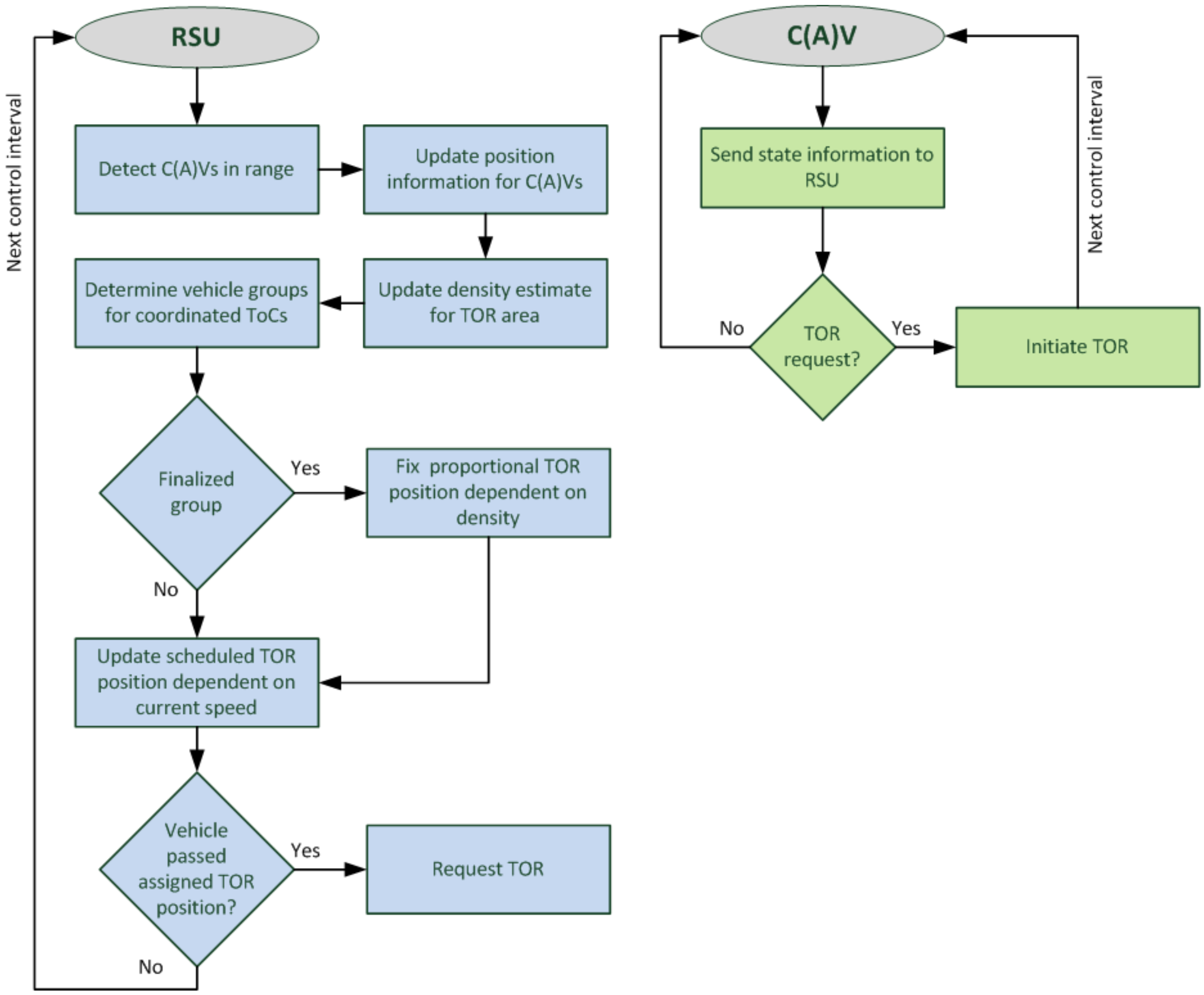

Figure 4: Traffic management service for use case 5.1.

Simulation results

Within TransAID, we simulate the different use cases first as a baseline using the earlier mentioned parameters, and then with the activation of the chosen traffic management service. Each time, we look at the impacts on traffic efficiency (network-wide in terms of average speeds and flows, and local in terms of tempo-spatial diagrams), traffic safety (by means of the number of events where a time-to-collision lower than 3 seconds occurred), and finally the environmental impact (considering CO_2 emissions as calculated by the simulation model). For service 5, we can see for example how, given the network, activation of the traffic management system leads to a higher average network speed compared to the baseline for Level of Service C, as shown in the graphs in Figure 5.

