D2.1

Use cases and safety and efficiency metrics

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■ PU : Public

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Executive Summary

The main objective of this Deliverable 2.1 is to describe and identify the use cases where disruptions of traffic flow are expected to be most severe because of transitions between automation levels, and to identify KPIs to evaluate those use cases. For those identifications, a state of the art literature review has been conducted, a workshop was held with road authority stakeholders, advisory board members have been consulted and experts have been interviewed.

The findings have been combined to identify the relevant aspects for TransAID scenarios and Transition of Control (ToC) in general. The large number of aspects (or dimensions) affecting automated vehicle behaviour and possible trigger conditions in combination with the many uncertainties regarding those aspects and conditions (e.g. what exactly triggers a ToC or Minimum Risk Manoeuvre?), posed a challenge for the use case and scenario definitions.

Through brainstorming using a template based on above mentioned aspects and conditions, TransAID has identified five generic services that can be applied to many situations. Because of their generic characteristic, these services are expected to mitigate negative impacts resulting from vehicles in Transition Areas, regardless of the uncertainties (i.e. even if certain conditions are different, the solutions still apply).

As a result, an overview was created of example situations where transition of control occurs regularly and causes traffic flow disruptions. By means of detailed services and use case descriptions, the deliverable gives a comprehensive overview on (negative) traffic safety and traffic efficiency impacts, for both urban, inter-urban and motorway situations, and proposes a preliminary set of (high-level) traffic measures.

1 Introduction

1.1 About TransAID

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, high complexity situations, etc. At these areas many automated vehicles will change their level of automation. We refer to these areas as “Transition Areas”.

TransAID develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, especially at Transition Areas. A hierarchical approach is followed where control actions are implemented at different layers including centralised traffic management, infrastructure, and vehicles.

First, simulations are performed to find optimal infrastructure-assisted management solutions to control connected, automated, and conventional vehicles at Transition Areas, taking into account traffic safety and efficiency metrics. Then, communication protocols for the cooperation between connected/automated vehicles and the road infrastructure are developed. Measures to detect and inform conventional vehicles are also addressed. The most promising solutions are then implemented as real world prototypes and demonstrated under real urban conditions. Finally, guidelines for advanced infrastructure-assisted driving are formulated. These guidelines also include a roadmap defining activities and needed upgrades of road infrastructure in the upcoming fifteen years in order to guarantee a smooth coexistence of conventional, connected, and automated vehicles.

1.2 How to reach the objectives

According to the described approach, TransAID is going to find solutions for problems arising related to the introduction of automated vehicles, esp. in the areas where automated driving cannot be supported by many vehicles. Therefore, the project first needed to identify which areas are highly relevant. This is not a simple task, as behaviour of future systems is not yet fully defined and as esp. detailed information about possible weaknesses of such systems is often not very well highlighted by the developers.

Several current and past researches have dealt with automated driving, and therefore several potential risks are already known or foreseen. TransAID has done a literature review to get access to this information, combined with expert interviews and stakeholder consultations. By having a closer look on this, already some additional potential risks have been identified.

The results have been integrated into a list of use cases. The use cases will not cover all existing problems but will focus on the most important ones which most likely will have a big impact on traffic efficiency and safety. To achieve a clear understanding on the impact, Key Performance Indicators (KPIs) and metrics have been defined. The use cases as well as the KPIs and metrics are described in this deliverable.

Then, in the upcoming deliverable D2.2, the list of use cases will be further structured to get a clear view on the precise situations and their requirements. By using this as starting point, TransAID is going to start the developments in the different work packages. WP3 is going to focus on modelling of the behaviour of future automated vehicles and their drivers. WP4 is going to model approaches for the road side. WP5 adds communication capabilities to vehicles and infrastructure, which includes electronic communication with V2X, but also communication to conventional vehicles by means of e.g. variable message signs.

All these work packages start implementing the state-of-the-art before new measures to enhance traffic efficiency and safety are included in each of the areas.

WP6 is then dealing with the integration of all developed models into a common simulation platform which covers driver, vehicle, infrastructure and communication simulations.

In the early phase of the project, simulations are performed which show the impact of the introduction of automated vehicles esp. in Transition Areas when no additional measures are taken. This serves as a baseline for additional simulations which include the new measures. The most promising measures are closely investigated and parametrised in detailed simulations. When reaching the highest possible level of impact, these measures are prototypically implemented into real world prototypes in WP7 in order to demonstrate the feasibility of the approach.

Finally, the results are discussed with stakeholders in WP8. This also includes the developments of a roadmap showing necessary stepping stones to cope with automated vehicles in the future and a guideline showing how stakeholders can achieve a higher level of traffic efficiency and safety during the phase of introduction of automated vehicles.

In order to be reactive to the findings, TransAID is using two iterations of implementation. While the first iteration covers the whole way from baseline simulations to prototypical implementations in the real world for a set of simple use cases, the second iteration is going to look into more detail and will investigate more complex use cases.

1.3 Purpose of this document

The purpose of this document is to define a list of use cases and KPIs/metrics for the investigation of Transition Areas. Both serve as basis for the creation of scenarios and requirements in D2.2 and as consequence for the developments done in the entire project.

See Section 5.2.1 for more information about the scope of this document in relation to the other work packages and the first part of TransAID.

1.4 Structure of this document

To fulfil the purpose, this deliverable first describes the approach of the use case formulation. This includes a background to TransAID (Chapter 2), a literature review provided in Chapter 3 followed by a detailed chapter about analysing aspects of transition of control, including constraints and necessary clustering to identify relevant TransAID situations for the use case definitions given in Chapter 5.

In Chapter 6, the safety and efficiency metrics used in TransAID are described, which are used to assess the effects of the new service developed to ensure a smooth introduction of automated vehicles, also in Transition Areas.

1.5 Glossary

Abbreviation/Term	**Definition**
AB	Advisory Board
ABS	Anti-Blocking System
ACC	Adaptive Cruise Control
AD	Automated Driving
AV	Automated Vehicles
$C0_2$	Carbon Dioxide
CAV	Cooperative Automated Vehicle
CAV Platoon	Cooperative Automated Vehicle Platoon
CC	Cruise Control
CV	Cooperative Vehicle
DRAC	Deceleration Rate to Avoid Collision
EC	European Commission
ESC	Electronic Stability Control
FCW	Forward Collision Warning
HF	Human Factor
HMI	Human Machine Interface
I2V	Infrastructure-to-vehicle
I2X	Infrastructure-to-anything
ITS	Intelligent Transport System
ITS-G5	Access technology to be used in frequency bands dedicated for European ITS
KPI	Key Performance Indicator
LDW	Lane Departure Warning
LKAS	Lane Keeping Assistance System
LV	Legacy Vehicle

MRM	Minimum Risk Manoeuvre
OEM	Original Equipment Manufacturer
PET	Post Encroachment Time
RSI	Road Side Infrastructure
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SD	Standard Deviation
SSM	Surrogate Safety Measures
TA	Transition area
TCC	Traffic Control Centre
TET	Time exposed Time-to-collision
THW	Time Headway
TIT	Time integrated Time-to-collision
TMC	Traffic Management Centre
TMS	Traffic Management System
ToC	Transition of Control
TransAID	Transition Areas for Infrastructure-Assisted Driving
TTC	Time-to-collision
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-anything
VMS	Variable Message Signs
WP	Work Package

2 Background

The development of vehicle automation functions started with the invention of low level systems, like the Anti Blocking System (ABS) or later the Electronic Stability Control (ESC) System. On the other hand, comfort systems have been developed, starting with Cruise Control (CC), and rapidly evolving to more complex systems like Adaptive Cruise Control (ACC). Also, safety systems have been further developed, resulting in systems like Forward Collision Warning (FCW) or Lane Departure Warning (LDW). By the introduction of Lane Keeping Assistance Systems (LKAS) and the combination of them with ACC, it first became possible that series systems were able to longitudinally and laterally control vehicles. At least since then (although addressed in research much earlier) the different systems could not be considered as individual sub-systems only. The complete system, consisting of various sub-systems for different tasks, had to be approached as whole. This included the necessity of defining clear roles in the vehicle, stating who is in control of the driving task and who has the responsibility, especially when something unexpected is happening.

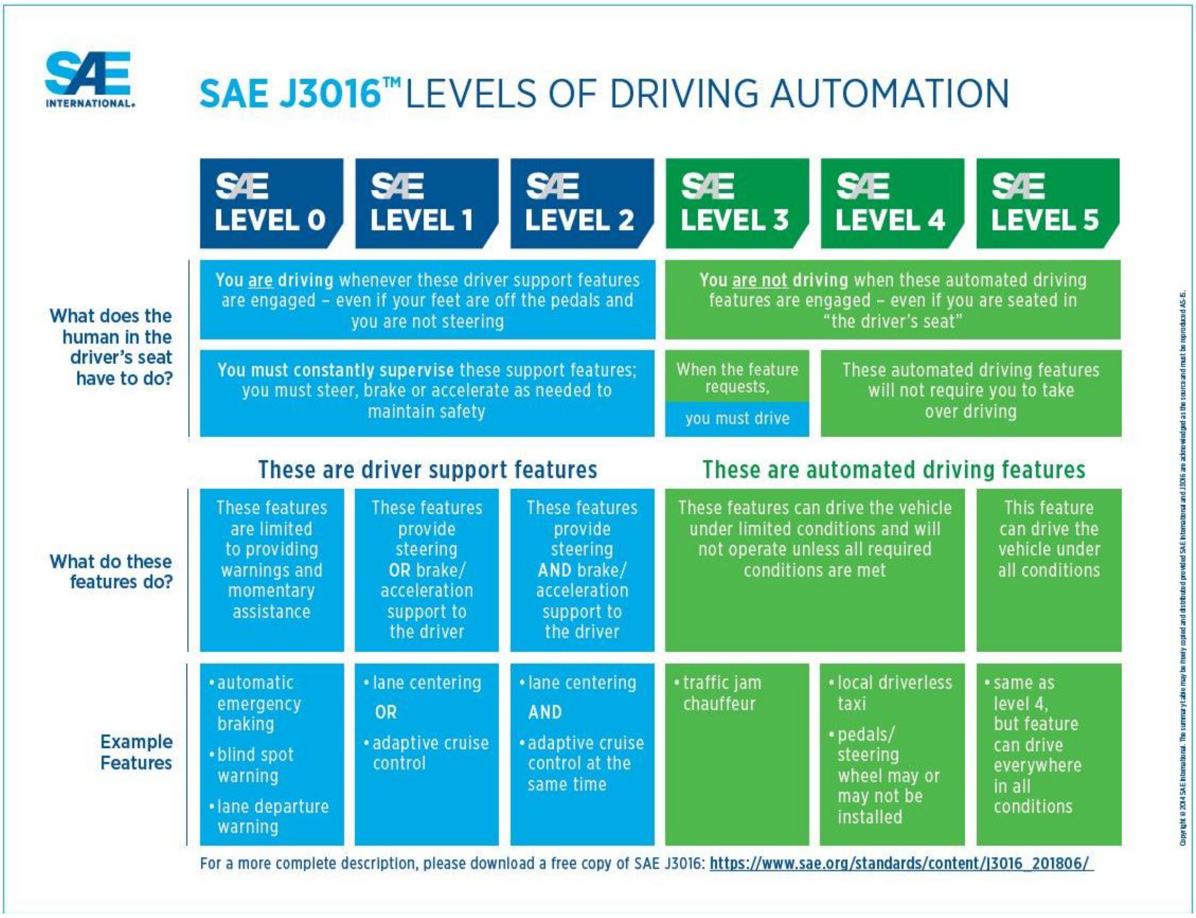


Figure 1: Levels of vehicle automation according to SAE J3016.

Several different classifications of automated driving have been developed. Currently, the automation levels defined by SAE International in J3016 (2016, see Figure 1) is one of the most referred standards in the community and used for TransAID as a basis. This standard defines 6 levels of automation, starting from manual driving (level 0) up to full automation in all roadways and environmental conditions (level 5). In present times, first level 3 systems like Highway Pilots are reaching the markets, where the vehicle itself monitors the environment and "fulfils all aspects of the dynamic driving task". In case the system is not able to handle a situation, the human driver must "respond appropriately to a request to intervene".

While the standard describes the overall capabilities of the complete system, it is important to mention that a level 3 system still consists of the aforementioned sub-systems for longitudinal and lateral control. When, for example, reaching an area without lane markings, the system can possibly still offer longitudinal control/ACC, forcing the driver to take over lateral control only. While the vehicle itself stays a level 3 vehicle, the activated system performs a transition of control from level 3 to level 1 in this case.

In general, the availability of sub-systems changes in the different driving situations and environmental conditions the system must cope with. In addition, some situations require the intervention of the human driver or the automation system, for example in case the system interpreted a situation in a wrong way or an obstacle is suddenly appearing on the road. Therefore, it is necessary that roles can be shifted. This includes the shift of responsibility, when for example the system is unsure about an upcoming situation and needs the driver to take over responsibility, but also the shift of control. In TransAID, we refer to this changing of roles as **Transition of Control (ToC)**.

A ToC therefore can happen in different ways. Either the driver initiates the transition, for example by switching on an ACC or Highway Pilot, or the system itself triggers the transition. The latter happens either when, for example, an obstacle appears on the road and an automatic evasive manoeuvre is performed, or when the system cannot handle an upcoming situation on its own. A ToC can happen <u>upwards</u> by giving control to the system or <u>downwards</u> by returning control to the driver.

One of the most critical factors of a ToC is the available timing. ToCs can happen instantaneous (e.g. by pressing a button) or need a specific amount of time. This is especially true when the system reaches an area where automated driving functions are no longer available. In these situations, the system must hand over control to the human driver in the vehicle. In lower levels of automation this can simply be done by dropping control (so long as the driver follows his/her role of monitoring the system at all times), but when reaching higher levels of automation (or in case of abuse), this is more difficult, as the driver may be distracted from the driving task or even asleep. In these cases, the driver has to recognise that he/she has to take over and has to understand what reaction is appropriate to the current situation. This can be very time consuming and therefore needs an early detection of the necessity of a transition.

If the required time is not available, or the driver is not responding, a level 4 system needs to (and a level 3 system should at least to some extend to avoid uncontrolled stopping) perform a so called **Minimum Risk Manoeuvre (MRM)**. This manoeuvre is used to bring the vehicle into a safe state. This can be done simply by braking or in a more sophisticated way by, for example, a lane change to the emergency lane on motorways (also shown in the European FP7 project HAVEit (HAVEit, 2008)).

For the sake of completeness, it has to be said that ToCs of level 5 vehicles (or special level 4 vehicles like automated people movers) are different compared to level 1 to 3 or vehicles on level 4, as those vehicles may lack a human driver and/or the needed devices for manual control, like a steering wheel or brake. If these vehicles need to perform a ToC, they probably only have the choice to stop or to perform the transition to a remote vehicle operator.

TransAID is focussing on ToCs from levels 2, 3 and 4 (where the system is in control) to levels 0 or 1 (where the human is in control), i.e. downward, and vice versa (upward). The project is esp. looking at areas where transitions are likely to occur very often, see Figure 2. These are areas on the road in front of or after e.g. construction sites or complex intersections, which cannot be handled by automated vehicles. TransAID is *not* looking into individual transitions happening anywhere else, e.g. due to a sensor malfunction.

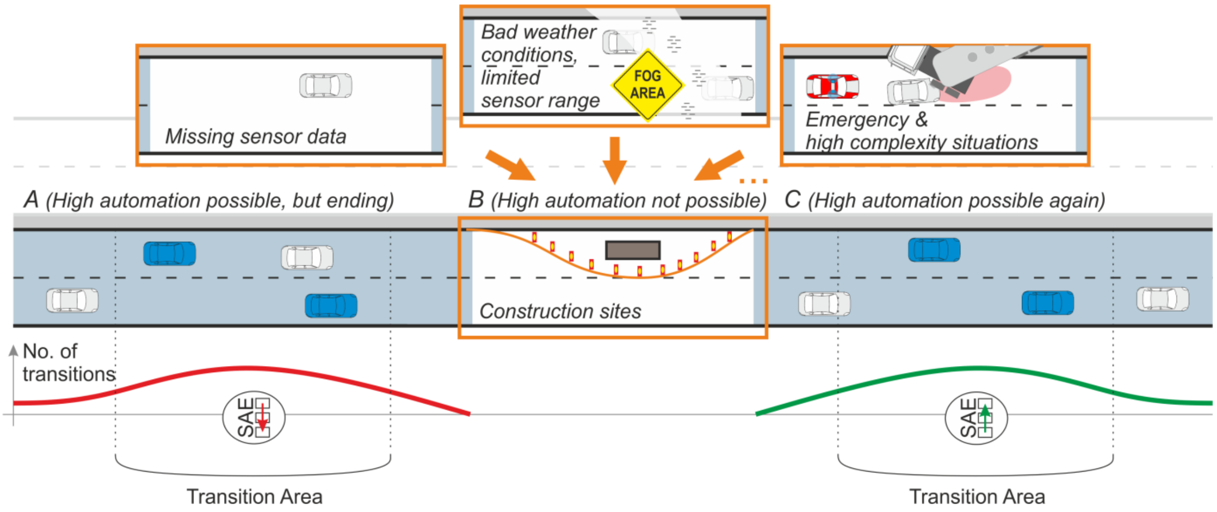


Figure 2: Areas on the road where ToCs are happening very often, so called “Transition Areas”.

Within the TransAID project, a system will be developed which helps in such **Transition Areas**. The system will follow a hierarchical approach, where vehicles with different automation and communication capabilities share information with the infrastructure (see Figure 3). TransAID therefore takes into account a foreseen mix of conventional/legacy vehicles (LV), connected non-automated vehicles (CV), automated vehicles (AV) and connected automated vehicles (CAV). The infrastructure will integrate the acquired information at the Traffic Management System (TMS). The TMS will generate progression plans for the vehicles which are taken over by the infrastructure and communicated to the vehicles, either by I2V communication or (in case of non-equipped vehicles (LV/AV)) by e.g. variable message signs (VMS).

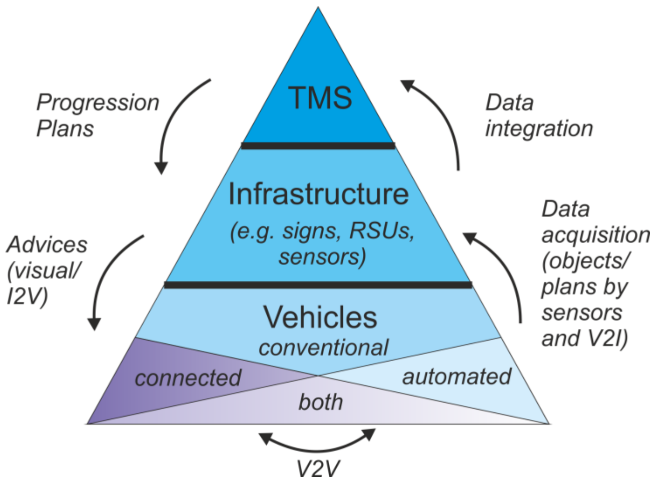


Figure 3: Hierarchical traffic management in TransAID

The purpose of the system is therefore first to minimise the number of occurrences of ToCs in the Transition Areas. In case the corresponding measures are not resolving all issues and ToCs take place, the system is going to help the vehicle currently performing the ToC by, for example, guiding it to a safe spot. In TransAID, these kinds of measures are focussing on connected automated vehicles (CAV) only. In addition, the system tries to reduce negative impacts (like reduced efficiency or safety) of the occurring ToCs to other road users, by, for example, informing other vehicles about the problems of the ToC performing vehicles or by separating automated vehicles from non-automated ones.

It is important to mention that in terms of connected (automated) vehicles TransAID is only focussing on ITS-G5 communication. Other kinds of communication (5G etc.) may also be used, and the TransAID techniques may also be applied to those, but this is out of project scope.

The TransAID system and sub-systems are further described in the section below.

2.1 System Decomposition

The exact details of the overall TransAID system depend on the implementation of measures, supported ITS-G5 communications and possible new non-conventional measures. For now the overall system design consists of the Road Side Infrastructure (RSI) on the one hand, and the vehicles on the road on the other hand (see Figure 4).

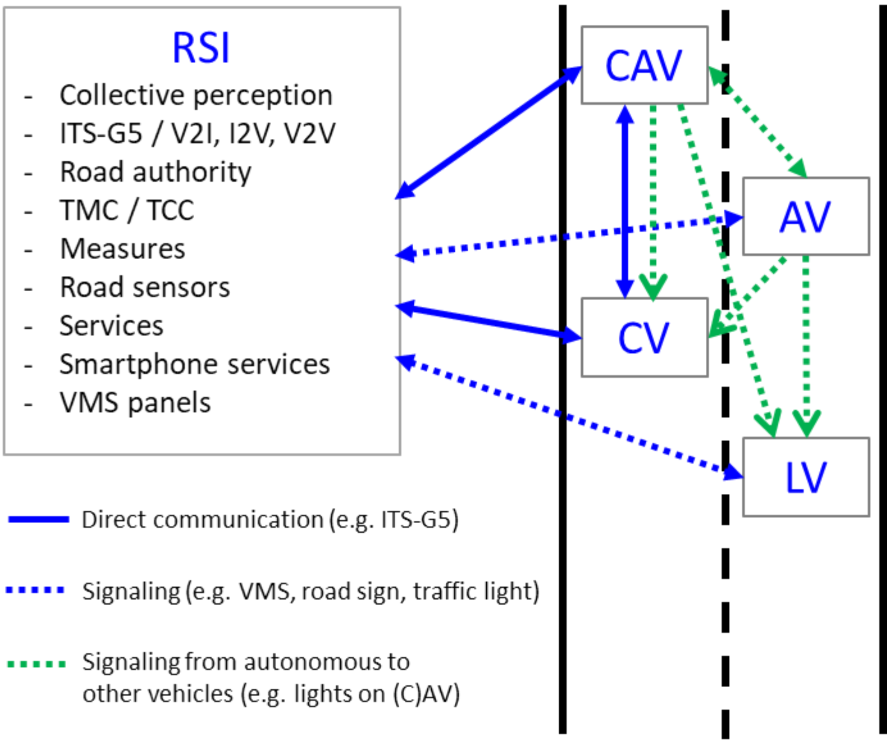


Figure 4: TransAID System.

One can see the verhicle types on the right and the Road Side Infrastructure on the left. The different arrows respresent diffent types of communications. The solid arrows indicate direct communication through, for example, ITS-G5. The dotted blue arrows represent conventional signaling measures such as, for example, VMS panels and possibly new measures to reach AVs. The dotted green arrows are more exclusive to TransAID and/or automated driving developments. Those arrows represent measures to convey information from automated vehicles to other vehicles via, for example, light indicators on the back of the vehicle. Preliminary measures are defined in this document (see Section 5.3) and are to be refined and expanded in WP4.

The sub-systems, RSI, CAV, AV, CV and LV, are elaborated on in the next section.

2.1.1 Sub-systems

This section defines the TransAID subsystems. Note that only general entities are considered here and not roles like for example a bus or an emergency vehicle.

Cooperative Automated Vehicle (CAV): A cooperative automated vehicle that can control automatically all the driving functions (braking, throttling, steering) under specific driving, traffic and environmental conditions. The driver can resume vehicle control by choice or in case a transition of control is initiated due to internal or external factors. The vehicle can execute a Minimum Risk Manoeuvre (MRM) if the take-over request fails due to driver irresponsiveness. It is equipped with the ITS-G5 communications technology and therefore can directly exchange information with nearby vehicles and with the road infrastructure. Besides, it includes a HMI for the communication between the vehicle and the driver.

Cooperative Automated Vehicle Platoon (CAV Platoon): This is a set of two or more CAVs driving close together (short head ways). This can be either reached through specific 'platooning' functions or simpler Cooperative Adaptive Cruise Control (CACC) functions. CAVs can join such platoons or leave those in a coordinated way. For remaining specification see the definition of CAV.

Automated Vehicle (AV): An automated vehicle that can control automatically all the driving functions (braking, throttling, steering) under specific traffic and environmental conditions. The driver can resume vehicle control by choice or in case a transition of control is initiated due to internal (system failure) or external (environmental limitation) factors. The vehicle can execute a Minimum Risk Manoeuvre (MRM) if the take-over request fails due to driver irresponsiveness. It includes a HMI for the communication between the vehicle and the driver, but it is not equipped with any wireless communication technology for real-time applications (e.g. V2V, I2V). It still may exchange uncritical data (map data, software updates etc.) via mobile communications.