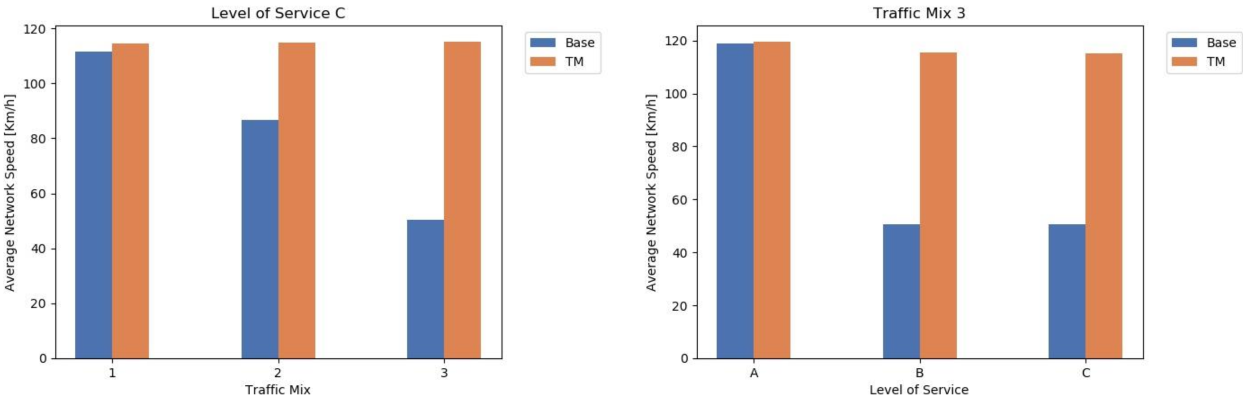

Figure 5: Average network speeds for use case 5.1 (motorway network) simulation experiments (varying the LOS and vehicle mixes). Different bar colours correspond to baseline and traffic management simulations.

Figure 6 illustrates the speed losses and reduced flows for the sample of LOS C, vehicle mix 3, seed 6. The NAD zone starts at a position of 2.5 km. For the baseline we observe a breakdown of average speed triggered by perturbances arising from several simultaneous ToCs at close locations. Such disruptions leading to a stationary bottleneck located at the NAD zone entry occur in most simulations runs sooner or later within the one hour simulation interval. Once developed, the bottleneck hardly dissolves if demand is not low (LOS B and C). In the depicted example the bottleneck emerges already after approximately five minutes and congestion rapidly grows filling the simulated area after approximately 25 minutes (cf. the red area in the upper left plot of the Figure).

These phenomena vanish in the presence of a coordinated distribution of TORs. Even if local disruptions are present (i.e. the lighter spots in upper left plot of the Figure), the prevention of locally concentrated series of ToCs allows them to dissolve such that a smooth flow is re-established (cf. the green-yellow areas in lower right plot of the Figure).

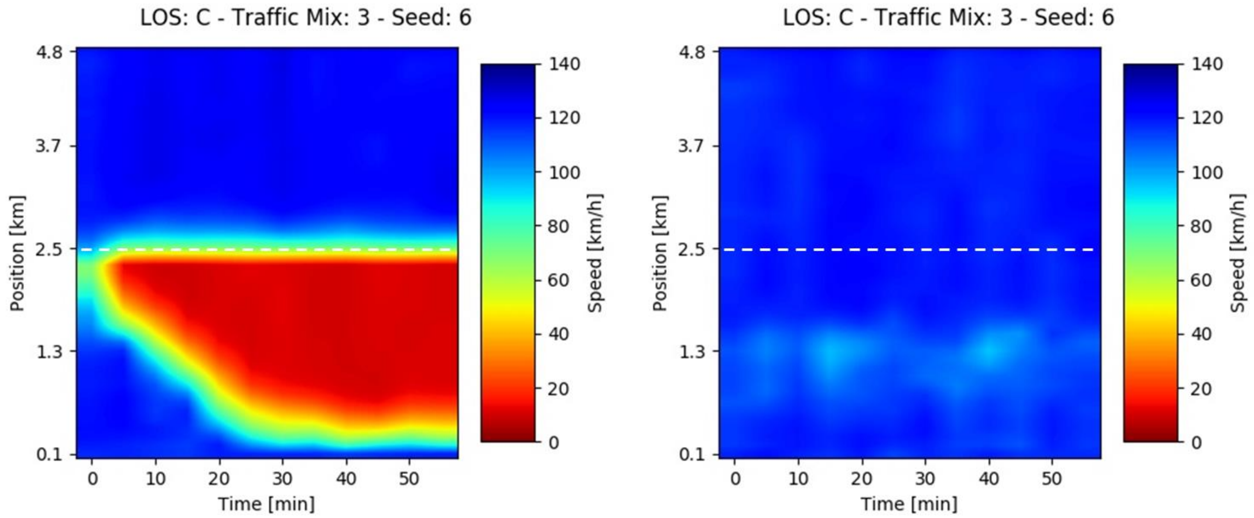

Figure 6: Example tempo-spatial diagrams for measured speeds for use case 5.1 (LOS C, vehicle mix 3, seed 6). The left diagram corresponds to the baseline and the right one to the applied traffic management Service 5 simulations. The white dashed line marks the entry position of the NAD zone.

Conclusions and next steps

It is clear that advanced traffic management procedures lead to a more performant, safer, and cleaner traffic system, when taking the capabilities of connected and autonomous vehicles into account. As an example of a traffic management service, our baseline simulations confirmed the hypothesis that a coordinated distribution of takeover events can prevent a drop in traffic efficiency in areas where an accumulated occurrence of transitions may be expected. For the assessment we assumed that in absence of a managed TOR coordination the takeover events will be concentrated closer to the area, where no automated driving is possible. Our simulation results encourage the pursuit of the approach of ToC distribution. As the main reason for the effectiveness of this we identified the prevention of compounding braking efforts occurring if a sequence of CAVs performs transitions to manual driving simultaneously.

Acknowledgements

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