Cooperative Vehicle (CV): A cooperative vehicle that is equipped with the ITS-G5 communications technology which enables it to directly exchange information with nearby vehicles and with the road infrastructure, but not perform any driving function automatically. Besides, it includes a HMI for the communication between the vehicle and the driver.

Legacy Vehicle (LV): A conventional manually-driven vehicle without any mobile/wireless communications technology for real-time applications (e.g. V2V, I2V). It still may exchange uncritical data (map data, software updates etc.) via mobile communications.

Road Side Infrastructure (RSI): an RSI is an entity that collects traffic information from vehicles using ITS-G5 communications and road sensors such us cameras or induction loops. That information could also be enriched information coming from C(A)Vs. The gathering of this complete information set from road side and vehicles, is referred to as 'collective perception'. RSI uses the collected traffic information to assist in the generation of traffic management policies for the smooth coexistence of different types of vehicles in transitions areas. It interacts with the vehicles, employing V2I communication for the interaction with cooperative vehicles (CV and CAV) and VMS panels or other conventional signalling for the interaction with non-cooperative vehicles (LV and AV), providing advisory information like speed advise, lane advise, or security distance advise.

2.1.2 Interfaces

TransAID entities define the interactions between the TransAID subsystems. There are 8 defined interfaces:

V2V communications between cooperative vehicles: interface between cooperative vehicles (CV and CAV) based on ITS-G5 communications. It is based on the ETSI ITS standards to transmit vehicle related information. It supports the definiton and/or the execution of traffic management policies. For this purpose, extensions to the already defined ITS message sets and/or new dedicated message sets will be defined.

V2I/I2V communications between connected vehicles and the infrastructure: interface between connected vehicles (CV and CAV) and the RSI based on ITS-G5 communications. It is based on the

ETSI ITS standards to transmit vehicle and road advisory related information. It supports the definiton and/or the execution of traffic management policies. For this purpose, extensions to the already defined ITS message sets and/or new dedicated message sets will be defined.

RSI to Variable Message Sign (VMS): interface between the RSI and variable message signs. It is employed to provide information of the traffic management policies defined in TransAID to non-cooperative vehicles (LV and AV).

Human Machine Interface (HMI): interface between the vehicle and the driver. It informs the driver about the relevant information to increase the situation awareness of the driver and thus the overall traffic safety (out of scope for TransAID).

Road sensors to RSI: interface between the road sensors and the infrastructure. Road sensors detect the presence of vehicles and other obstacles in the road and inform the infrastructure.

Detection of obstacles and other non-cooperative vehicles by cooperative automated vehicles: using the environmental perception of cooperative automated vehicles to detect obstacles on the road and other vehicles.

Detection of cooperative vehicles by cooperative vehicles: the usage of V2X communications based on ITS-G5 allows the detection of other cooperative vehicles (CV and CAV) inside the communications range.

Detection of cooperative vehicles by the RSI: the usage of V2X communications based on ITS-G5 allows the detection of cooperative vehicles (CV and CAV) inside the communications range.

3 Literature review

To better understand relevant aspects to be addressed by TransAID use cases, a literature review was completed. Five topics were considered for this review:

1) Transition of control and human factors,
2) Impact of automated vehicles on traffic flow efficiency,
3) State-of-the-art traffic management
4) Motion planning and control algorithms for automated vehicles, and
5) State-of-the-art on use cases on automated driving.

3.1 Transition of control and human factors

Transition of control (ToC) is an important topic in automated driving. As long as automated vehicles (AVs) do not reach the highest level of automation where the driver or operator of the AV is effectively out of the loop, the operator of the AV acts as a fall-back level for the automation. This is necessary whenever the automation reaches its system limits and cannot handle a situation on its own. In other cases, the operator does not feel safe or comfortable or merely wants to drive the AV on his own, thus initiating a ToC to take control over the AV.

ToCs can be categorised in several ways (Lu et al., 2016). Transitions in general can occur downwards (to the driver) or upwards (to the system). The initiator of the ToC can either be the operator or the automation. The same is true for the target controller of the AV, so either the operator or the automation is in control after a ToC. Also, the operator might force a ToC (then called mandatory transition). ToCs initiated by the automation can generally be categorised as mandatory as there are no choices involved, every decision is programmed and determined. Note that this classification refers to the actual decision itself. Thus, if the automation leaves the choice for a ToC to the operator (e.g. the automation offers to take over control on a motor way), it is defined as an optional ToC initiated by the operator as he had the final choice.

Furthermore, active and passive transitions can be distinguished. In an active ToC, the initiator of the ToC is in control after the transition (e.g. the operator of the AV initiates a ToC in order to get the control of the AV). This implies that the ToC generally is less critical as the initiator should be prepared to take control over the AV (Lu et al., 2016). This is different in a passive ToC, as here the initiator is not in control after the transition, e.g. when the operator gives control to the system or when the system wants the driver to take over. In that case it is not certain that the final controller is prepared to take control of the AV. A passive, mandatory ToC from the automation to the operator is particularly critical in that regard as it is the fall-back strategy for the situations the automation cannot handle. So, it only seems reasonable that most studies focus on that specific transition. Any further mention of ToCs will refer to this specific ToC.

Generally, it was found that the higher the level of automation, the more time operators need to re-obtain situation awareness and take over manual driving (Lu & de Winter, 2015). This has several reasons: Highly distracted operators need to shift focus from the distraction back to the current driving situation (Zeeb et al., 2015; Merat et al., 2014) and higher automation levels can also lead to more operator fatigue and more regular engagement in secondary tasks (Morgan et al., 2016; Jamson et al., 2013). Drivers may even be completely out of the loop, e.g. by sleeping. Meanwhile operators who monitor the AV during the automated drive show better results in duration and quality of ToCs. Another indicator for this correlation can be seen in traffic situations with higher traffic density: This more complex situation also leads to increased durations and lower quality of ToCs (Gold et al., 2016; Eriksson and Stanton, 2017). The more complex the situation, the more visual scanning to re-obtain situation awareness was observed and ToCs led to more critical situations (lower time-to-collision and a higher accident rate). Another study (Jamson et al., 2013) found operators to be more vigilant in heavier traffic situations, mostly because they did not trust the capabilities of the AV as much in the more complex environment. On the other hand, operators were easily distracted and fatigued in light traffic where trust in the automation was high.

Furthermore, with shorter warning times a worse take-over quality was observed (Lu and De Winter, 2015). Appropriate warning times determined in studies range from 5 over 10 up to 15 seconds for critical situations (Merat et al., 2014; Mok et al., 2015; Melcher, Rauh et al., 2015; Spulber and Wallace, 2016). In non-critical situations, time spans of up to 17 seconds were observed with staged warnings up to 50 seconds before an action was necessary (Blanco et al., 2015). While lower warning times did not lead to good results (Mok et al., 2015), a lot of studies did not take into account the quality of the ToC. This seems to be an important issue as durations as long as 40 seconds were observed before the operators resumed adequate and stable control of the AV after a ToC (Merat et al., 2014). It should also be mentioned that there were several cases where operators did not react to take-over requests at all or only after extensive hinting (Gold et al., 2016; Blanco, et al., 2015). As shown e.g. in HAVEit, 2008, the design of the HMI is crucial when the system tries to bring the operator back into the loop. The HMI has to show that there is a problem very early and has to inform the operator about possible reasons. In best cases, the HMI also offers solutions for the problem and guides the operator in solving the problem (Lapoehn et al, 2016).

Overall a contradiction seems to develop: The more situations the automation can handle, the more trust the operators have in the system. On the other hand, situations in which ToCs occur become more and more critical, while operators are probably engaged in secondary tasks or fatigued (Morgan et al., 2016; Dixit et al., 2016). Additionally, operators might even experience degrading driving skills resulting in worse decision making and longer ToCs (Aria et al., 2016), making operators less and less reliable as the fall-back level for the automation. This is particularly concerning as the main reason for disengagement from automated driving is system failure (Dixit et al., 2016).

Overall it seems to be a reasonable approach to try and prevent as many ToCs as possible or at least organise them in a way that there is enough time for the operators to re-obtain control of the AV properly. Otherwise minimum risk manoeuvres and critical situations could become the norm in everyday traffic, nullifying most advantages attributed to AVs.

3.2 Traffic flow efficiency

Atkins (2016) stated that connected and automated vehicles could impact network performance, traffic flow and capacity. This includes changed longitudinal following behaviour, changed gap acceptance and merging behaviour, changed profiles of acceleration and deceleration, improved decision making due to better provision of information, and cooperative driving for user and network benefit. Vehicle automation is considered to be a major step towards a more efficient road system, both in terms of producing a more stable traffic flow that reduces the risks of congestion, as well as improved fuel efficiency due to increases in aerodynamic performance (Van Loon and Martens, 2015).

Automated driving is expected to have an influence on traffic flow behaviour. The relationship between automation of vehicles and its impact on traffic flow efficiency was studied by Hoogendoorn et al. (2014). They reviewed the influence of automation of the longitudinal control task through Adaptive Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC) on several indicators of traffic flow efficiency, i.e., the influence of automation on capacity, the capacity drop and traffic stability. It was concluded that automation of longitudinal driving tasks may indeed have a beneficial influence on these indicators. Moreover, a theoretical framework for the relation between automation and traffic flow efficiency was provided. In this framework, the system settings of automation first influence the desired time headway and speed choice, which in turn affect car-following behaviour, lane choice and lane changing behaviour. These are also assumed to incorporate the behaviour of manually driven vehicles and vehicles with differing levels of automation. Thereafter, the resulting driving behaviour is associated with free flow capacity, lane distribution and flow stability, which determine the effective capacity and capacity drop, and eventually vehicle loss hours. Based on naturalistic driving data (Schakel et al., 2016) analysed spacing, headway, speed, acceleration, lane use, and the number of lane changes, and compared these between ACC On and ACC Off in different traffic states. Results showed that with ACC On, average spacing and headways were larger, whereas standard deviations were smaller. The former can be assumed to reduce capacity, whereas the latter indicates more stable traffic. However, for strong accelerations, i.e. +/-0.5m/s^2, headways were smaller with ACC On than with ACC Off. On the one hand this indicates that ACC lacks anticipation but also indicates an increased queue discharge rate. Microscopic simulation results by Huisman (2016) confirm significant deterioration in traffic flow performance on a motorway segment, at on-ramps and weaving sections, as average speeds decrease, and average densities and delay time increase for increasing market penetration rates of ACC. Contrarily, effects are opposite and therefore much more promising for CACC. At capacity both ACC and CACC have a homogenizing effect which is a positive effect. Another study (Shladover et al., 2011) also concludes that ACC is unlikely to produce any significant change in capacity as headways are very similar if not larger compared to manual driving. Similarly, yet another experiment (Calvert et al., 2017) showed that any improvement in traffic flow will only be seen at penetration rates above 70%, while the capacity drop appeared to be slightly higher with the presence of ACC vehicles. In contrast, due to its higher dynamic response capabilities CACC has the potential to substantially increase motorway capacity. Lane capacity is estimated to increase approximately linearly from 2000 to 4000 as the percentage of CACC vehicles increases from zero to one hundred. There is no consensus concerning the optimal market penetration level for CACC, which ranges from less than 30% as concluded by Huisman (2016) up to moderate to high as found by Shladover et al. (2011).

Using a microscopic simulation framework, which includes car following models for regular vehicles with human drivers, communication-ready vehicles and automated vehicles, an adapted lane-changing model, and communication flow aspects, Mahmassani (2013) studied in great detail the impact of automated vehicles and connected vehicles on traffic flow and operations, especially in mixed traffic situations. Analysis of stability and throughput revealed that low market penetration rates of automated vehicles do not appear to result in significant stability improvements as opposed to connected vehicles which improve stability even at low market penetration rates. However, high market penetration rates of automated vehicles result in more stable traffic flows compared to similar rates of connected vehicles. Due to very low (0.1s) reaction time, automated vehicles are specifically good at dampen small perturbations and prevent shockwaves from propagating upstream at the onset of shockwave formation. At low penetration rates, the impact was minimal, but at high penetration rates substantial improvements were observed. Analysis of throughput showed that high market penetration rates of automated vehicles result in higher throughput compared to high market penetration rates of connected vehicles. Moreover, automated vehicles at a given market share exert a greater effect on throughput and produce less scatter in the fundamental diagram than the same share of connected vehicles. A theoretical and fundamental analysis also provided in the paper suggests that these technologies have the potential to improve the throughput by more than 100%. A slightly nuanced perspective is provided by Bierstedt et al. (2014), which conclude that capacity benefits are strongly dependent on how the performance of automated vehicles is programmed. With safety-conscious conservative programming, i.e. lower speeds and larger headways, densities and flow decrease therefore automated vehicles could at worst degrade motorway capacity. Simulation results reveal that only on freeways at a fleet mix of at least 75% automated vehicles and assuming performance is programmed at intermediate levels between conservative and aggressive, it is likely to achieve traffic flow benefits of 25-35%. Similarly, others (Atkins, 2016) implied the existence of a tipping point, i.e. the proportion of enhanced vehicles required before major benefits – up to 40% reduction of delay – are seen. Presumably this requires a market penetration level of automated vehicles of 50% and 75%. Aria et al. (2016) found largest improvements of density, average speed and travel time in the range of 9-10% for a market penetration level of automated vehicles of 100%. Moreover, the study revealed that the positive effects are especially highlighted with high traffic demand, which suggests that automated vehicles are most effective when traffic conditions are most challenging. This finding is confirmed by Atkins (2016), which also concludes that the impact of automated vehicles on delay, travel time and especially travel time reliability are largest with high demand.

Finally, Mahmassani (2016) discusses several control measures for improving the efficiency and quality of traffic flow. The first measure is the use of dedicated lanes for automated vehicles, similar to the concept of High Occupancy Vehicle (HOV) lanes and express lanes. Findings from a cited study Talebpour et al. (2017) indicate that out of three operational policies only optional use of the reserved lane without any limitation on the type of operation can improve congestion and traffic flow stability. By contrast, limiting automated vehicles to the reserved lane and preventing automated operation in regular lanes could significantly increase congestion as mandatory lane-changing manoeuvres of automated vehicles are the main source of shockwave formation. Also, the market penetration level of automated vehicles is a factor of importance as the study indicates that reserving one lane for automated vehicles is only beneficial at market shares above 30% for a four-lane motorway and 50% for a two-lane motorway. The second measure discussed by Mahmassani (2016) is speed harmonisation, which benefits from connected vehicle technology in two ways: 1) shockwave detection algorithms can identify flow breakdown earlier and more accurately, and 2) speed limits can be displayed to drivers in connected vehicle individually, thereby allowing a finer gradation and greater range for the effectiveness of the strategy. Simulation results confirm a higher flow rate and less significant speed drop but are subject to signal interference that causes information time lags. The third measure is intersection control for which three strategies are suggested: 1) Using data from connected vehicles to improve adaptive signal control operation, 2) Improving service rates through opportunistic coordinated platooning, and 3) eliminating signals altogether through individual trajectory coordination in a 100% connected environment.

To maintain a satisfactory safety ecosystem, Van Loon and Martens (2015) raised three issues related to the compatibility of partially or fully automated vehicles. The first issue is the ability of automated vehicles to anticipate the behaviour of other (manually driven) vehicles, defined as backwards compatibility. The main challenge here is the inability to externally measure unsafe driving behaviour. Surrogate measures like speed, longitudinal and lateral acceleration, and lane position might be used instead to predict upcoming changes in driving behaviour or upcoming safety-critical situations. The second issue is the ability of automated vehicles to exhibit human-like driving patterns to avoid unexpected disturbance of the safety ecosystem, which is referred to as forward compatibility. Addressing this issue requires a better understanding of what human drivers consider to be human-like behaviour and to what extend they are capable to distinguish this behaviour from other behaviour. The third and last issue is related to the acceptance of the behaviour of the automated vehicle and the compatibility of that behaviour with the expectations of the occupant. The authors stated that incompatible behaviour could potentially lead to discomfort with or even mistrust of the automated vehicle.

3.3 State-of-the-art traffic management

Autonomous vehicles will – by themselves – not solve traffic congestion. Even if all vehicles would become self-driving, then we would still need advanced control scenarios, both for intra- and intercity traffic. In this concise literature review, we present the state-of-the-art for traffic management procedures, giving attention to (i) general traffic management, (ii) coordinating CAVs, and (iii) artificial intelligence. For a more in-depth treatment of the subject, we refer the reader to D4.1 (Overview of Existing and Enhanced Traffic Management Procedures).

General traffic management

A new trend in traffic management is to not just look at single locations, but rather to use the entire network to distribute traffic more wisely and as such postpone or even prevent the formation of congestion. This ‘coordinated network-wide traffic management’ has been tested by Smits et al. (2016) in The Netherlands (Amsterdam), where they controlled a corridor section of the A10-West motorway. Going further, Birnie (2015) describes how regional traffic management implies a tighter coordination among different actors that are spatially separated. Tactically streamlining by coordinating road works, performing incident management, proposing alternative routes, ect. is then done via regional agreements and collaborating teams of operators and policy makers that exchange the necessary information. A promising way of turning traffic management into a very lean service is by means of KPIs, making the entire system performance-based, as explained by Quirijns and Rakic (2017). Finally, the paradigm of Traffic Management as a Service (TmaaS) goes beyond a simple in-car delivery of traffic-related information. The idea that traffic management can be furnished as a private service is quite unique. Actually, such a cloud-based system architecture provides the perfect means for almost one-on-one communication between individual road users and road operators.

Coordinating CAVs

The trend towards more cooperative systems is well-suited for enhanced traffic management. V2V and V2I allow to target vehicles individually, with them effectively becoming both sensors and actuators in a control system. In a broader setting, more and more countries are finding the way to enabling C-ITS on their major roads, albeit mostly in pilot trials as explained by van Waes and van der Vliet (2017), which will, in turn, facilitate the uptake of the so-called Day 1 and Day 1.5 services. With respect to the advice that a traffic management system may give to (fully) automated vehicles, the task of platooning provides a promising approach whereby vehicles are arranged in closely spaced groups, called platoons, having a single leader and a group of followers. In light of the transition towards more and fully automated vehicles, several questions need to be answered, e.g. as asked by Blyte: “*What is the remaining role for infrastructure?*”, “*How will traffic management evolve?*”, and “*How will these evolutions impact road safety?*”. The collaborative approach for automated vehicles is also high on the agenda for future traffic management systems. Shifting away from ‘each to their own’ autonomy becomes paramount in order to optimise road networks and take full advantage of the evolution towards full automation as described by Hart (2016).

Artificial intelligence

To conclude, we note that AI involvement in traffic control is typically centred around the study of ‘intelligent agents’ (optimisation), having the goal to mimic cognitive functions learning / problem solving. Machine learning techniques are widely adopted, albeit most of the time in a simulation setting rather than a real-life online system. Currently, AI is mostly found in traffic light control and congestion / queue length predictions. Traffic management by itself using AI is more rare to be encountered in a broader setting.

3.4 Motion planning and control algorithms for automated vehicles

The development of motion planning and control algorithms for automated vehicles plays a pivotal role in the evolution of automated driving. These algorithms ensure that the automated driving systems can safely and comfortably manoeuvre the AV to maximise traffic and energy efficiency. According to the VIAC project (Bertozzi et al., 2011) and Daimler with KIT (Ziegler et al., 2014), the primary layers of AVs control logic are perception, decision and control. AVs use on-board sensors to perceive the road environment in real-time to plan and control the vehicle motion, while Cooperative AVs (CAVs) fuse data from communication networks (connectivity with the infrastructure and other vehicles) into the information collected from on-board sensors to enhance situation awareness and enable cooperative manoeuvring with other road actors.

The decision layer of the AVs control architecture encompasses motion-planning techniques (Gonzalez et al., 2016). Motion planning techniques are categorised in global and local planning techniques (Kunchev et al., 2006) and have been developed based on methodologies mainly adopted from the field of mobile robotics. They estimate paths given vehicular dynamics, road geometry, obstacles and occasionally real-time traffic information. The existing methodologies proposed for motion planning are: graph search (Dijkstra Algorithm, A-Star Algorithm, State Lattices), sampling (Probabilistic Roadmap Method, Rapidly-exploring Random Tree), interpolating (Lines and Circles, Clothoid Curves, Polynomial Curves, Bézier Curves, Spline Curves), and numerical optimization (Function Optimization) (Katrakazas et al., 2015). Real-time motion planning is rather expensive in terms of computational efficiency on dynamic environments (urban roads) and this fact affects significantly road safety within the context of automated driving. V2X communications are expected to prolong the perception horizon and minimise perception uncertainties of AVs, thus facilitating the real-time estimation of paths that do not entail safety-critical situations.

On the lower control level, the lateral and longitudinal motion of AVs is dictated according to the vehicle controllers and their properties. Example vehicle controllers pertaining to the longitudinal motion of AVs are the Adaptive Cruise Control (ACC) (Kesting et al., 2008), and the Cooperative Adaptive Cruise Control (C-ACC) (Van Arem et al., 2006) systems. ACC systems that are currently available on the commercial market enable automatic following of a preceding vehicle by controlling the throttle and/or the brake actuators of the AV. As an extension to ACC functionality, the C-ACC systems are designed to exploit information provided by vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I) communication via wireless technology or ad-hoc networks. C-ACC systems offer high potential to further improve traffic safety and optimise traffic flow at road networks, since the CACC-equipped vehicles can follow their predecessors with higher accuracy, faster response to changes, and shorter time gaps (Milanes et al., 2014). The development of lane changing controllers for AVs has also received significant research attention. Wang et al. (2015) developed a predictive lane-changing controller that addresses tactical-level lane change decisions based on a game theoretic approach where controlled vehicles make decisions based on the expected behaviour of other vehicles. Discrete choice analysis, reachability analysis and model predictive control were used for the development of a lane change manoeuvre algorithm that determines if, when and how an AV can perform a lane-change. Latest studies focus on the development of vehicle controllers that can function efficiently under a wide spectrum of traffic conditions (Xiao et al., 2017).

3.5 State-of-the-art on use cases on automated driving

Different current and past research projects dealt with the topic of automated driving in different ways. As result, different use cases have been investigated. In the following, some examples are given.

3.5.1 AUTONET2030 project

AutoNet2030 is an EU FP7 project aimed to design, develop and validate cooperative automated driving technology based on a decentralised decision-making approach enabled by the mutual information sharing among nearby vehicles via V2X communications. For this purpose, the project decided to explore and demonstrate cooperative automated driving use cases under both motorway (e.g. cooperative manoeuvring in a convoy formed by a truck and an automated car; cooperative manoeuvring in a small convoy of mixed automated and non-automated cars) and urban environments (close-by car following and braking; cooperative manoeuvring for cars merging on the same road). In this context, AutoNet2030 experimented a system to realise cooperative decentralised control systems on fully-automated vehicles and execute advised manoeuvring on manually-driven vehicles. It proposed manoeuvring algorithms for leader-less convoys where participants run the same set of rules and use V2X to reach consensus (Marjovi et al., 2015; Navarro et al., 2016), as well as semi-distributed hierarchical control algorithms where a supervisor coordinates (via V2X) the rest of convoy vehicles (Qian et al., 2016; Qian et al., 2016). Finally, AutoNet2030 explored new cooperative manoeuvring use cases supported by customised V2X communication schemes (AutoNet2030, 2015; AutoNet2030, 2016; Qian et al., 2014). These include V2X for manoeuvre intentions/targets sharing, V2X to create and maintain convoys, V2X to perform lane changes, V2X communications for cooperative object perception and V2X for cooperative intersection control.

3.5.2 iGAME GCDC project

iGAME is an EU FP7 project aiming at promoting the introduction of cooperative automated driving by joint development and demonstrations. Development focuses mostly on environmental perception, actuation and interaction, wireless communication, guaranteed safety and mixed-traffic operation in a way to provide interoperable solutions among multi-vendor/developer systems. Demonstrations are addressed by proposing a challenge in which participants presents own implementation solutions that have to cooperate in the execution of predefined use cases. The three use cases defined are cooperative platoon merging on motorway, cooperative intersection crossing (approaching vehicles from different intersection approaches drive as they were in a virtual platoon) and emergency vehicle warning. The starting point for the definition and later implementation of the iGAME use cases is the specification of interaction protocols (iGAME, 2015-1; Kazerooni and Ploeg, 2015). Interaction protocols regulate the sequence of required manoeuvres to be executed by specific vehicles as well as the sequence of required message exchanged for that purpose (dedicated flowcharts are used). Each manoeuvre is decomposed in a set of automated functions/applications needed to support it (e.g. merging is supported by cooperative automatic cruise control, obstacle avoidance and lane changing). The common principle behind iGAME interaction is to adopt distributed decision making where each vehicle uses its local information to decide its relevant role during the execution of the use case.

iGAME also specifies a set of reference real time control mechanisms for the automated functions/applications needed to implement the above-mentioned manoeuvres. The specifications and simulation results of these mechanisms are provided in (iGAME, 2015-2). Of course, cooperative interaction is only possible via communications. For this purpose, iGAME specifies a set of V2X communication specifications (iGAME, 2015-3) that project participants have to respect for the implementation of the use cases. Along with certain communication performance requirements, these specifications rely on the plain use of the currently available ETSI ITS G5 communication stack (including geonet and basic transport protocols), excluding complex functionalities like multichannel operation and congestion control. In terms of message sets, iGAME specifies extensions of standard CAM messages, and defines a customised Cooperative Lane Change message to support the envisioned use case interactions and the signals needed for the in-vehicle control mechanisms (iGAME, 2015-4).

3.5.3 MAVEN project

The MAVEN project (Managing Automated Vehicles Enhances Network) aims to provide solutions for managing highly automated vehicles (HAV) at (urban) signalised intersections via V2X communications. It develops algorithms for infrastructure-assisted guidance of HAVs (possibly driving in small platoons) using C-ITS based-negotiation processes between vehicles and the infrastructure. HAVs receive advice and/or requests from the road infrastructure to adjust their trajectory and manoeuvring policies, while infrastructure dynamically adapts traffic light timing at single or multiple intersections. This bi-level optimisation is expected to contribute to maximising the economic benefit of traffic flow while reducing energy consumption and environmental impact as well as ensuring traffic safety. In this context the MAVEN use cases can be categorised in the following way (MAVEN, 2017; Vreeswijk et al., 2017):

1) Infrastructure to vehicle interactions: including V2X negotiation processes between cooperative automated vehicles and cooperative intersections, Lane change advices and lane-specific GLOSA advices
2) Signal optimization: including vehicle priority management, Queue length estimation, Local level routing and Network coordination – green wave
3) Platoon management: including V2V assisted Platoon initialisation, Joining a platoon, Travelling in a platoon, Leaving a platoon, Platoon break-up and Platoon termination mechanisms
4) Inclusion of non-cooperative road users: dealing with ADAS reactions on cooperative automated vehicles using local sensors and V2X collective perceptions
5) Emergency situations: including reactions to system failures or presence of emergency vehicles

3.5.4 IMAGinE project

The IMAGinE (Intelligent Maneuver Automation – cooperative hazard avoidance in real time) project [1] aims at developing innovative driving assistance systems for cooperative driving. Cooperative driving refers to road traffic behaviour in which road users cooperatively plan and execute driving manoeuvres via V2X communications. Through this approach, individual driving behaviour is coordinated with other road users using automatic information exchange between vehicles and infrastructure. In this way, critical situations can be avoided or mitigated, thereby making driving safer and more efficient. To achieve these goals, IMAGinE develops suitable cooperative functions and communications, defines a collective environmental model and adopts suitable HMI techniques. The investigated use cases range from cooperative merging on motorways, cooperative longitudinal control on motorways, cooperative overtaking on rural roads,

[1] https://imagine-online.de/en/cooperative-functions/

cooperative strategic traffic distribution, cooperative turning at junctions, up to cooperative overtaking by heavy-goods vehicles on motorways. These use cases will be tested in simulations and in prototype passenger cars and trucks on motorways and highways

3.5.5 interACT project

The objective of the interACT project is to enable the safe integration of Automated Vehicles into mixed traffic environments by developing solutions for safe, cooperative, and expectation-conforming interactions between the Automated Vehicle and both its on-board driver and other traffic participants (interACT, 2018). For the development of these solutions, methods for road users' intention assessment and prediction, as well as techniques for their communications and execution (including HMI) of these intentions will be delivered.

3.5.6 ADAS&ME project

The ADAS&ME project develops advanced driver assistance systems that consider the driver state and the situational and environmental context to automatically transfer control between the vehicle and the driver. The project aims to develop robust algorithms for monitoring the driver states such as fatigue, sleepiness, stress, inattention and impairing emotions considering also traffic and weather conditions received via V2X communication and personalising them to individual driver physiology and driving behaviour. The work is based on different uses cases that take into account the states of drivers of cars, trucks, buses and motorcycles and also different road topologies such as motorways, urban or mountains roads (ADAS&ME, 2017).

3.5.7 HAVEit project

HAVEit aimed to realise the long-term vision of highly automated driving for intelligent transport. The project developed, validated and demonstrated important intermediate steps towards this vision. HAVEit significantly contributed to increased traffic safety and efficiency for passenger cars, busses and trucks by developing and implementing a failure tolerant safe vehicle architecture and a new ADAS system with and optimised task repartition between the driver and the automated vehicle. The HAVEit project created different demonstrators such as an automated queue assistance, an automated assistance for road works and congestions, a temporary auto-pilot or an active green driving application. Those demonstrators are applied in different scenarios such us road works, lane change in motorways, emergency braking on motorways or traffic jams (HAVEit, 2008).

3.5.8 PAC-V2X project

At the time of writing, the PAC-V2X project[2] aims to increase the perception of cooperative vehicles in environments and situations that do not allow them to achieve a sufficient level of environmental perception to avoid collisions. The increase on the environmental perception will be achieved by cooperation between vehicles and RSU equipped with road sensors, such as cameras or radars, and positioned at strategic location to perceive the overall traffic environment. The project will implement different use cases focused on the collision avoidance, in particular the implemented use cases will be lane merge assist and lane change assistance in motorways, detection of vehicles in opposite directions, detection of vehicles ignoring traffic signals at intersections and also contextual speed advisory for scheduling traffic.

[2] https://project.inria.fr/pacv2x/

3.5.9 INFRAMIX project

The INFRAMIX aims to prepare the road infrastructure to support the transition period and the coexistence of conventional and automated vehicles. The main objective of the project is the design of both physical and digital elements of the road infrastructure to ensure a safe and efficient traffic. The key outcome will be a hybrid road infrastructure able to handle the transition period and be the bases for future developments. The INFRAMIX project will investigate novel signalling and visualization elements for conventional and automated vehicles, novel physical and digital segregation elements and new standards of automated vehicles. Three different scenarios are considered, a road works zone, dynamic lane assignment and bottlenecks in different situations, i.e. on-ramps, off-ramps, tunnels, bridges.

3.5.10 CoEXist project

The CoEXist project[3] aims at preparing the transition period during which conventional vehicles will coexist with automated vehicles on cities' roads. The objective of CoEXist is to increase the capacity of road authorities and other urban mobility stakeholders to be prepared for the transition towards a network with an increased number of automated vehicles sharing the road with conventional vehicles. CoEXist will test the developments of the project in four European cities (Helmond, Milton Keynes, Gothenburg and Stuttgart) considering different types of roads such as signalised intersections, transitions from interurban motorways to arterial roads, long-term construction works or waiting and drop-off areas for passengers.

3.5.11 BRAVE project

The BRAVE project considers that for a successful adoption of automated vehicles the technical aspects must be in compliance with other social aspects as user acceptance or legal and ethical considerations. The main objective of the BRAVE project is to improve safety and market adoption of automated vehicles by considering the needs and requirements of the users (BRAVE, 2018). The BRAVE project aims at developing innovative Human Machine Interface-paradigms and enhanced advanced driving assistance systems while guarantying the system robustness and reliability. The project specifies two different use cases involving Vulnerable Road User (VRU), one use case where the VRU drives parallel to the vehicles' trajectory and another where both trajectories cross at some point and therefore there is a risk of collision.

3.5.12 Collective Perception Use cases

Some of the reviewed projects use collective perception. Since TransAID will also use this concept, it is highlighted and explained in this section. Collective perception is a V2X service through which cooperative vehicles share the objects perceived by local perception sensors in form of abstract descriptions. This allows the implementation of use cases, like ADAS or automated driving, aiming at increasing safety by gaining an improved awareness of the local surrounding that goes beyond the sensing capabilities of a given cooperative automated vehicle or infrastructure station. For example, the concept of Collective perception for automotive applications has been introduced in (Mourllion et al., 2004) with focus on collision avoidance. Similarly, the AUTONET2030 project proposes a so-called Cooperative Sensing Message (CSM) (AutoNet2030, 2015) containing relevant data fields for the description of locally perceived objects. In (Günther et al., 2016), the

[3] COEXIST leaflet, https://www.h2020-coexist.eu/resources/

authors introduce a definition of the Environmental Perception Message (EPM) for exchanging sensor data and present an object fusion architecture. The fusion architecture abstracts the information achieved by individual sensors to create a list of detected objects represented in the same format, which increases sensor modularity and benefits applications. For safety reasons, the list is fused at two different levels: one to create a set of objects detected by local sensor only, and the other to create another set that also considers detections via V2X. Based on their criticality, ADAS applications can decide which of the two sets is considered. The proposed EPM includes, besides a list of detected objects and their characteristics, also a list of local sensors and their capabilities. The proposed approach is implemented and demonstrated on prototype vehicles, which shows the advantages of cooperative sensing in providing more time to receiving vehicles for reaction or trajectory re-planning.

4 Analysing aspects of transition of control

As explained in Chapter 0, the goal of TransAID is to gain insight into measures that mitigate the (possible) negative impact of passive and mandatory Transition of Control (ToC) in each type of automated vehicle (AVs and CAVs) on traffic flow, efficiency and/or safety in Transition Areas. To reach that goal, situations in which a ToC causes a problem for traffic need to be identified and studied.

To do that, literature was reviewed (see previous chapter), a workshop was organised (see Appendix A), advisory board (AB) members were consulted, and experts were interviewed. Based on the information gathered, the following considerations can be done. Why, when, and where exactly ToC is triggered and how, where, and when it disturbs the traffic flow and/or decreases traffic safety depends on, in general, three factors: the **environment**, the **automated driving (AD) functions** and the **ToC process**. Below, in Figure 5, the relations between these three factors are shown.

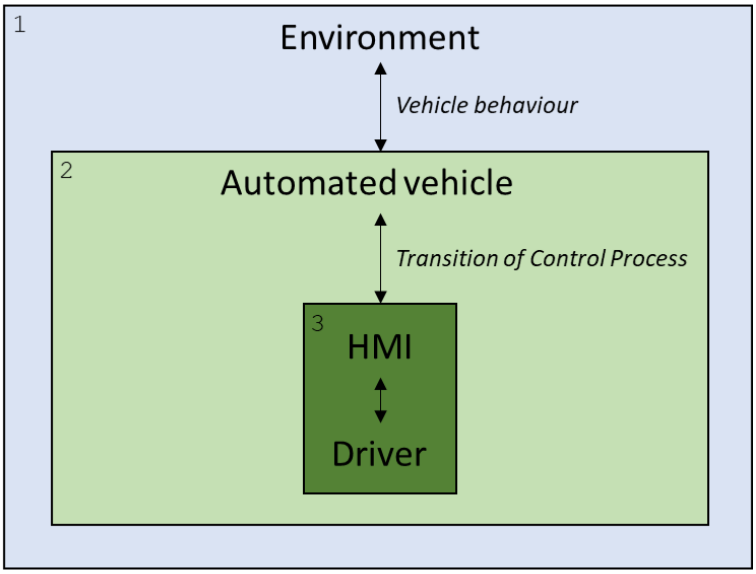


Figure 5: Interrelation of triggering conditions for ToC.

These factors together form the triggering conditions for down- or upward ToC and determine the effects of ToC. TransAID evaluates measures to mitigate negative effects of ToC by comparing situations with and without those measures in terms of the key performance indicators (KPIs) described in Chapter 6. The factors are thus relevant for identifying possible use cases, defining ToC scenarios and, also for evaluating the impact of TransAID measures in those use cases and scenarios.

First, the factors will be described together with how they determine pre- and post-conditions for ToC. Next, ToC aspects are identified at a more generic level, mostly from the perspective of the vehicle. Finally, it is explained how these gained insights are combined in a template used to identify TransAID situations and use cases.

4.1 Three factors

4.1.1 Environment

The environment is defined as everything that surrounds the automated vehicles and is thus outside the system boundary (indicated as area 1 in Figure 5). Each change in the environment can change the vehicle behaviour and vice versa. The environment contains static, semi-static and dynamic elements.

The **static** elements consist of the infrastructure layout (i.e. number of lanes, intersections, merging areas, bus lanes, crosswalks, road markings, road furniture, etc.) and the elements not being part of the road infrastructure and sometimes representing obstacles limiting the sensing capabilities of automated vehicles (i.e. buildings, trees, foliage, etc.).

The **dynamic** elements consist of surrounding vehicle types, vulnerable road users (e.g. pedestrians, bicyclists), weather conditions like rain, snow, or mist and dynamic traffic management elements like traffic lights, variable message sign (VMS) images, and connected and/or cooperative messages from infrastructure, service providers, and other vehicles.

Finally, the **semi-static** elements consist of temporary elements, for example, used for road works (e.g. pylons, truck mounted attenuators, yellow markings, barriers, additional traffic signs, etc.) or damaged infrastructure (e.g. pothole, bad road surface) that is usually repaired within days.

As said, all the elements described above will influence vehicle behaviour. As a result, these elements, and any combination of them, might trigger a ToC. However, the exact behaviour might depend on the automated vehicle type: while in some situations an automated vehicle might require a downward ToC when approaching traffic lights, this might not be the case for others. In addition, there can be another group of vehicles that only need a ToC when approaching a traffic light without cooperative messages. The other way around can also be true: some vehicles might perform upward ToCs in the presence of cooperative messages, while others do not.

Besides these environmental factors, why, where, and when exactly ToC occurs also largely depends on the automated driving functions as explained below.

4.1.2 Automated driving functions

How a vehicle reacts to the environment depends on the exact implementation of the automated driving (AD) functions (indicated as area 2 in Figure 5). In general, the AD functions determine the SAE level of driving automation (level 0, no automation to 5, full automation; see Chapter 2 and SAE International, J3016 (2016)). This level describes the vehicle’s high-level capabilities (e.g. automated steering, accelerating/braking, lane change capability, etc.

All levels, except level 5, include situations where the driver must take over the driving task from the AD system, but the parameters of these situations can be very different. For example, a level 4 vehicle might be able to cope with a road works scenario, while a level 3 vehicle might not. Also, vehicles that are capable of level 4 might shift up from level 3 to 4 when environmental conditions relax.

Besides the high-level SAE classification, the details of the **AD functions** also impact the triggering conditions for a ToC and its effects. This impact is two-fold. On the one hand, the details determine the exact conditions prior to a ToC and thus the triggering conditions, and on the other they determine the traffic situation after a ToC.

To explain: the implemented driving distance, maximum lateral displacement with respect to lane markings, minimum/maximum acceleration and braking capability all determine the vehicle behaviour on the micro-level. Thus, vehicles that have higher braking and lateral displacement capabilities might not need a downward ToC in critical situations where the vehicle must react immediately. Contrary, those with more limited capabilities would require a ToC or MRM. Even if both types of vehicles would need a downward ToC, the resulting post-ToC traffic situations can be very different because of applying different AD parameters. Depending on this, some vehicles might execute a downward ToC and some others not.

Moreover, AD functions can also just **fail**. They can fail partly or completely, hardware- or software- wise, and cause a fall back in the level of driving automation or transition control back to the driver entirely. The way the vehicle handles such failures in terms of human-machine interaction and minimum risk manoeuvres obviously impacts the ToC process. Also, the type of failure can result in different actions. For example, a defect sensor can lower the reliability of the AD functions somewhat, but still allow the vehicle to manoeuvre to a more suitable position before starting a ToC, while a complete failure of one of the core functions (bug, crash, chip failure, etc.) does not.

Note that TransAID focusses on transition areas where multiple ToCs occur. Hence, ToC because of complete AD system breakdowns, and other unlikely and sporadic malfunctions are generally not in scope. For this reason, only system breakdowns that affect multiple vehicles (e.g. RSU failure, environmental factor causing sensor disturbance) are in scope.

In the end, as described in the next paragraph, what exactly happens during a ToC depends on the implementation of the ToC procedure when giving control back to – and taking control from the driver.

4.1.3 Transition of Control Process

The ToC process (indicated as area 3 in Figure 5) implies interactions between the system and the driver during an upward or downward ToC. This process is important, because during the interactions, it is expected that the **driving behaviour of the car will change** and thus impact its environment (e.g. other cars and traffic monitoring sensors). Because of this change, traffic flow and/or traffic safety might improve or deteriorate. How exactly the behaviour of the vehicle changes depends on several aspects.

One of these aspects is the **Human Machine Interface (HMI)** design. For ToC the most important part of the HMI are the elements (i.e. signals and controls, e.g. turning AD on/off or perhaps adjust parameters like headway) that relate to automated driving functions, but other more common elements (from controls on the steering wheel to head-up displays) can be relevant as well. How exactly the vehicle signals the driver that attention is needed can differ from vehicle to vehicle and can impact the **duration** of the entire ToC process (Petermeijer, Cieler, & de Winter, 2017). Also, the **fluidity** of the ToC depends on, whether the ToC is implemented at once or stepwise. For example, the vehicle might first give back steering control and after a few seconds signal that acceleration control is to be taken over as well.

Another aspect is the **Human Factor (HF)**. Many studies have been done on how people respond to ToC, specifically in relation to the HMI. The most challenging situation is probably a level 3 driving automation vehicle (Gold, Naujoks, Radlmayr, Bellem, & Jarosch, 2017). At that level, most of the driving functions are performed by the vehicle and the vehicle monitors the Driving Environment, but the driver is expected to respond at any moment, if required. Since, by definition, the driver is not required to monitor the Driving Environment at level 3, situation awareness is very low. It will require some time before the driver is ready to take over control, but that is only possible if time allows. Therefore, how exactly the vehicle behaves during a ToC from level 3 downwards, depends largely on the prediction capabilities of the vehicle and on the capabilities/skills and level of arousal (alertness, attention level and information processing) of the driver. Since the driver must process the state of the environment, that state is of importance as well (Gold, Körber, Lechner, & Bengler, 2016). The point just made, obviously holds for downward ToC from any level. In general, the higher the level of driving automation, the higher the engagement of the driver in secondary tasks (Naujoks, Purucker, & Neukum, 2016). This might negatively impact the driver’s situation awareness and level of arousal.

Another typical HF example is when the vehicle detects that driver is no longer responsive or attentive. In such a situation the AD system must conclude the driver is unable to take over control when required (level 1 – 4), and thus try to alert the driver. As highlighted in Chapter 2, in absence of a timely response, the AD system must perform a MRM. The other way around is also possible: the driver notices/expects that the vehicle is underperforming on the driving task and decides to take over.

The last aspect is the exact **implementation of the driving when the automation level changes**. Not much can be found on how different vehicles implement level change functions. This will be dependent on specific implementations of different OEMs, which leaves many questions open. For example, does the vehicle allow any change to the active vehicle functions, including changes which affect the required driver attention, like from level 4 functions to level 2 functions? Exactly what attention is required from the driver at certain levels of driving automation? Is a level change allowed that also changes the required driver attention? Can the vehicle change levels in both directions without acknowledgement? Depending on the answers to such questions, the exact vehicle behaviour during ToC can differ.

Besides these higher design choices, the **detailed parameters of ToC functions** also can result in different driving behaviour. For example, how much headway is planned prior to ToC, does the vehicle first move to a more suitable position?

4.1.4 Considerations

As already mentioned in the previous subsections, all the aforementioned factors will vary according to the AD levels supported in a given vehicle and on specific AD implementations from different OEM manufacturers. This implies that TransAID must thoroughly specify the capabilities of distinct categories of automated vehicles in the situations and scenarios considered in the project. This definition work, done in Task T2.2 and extending in WP3, will limit the scope of the AD modelling, and enable an unambiguous interpretation of the TransAID investigations result. A first categorisation of vehicles has already been done in Chapter 2 and is used in the descriptions of services and use cases in Chapter 5.

4.2 AD Disturbances and countermeasures

From the three factors it is now clear that identifying the details which exactly trigger a ToC or MRM and the possible impact is a complex task. It is therefore useful to also look to the triggers or causes for ToC on a more general level as an intermediary step.

When looking at what is needed to keep driving automated, a set of generic capabilities can be identified. If any of these capabilities is compromised, that generates a possible cause for ToC. The disturbance that compromises one of the generic AD capabilities potentially results in a transition area. Given the goal of the automated vehicle (driving to a wanted destination), the generic automated driving capabilities are:

1. The vehicle needs to be aware of its environment by sensing its surroundings.
2. The vehicle needs to determine action(s)
3. The vehicle needs to perform the action(s).

If all these capabilities are supported, associated automated tasks are executed and eventually the goal is reached. However, each of these capabilities can be disturbed by the following three disturbance types:

1. Environmental disturbance: the vehicle knows what to do but cannot sufficiently sense the environment. Examples of these disturbances are: *sensor malfunction, sensor interference (e.g. bad weather), low or sub-optimal quality of road infrastructure (absent or poor markings, temporary markings in addition to pre-existing markings at road works areas), etc.*
2. Action determination disturbance: the vehicle can sense its environment but does not know how to or which action(s) to take to achieve its goal. Examples of these disturbances are: *exiting the motorway while deceleration lane is blocked by queue, changing lane before intersection when target lane is blocked by queue, target road is blocked and traffic laws need to be broken, how to give way when an emergency vehicle approaches, which way to drive when encountering unknown/new infrastructure etc.*
3. Execution disturbance: the vehicle knows which actions to take but is incapable of executing them or cannot rely on the driver (i.e. the driving system, vehicle & driver, does not respond). Examples of these disturbances are: *ice on road/black ice, malfunction in vehicle (steering, braking, acceleration), unresponsive driver, etc.*

To identify situations that result in transition areas, one can look for scenarios where these kinds of disturbances occur more frequently. In addition, suitable measures that mitigate the mentioned disturbance types can be identified as follows:

1. Provide environmental information. Examples of this information are: *digital map, position of other vehicles/objects/vulnerable road users, etc.*
2. Determine action (i.e. enable an action or suggest a different action). For example: *instruct vehicles in a queued lane to leave a gap for the vehicle that has that lane a its target lane, instruct the vehicle to move to end of the queued lane, suggest to cross a continuous line, , instruct to move to the rightmost lane to give way to emergency vehicle, suggest to take the left lane to reach the destination, etc.*
3. Manage the environment. In this case, not much can be done for the vehicle or driver itself, but from a traffic management perspective, warnings or actions for the other vehicles can be provided to minimise the impact of the incapacitated vehicle. For example: *sending warnings from a vehicle performing a MRM to other vehicles directly from the incapacitated vehicle and via road side infrastructure.*

To summarise, the provided disturbances provide a first insight into which situations potentially result in transitions areas and a rough indication of how to cope with unintended ToCs in automated vehicles.

4.2.1 Solution implementation

Based on the aforementioned ToC factors, AD disturbances and possible countermeasures, the TransAID partners started to define initial transition area situations and propose suitable solutions. The following attributes were adopted:

1. Specific disturbance and applicable situation:
   E.g. automated vehicle needs to leave the motorway, but the target deceleration lane is occupied by queued vehicle. The vehicle does not know where/when to merge and ask the driver to take over control of the vehicle (ToC). This is a clear example of action determination disturbance in a specific situation.
2. Solution category, in line with the aforementioned countermeasures (provide environmental information, determine action, manage environment):
   E.g. in the above-mentioned situation, the ToC in the merging automated vehicle can create dangerous situations if the driver is not responding. The merging vehicle can be a risk for

the oncoming vehicles downstream as well as block the traffic and hence deteriorate the traffic flow. To cope with this situation, determining the action for the automated vehicle to effectively merge without a ToC is needed.

3. Main goal:
   E.g. in the example, preventing the ToC by create a gap in a queue so that the vehicle can automatically merge in it.
4. Measures:
   E.g. the road infrastructure requests vehicles in queue to slow down/stop, upstream vehicles in queue to keep moving, and the merging vehicle to move to the gap.
5. Implementation of measures:
   E.g. depending on the specific situation (in this case type of involved vehicles), several means can be used such as: C-ITS messages, VMS messages, traffic laws, road signs, etc.

Through this exercise, it became clear that how exactly a solution mitigates the negative impact of a ToC depends on the specific situation. However, from all the identified transition area situations and proposed solutions, it was found that in the end each solution has one of following three aims:

1. Prevent ToC/MRM.
   The road infrastructure suggests a given traffic management policy for automated vehicles to maintain their automated driving state. As a result, the traffic flow is undisturbed.
2. Manage or support ToC/ MRM.
   In some situations, a ToC/MRM might not be preventable and there is no time or space to do it elsewhere. The ToC/MRM can be managed by the road infrastructure (e.g. indicate to the target automated vehicle to finish an MRM at a safe spot) and supported (e.g. inform surrounding vehicles to give way).
3. Distribute (in time and space) ToC/MRM.
   In situations where the problem is predictable, but despite the predictability ToC/MRM cannot be prevented, it is best for the road infrastructure request for phasing ToC/MRM. That way, not all vehicles perform a ToC/MRM at the same time at the same place, but sequentially and distributed along the road, thereby minimizing the impact.

To reach these aims, solutions need to contain certain traffic management measures that result in the desired behaviour of all involved actors (i.e. CAV, AV, CV, LV, RSI, etc.).

4.3 Finding TransAID use cases

The aforementioned work on identification of transition area situations and possible solutions was used as a preliminary step to determine a list of representative use cases suitable for TransAID studies.

As pointed out in Sections 4.1 and 4.2, causes for ToC or MRM can be found in several factors (i.e. environment, AD functions, transition of control processes) and can be based on any of the mentioned AD disturbances. Moreover, any combination of factors might trigger a ToC as well. Since any combination can result in different pre- and post-conditions suitable for investigation, in theory any combination should be considered as a separate use case. Nevertheless, such an approach would result in too many use cases to study. This, in addition to the many variable aspects to consider for each of the factors (e.g. OEM-specific implementation of AD and ToC functions, human behaviour in unprecedented situations, etc.) posed clear challenges for the use cases determination.

To tackle this challenge an abstraction method was introduced to define the problems that cause a ToC/MRM. This method was then combined with the three factors and solution categories introduced above. This combination resulted in the relevant aspects considered by the TransAID partners as parameters to identify use cases and define their properties.

4.3.1 Problems (i.e. causes)

Below the abstraction of problems is described. It identifies relevant aspects and ways problems (or causes) relate to transition areas. These problem aspects directly relate to possible solutions and measures. For example, the predictability of a problem either means one can prepare for it or not.

In TransAID the following cause properties are defined:

- Location type
    - Fixed
        - Predictable
        - Unpredictable
    - Random
        - One-off/incidental, short term (i.e. seconds)
        - Stationary for long term (i.e. minutes, hours)
- Affection range
  The type and size of an area where ToCs might occur (e.g. one spot, trajectory, area)
- Cause duration
  How long a cause for ToCs persists (e.g. seconds, minutes, hours, days, longer than days)
- ToC urgency
  Whether cause requires an immediate ToC or if there is some more time (e.g. several minutes for ToC, … anything in between…, ToC now!)
- Share of vehicles impacted by the cause per SAE level
  e.g. 75% level 2 vehicles impacted and 25% level 3 vehicles.

4.3.2 Scenario variables

Two important aspects for the use case identification are now defined: solutions (see Section 4.2.1) and problems with causes (previous paragraph). In addition to these, the scenario variables need to be considered. Depending on the properties of the ToC/MRM cause and the designed solution, several scenarios are possible in which the problem arises, and the solution is applied. These scenario variables can be mapped to the three factors introduced in Section 4.1:

- Environment (see Section 4.1.1)
    - Static
      road network
    - Dynamic
      traffic composition and condition
    - Semi-static
      presence of road works, closed lanes, accidents, damaged road surface, etc.
- Automated driving functions (see Section 4.1.2)
    - AD functions
      parameters of automated driving like headway, acceleration, etc.
    - MRM implementation
- Transition of control process (see Section 4.1.3)
    - Duration of ToC process
    - Implementation
      phased vs. instantaneous (e.g. first steering and then acceleration vs. both at the same time)

    - Vehicle behaviour during ToC
      lateral movement variation, speed variation, etc.

4.3.3 Relevant aspects for use cases identification

At this point all the ingredients needed to be considered for use case identification are available. Combining Sections 4.2.1 Solution implementation, 4.3.1 Problems (i.e. causes) and 4.3.2 Scenario variables, these are:

1. Main goal
   e.g. create a gap in a queue
   a. Background (rationale behind the goal)
2. Involved actors (i.e. involved entities)
3. Measures
   e.g. vehicles in queue slow down/stop, upstream vehicles in queue keep moving, approaching CAV slows down and moves to the soon to be gap
   a. Implementation of measures (C-ITS messages, VMS messages, V2V display, traffic laws, road signs, etc.).
4. Problems (i.e. causes)
   a. Location type
      i. Fixed
         1. Predictable
         2. Unpredictable
      ii. Random
         1. One-off/incidental, short term (i.e. seconds)
         2. Stationary for long term (i.e. minutes, hours)
   b. Affection range
      The type and size of an area where ToCs might occur (e.g. one spot, trajectory, area)
   c. Cause duration
      How long a cause for ToCs persists (e.g. seconds, minutes, hours, days, longer than days)
   d. ToC urgency
      Whether cause requires an immediate ToC or if there is some more time (e.g. several minutes for ToC, … anything in between…, ToC now!)
   e. Share of vehicles impacted by the cause per SAE level
      i. e.g. 75% level 2 vehicles impacted and 25% level 3 vehicles.
5. Scenario variables
   a. Environment (see Section 4.1.1)
      i. Static
         1. road network
      ii. Dynamic
         1. traffic composition and condition
      iii. Semi-static
         1. presence of road works, closed lanes, accidents, damaged road surface, etc.
   b. Automated driving functions (see Section 4.1.2)
      i. AD functions
         1. parameters of automated driving like headway, acceleration, etc.
      ii. MRM implementation
   c. Transition of control process (see Section 4.1.3)
      i. Duration of ToC process

   ii. Implementation
   phased vs. instantaneous (e.g. first steering and then acceleration vs. both at the same time)
   iii. Vehicle behaviour during ToC
   lateral movement variation, speed variation, etc.
6. Expected impact without measures.
7. Expected impact with measures.
8. Possible V2X solutions and requirements
9. Possible implementation feasibility in real world prototypes

4.3.4 Use cases proposal and consolidation

As stated before, these aspects were collected in a template and used by the TransAID partners to provide individual use case proposals. These proposals were cross-checked via expert interviews and shared in the TransAID consortium where they were used to establish a discussion about their suitability and meaningfulness from a traffic management and/or OEM points of view as well as for justifying their adoption to fulfil the research objectives of individual partners and work packages.

A rating process was adopted to identify the most suitable and interesting use cases. After that, consolidation work was initiated to eliminate observed overlap between some of the proposed use cases. In fact, it was identified that situations described in certain use cases could be solved by the measures described in other use cases. It was observed that the resulting use cases could be grouped in use cases categories associated with common measures. Five “services” defined as use case categories were identified. These services and the associated use cases are presented in the next chapter.

5 Services & use cases

As explained at the end of the previous section, the use case identification work led to the definition of five services defined as use cases categories characterised by the use of a common set of measures. In this chapter these services as well as the associated selected use cases will be presented.

The next subsection will provide the needed definitions for the correct understanding of services and use cases. For the description of such services, the very detailed list of relevant aspects presented in Section 4.3.3 is too specific and not suitable. A simplified use case description template, also used as a basis in several other projects (e.g. MAVEN, InterCor), is used instead and presented in the next subsection.

5.1 Global perspective / definitions

In the definitions of services and use cases in Section 5.3, the following terminology is adopted:

Service: clustering of use cases based on a common denominator, for example being an objective like prevent ToC through a certain type of measure or a context like road works.

Use case: function of the TransAID system, the desired behaviour (of the system and actors), and specification of system boundaries and definition of one or more usage scenarios.

Scenario: describes temporal development in a sequence of situations (e.g. initial and after) based on events and actions. It is story telling.

Situation: describes relevant scenery (everything within a static snapshot) considering (driving) function-related goals and values.

Actors: are the entities (sub-systems) that interact with the TransAID system as listed in Chapter 2. The system affects and is affected by the behaviour of actors; therefore, these relations are described in the use case descriptions.

Two templates are used: one for the description of the service and another for the description of the selected use cases within a given service. For the service, the template contains the following items:

Service introduction	
Summary	Provides a short summary of the service.
Background	Describes the motivation/rationale of the service.
Objective	Describes the intended outcome of the service.
Expected benefits	Describes the added value and actor benefits of the service.
Notable case variables	Describes the most notable variables for use cases based on Sections 4.3.1 and 4.3.2.
Selected use cases	Gives a list of selected use cases – for each listed use case a use case description is provided.

For the selected use cases, the following template is adopted, which is a combination of use case introduction and use case description

Use case introduction	
Summary	Provides a short summary of the use case.
Background	Describes the motivation/rationale of the use case.
Objective	Describes the intended outcome of the use case.
Desired behaviour	Describes the behaviour of the system and the intended behaviour of actors.
Expected benefits	Describes the added value and actor benefits.

Use case description	
Situation(s)	Describes one or more situations relevant to the use case, typically a road configuration.
Actors and relations	Lists all relevant actors/sub-systems and their relation/interaction to the system and their role in the use case (incl. sender and receiver). The actors are based on those described in Chapter 2.
Scenario(s)	Describes the story of the use case based on a sequence of situations (e.g. initial and after), events and actions. It provides explanatory illustrations. Sender and receiver should be addressed, in stakeholder neutral manner.
Functional constraints / dependencies	Describes functional constraints and dependencies that are requirements (if any) related to the use case (e.g. system / actor capabilities, expected behaviour).

5.2 Defined services and use cases

As a result from the procedure described in Section 4.3.4, five services were identified. The titles and summaries of these services are listed below for overview purposes. The full descriptions can be found in sections unterhalb.

1. Prevent ToC/MRM by providing vehicle path information
   To prevent ToCs/MRMs, detailed information is provided about the path a CAV should take.
2. Prevent ToC/MRM by providing speed, headway and/or lane advice
   This service provides speed, headway and/or lane advice to vehicles to prevent the initiation of ToC/MRM due to complex traffic situations emerging from either planned or unpredictable events.
3. Prevent ToC/MRM by traffic seperation

Different vehicle types (CAV, AV, CV, LV) are separated by giving lane advice per type before critical situations. Vehicle interactions are reduced to reduce the chance of ToCs/MRMs and thus prevent those.

4. Manage MRM by guidance to safe spot
In case a vehicle is going to perform a MRM, infrastructure helps by providing detailed information about possible safe stops.
5. Distribute ToC/MRM by scheduling ToCs
Whenever multiple ToCs need to be executed in the same area, this service distributes them in time and space to avoid collective ToCs and possibly MRMs in a small area.

As one can see the first three services focus on preventing ToC/MRM by providing specific actions or harmonising traffic to support collaboration between vehicles and/or limit vehicle interactions.

The fourth service is a bit different from the other services in that it assumes an MRM needs to be performed around a transition area without going into why or how exactly. To limit the impact of the MRM, the service aims to guide the MRM performing vehicle to a safe spot instead of just stopping on the lane it is driving. It therefore is like another layer on top of the other services in case a ToC could not be prevented and a MRM needs to be executed. It is the intention to combine this service with the others at some point in the project.

The fifth service, schedule ToCs before or after transition areas is quite generic. To prevent issues due to collective ToCs/MRMs around transition areas, ToCs can be prevented, but this service aims to spread out those ToCs (and possibly MRMs) in space and time. Given there is enough space and time to do so, the service can be applied to many of the situations described in the other services as well. Also, this is the only service that aims to mitigate possible negative effects due to collective upward transitions. Managing those upward transitions can be applied to any situation where there was no automated driving (due to e.g. geo-fencing, factors limiting AD functions, traffic laws, etc.) and afterward automated driving is possible (e.g. entering motorways, exiting a geo-fence, etc.).

Within the five services the use cases below were selected. The full descriptions for these use cases can be found in Section 5.3.

Service 1
1.1 Provide path around road works via bus lane
1.2 Provide path around stopped vehicle via bus lane
1.3 Provide path to end of queue on motorway exit
Service 2
2.1 Prevent ToC/MRM at motorway merge segments
2.2 Prevent ToC/MRM at motorway merge segments (CAV Platoon)
2.3 Intersection handling due to incident
2.4 Intersection handling due to road works
Service 3
3.1 Apply traffic separation before motorway merging/diverging
3.2 Apply traffic separation before motorway on-ramp
3.3 Apply traffic separation before roadworks areas

Service 4
4.1 Safe spot outside carriageway
4.2 Safe spot in lane of blockage
Service 5
5.1 Schedule ToCs before no AD zone
5.2 Schedule ToCs after no AD zone

5.2.1 Variables and TransAID scope

In the introduction of Section 4.3 it was explained that there are many aspects/variables regarding transition of control or transition areas which can be of relevance to the TransAID project. Not all combinations of those variables can be studied, thus a specific approach is chosen.

The use cases were selected through collaboration between the TransAID partners based on specific interests and relevance to road operators. Many other use cases are possible within each of the five services. One can, for example, easily choose an alternative road configuration (e.g. 3 lanes instead of 2, different intersections, etc.) as a situation in the described use cases. Such ‘generic’ variables (e.g. Environment, Section 4.1.1 and Causes, Section 4.3.1) together determine the situations to which the services can be applied. For some services, very specific variables (e.g. type of safe spot for Service 5) can be identified. If that is the case, such variables are noted in the ‘Notable use case variables’ field in the service description.

It is important to note that TransAID focusses on transition areas where multiple ToCs occur. Hence, ToC because of complete AD system breakdowns, and other unlikely and sporadic malfunctions or events are generally not in scope. For this reason, only system breakdowns that affect multiple vehicles (e.g. RSU failure, accidents, environmental factor causing sensor disturbance) are in scope. In addition, because TransAID aims at mitigating situations where automated vehicles would collectively change their level of control, situations where they (explicitly) might crash are not in focus. However, due to the generic characteristics of the five TransAID services, those services could be applied to situations where automated vehicles are in danger of crashing as well.

Since TransAID has two iterations in which use cases are worked out, the first iteration is planned to focus on the simpler use cases presented here. The selection of those use cases will be done in Deliverable 2.2. In the second iteration, based on the insights gained from the first iteration and the remaining use cases, the use case set will be updated, and a new selection to study, possibly through combining use cases, will be made. In this way many combinations of the mentioned ‘generic’ variables are considered.

The other variables, namely included actors, AD parameters, ToC parameters, MRM implementation, vehicle mix/composition, are considered simulation variables. That means, based on work done in D2.2 and other work packages, values for those variables are determined and several simulations are run with different combinations of those values. That way, insights are gained into the impact of those variables on the effectiveness of the services.

Variables such as HMI design, detailed human factors (e.g. arousal level), day and night conditions are considered out of scope for TransAID. The ‘weather’ variable is only considered as a possible cause for ToCs, but not as an additional scenario variable (e.g. scenario with road works and sunshine and another but with rain).

The implementation of measures was also considered a variable in Section 4.3.3. For this document, the focus is on measures for CAVs and where applicable for CAV Platoons and/or CVs. Through a preliminary description of the implementation of these measures and the described desired behaviour in the use cases, it is explained how the services should work. In WP4 and WP5, the measures will be worked out in more detail. That means, the described measures will be elaborated (WP4) and supported by V2X and I2X communication protocols (WP5). Also, the descriptions of the 'Actors and relations' use 'supportive measures' for the other actors. Those are also to be designed in WP4 (e.g. VMS, lights on CAV informing non-cooperative vehicles, and supportive messages to CVs).

Finally, regarding the measures, the focus of the use cases is mostly on infrastructure assisted measures with centrally coordinated advices and/or requests. That does not mean that for the design of the detailed measures (in WP4) a more distributed approach, with more intelligence in the (connected) vehicles is excluded. In addition, traffic management policies could be supported by V2V communications for coordinating the manoeuvres of the vehicles. For example, the infrastructure could provide vehicles with high-level advices about the lane recommended, vehicles could locally coordinate with each other for a lane change using V2V.

Below the full descriptions of the services and use cases is given.

5.3 Service and use case descriptions

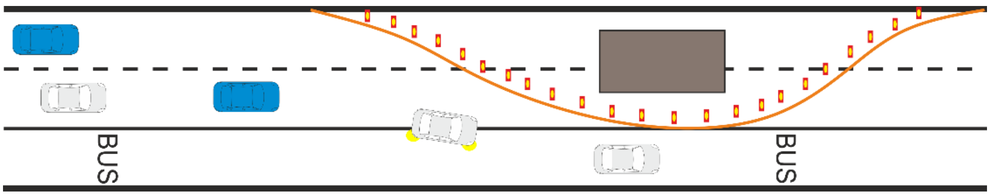
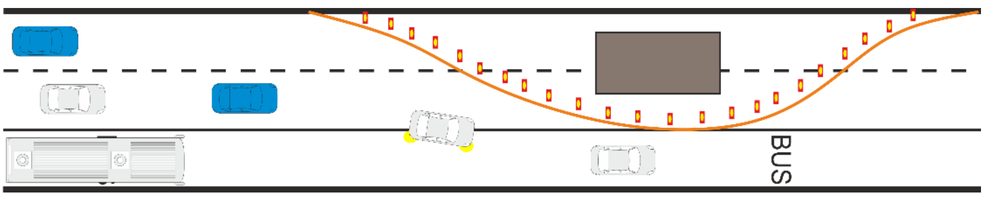
5.3.1 Service 1: Prevent ToC/MRM by providing vehicle path information

Service introduction	
Summary	To prevent ToCs/MRMs, detailed information is provided about the path a CAV should take.
Background	In situations where CAVs would be unable to continue driving because it does not know where to drive, it needs information about what path to take. RSI can help the CAVs by providing path information. That way, CAVs can, for example, temporarily break traffic laws and circumvent obstacles by driving across a bus lane, bicycle lane or side walk. The path along which the CAVs should drive is provided explicitly.
Objective	Prevent the CAVs performing a ToC/MRM and enable the CAVs to pass the problematic situation and continue driving.
Expected benefits	The CAVs will be able to continue driving without having to perform a ToC/MRM. As a result, the driver will not have to intervene. Other vehicles will not be impacted by potentially stopped vehicles or changing behaviour because of ToCs in CAVs. Traffic flow as a whole can maintain a higher service level and safety is increased because CAVs can drive smoothly following the general traffic flow.
Notable use case variables	This service provides a path to CAVs in case the vehicle does not know where to drive. Most common situations are those where there is a blockage

	and the vehicle needs to drive across an area normally not allowed for driving (i.e. restricted area, see below). The following variability occurs: 1) Type of blockage: The type of blockage impacts the type of measures and functional requirements / constraints. For example, a sudden blockage because of an accident, breakdown or queue is unpredictable, whereas road works are predictable, and measures can be prepared. 2) Type of restricted area: When the normal road is fully blocked there might be a path around the blockage across a restricted area (e.g. emergency lane, bus lane, bicycle lane or sidewalk).
Selected use cases	1.1 Provide path around road works via bus lane 1.2 Provide path around stopped vehicle via bus lane 1.3 Provide path to end of queue on motorway exit

Use case 1.1: Provide path around road works via bus lane

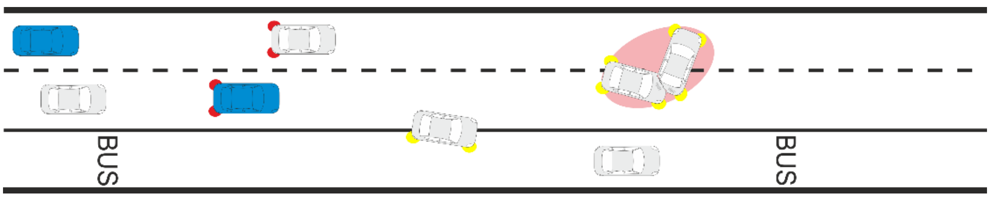
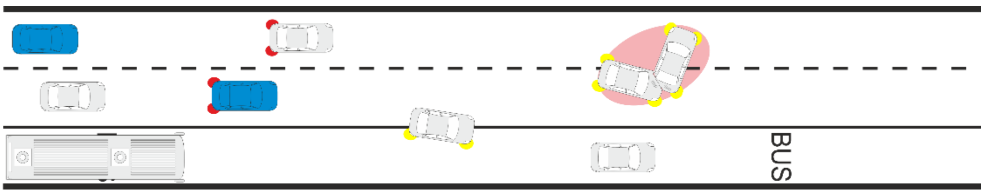
Use case introduction	
Summary	In preparation of the road works a path around it is prepared. That path is distributed by the RSI to approaching CAVs. CAVs receive, process, and follow that path. ToCs/MRMs are prevented.
Background	In most situations where road works block the normal lanes and there is a bus lane, that lane is provided as an alternative route to circumvent the road works. Automated vehicles might not have the (correct) logic to determine such an action is tolerated in the given situation (i.e. unable to detect the situation and corresponding correct lane markings). Also, especially in urban situations, such markings might not always be provided (in every country). By explicitly providing a path around the road works from the road side infrastructure, CAVs can drive around the road works and maintain their automated driving mode. That way, it is clear from where to where the CAV is allowed to break the traffic rules and drive across the bus lane.
Objective	Prevent the CAVs performing a ToC/MRM and enable the CAVs to drive around the road works.
Desired behaviour	CAVs use provided path information to circumvent the road works via the bus lane while maintaining their automated driving mode.
Expected benefits	The CAVs can keep their automated driving mode and the drivers do not need to interfere. Other vehicles are not delayed because of ToCs or MRMs by the CAVs or impacted otherwise as a result of those. As a result, travel times are improved, and safety is not negatively impacted.
Use case description	
Situation(s)	1. An urban two-lane road with to the right a bus lane. The normal lanes are blocked by road works and there is no bus approaching. 2. An urban two-lane road with to the right a bus lane. The normal lanes are blocked by road works (accident, breakdown) and there is a bus

	approaching.
Actors and relations	<u>RSI:</u> Provides prepared path information to the CAVs including the indication that the bus lane is allowed for driving. <u>CAV:</u> Receives the path from the RSI, processes it, and drives along the path around the road works. The driver responds or doesn't respond to ToC requests when the CAV has no path information. V2V communications could help coordinating the manoeuvres of the vehicles, if needed. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV drives around the road works. <u>CV:</u> Also receives the path from the RSI and possibly a (road works) warning message. Drives around road works possibly affected by supportive measures individually. <u>LV:</u> Drives around road works possibly affected by supportive measures as a group. <u>BUS:</u> The bus drives along the bus lane according to the maximum speed.
Scenario(s)	<u>Scenario 1, based on situation 1, No bus</u>  There are road works on a two-lane road with a bus lane next to it. The RSI has a prepared path ready and is distributing it. Approaching CAVs receive the path from the RSI and use the path to drive around the road works. <u>Scenario 2, based on situation 2, Approaching bus</u>  This scenario is like Scenario 1, but at some point, a bus approaches on the bus lane driving at the maximum speed. CAVs take the bus into account by getting in front of it, provided they can do so without slowing down the bus, or slow down to switch lanes to get behind the Bus.
Functional constraints / dependencies	It must be possible to prepare a path around the road works via the bus lane and have it available for the RSI before the road works start. The RSI must be able to distribute the path to CAVs. CAVs need to be able to receive and understand the path information. CAVs need to be capable of driving along the provided path. CAVs need to understand that they are allowed to drive on the bus lane via

	the path. CAVs need to be able to merge before or behind the approaching Bus.

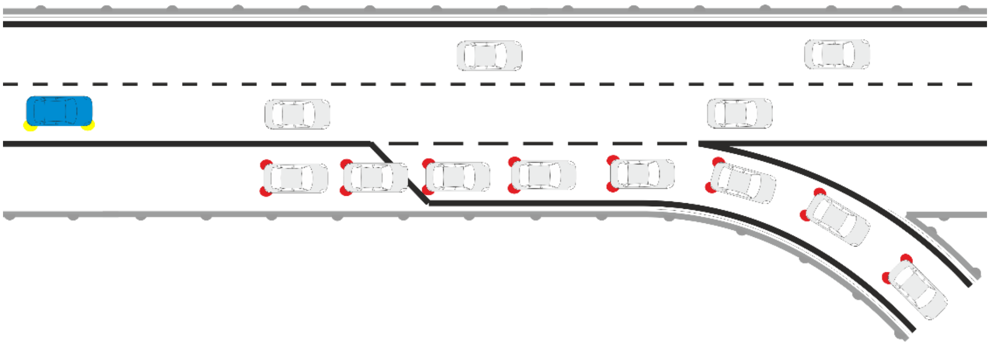
Use case 1.2: Provide path around stopped vehicle via bus lane

Use case introduction	
Summary	A stopped vehicle, blocking the normal lanes, is detected by the RSI and a path around it is determined and distributed to approaching CAVs. CAVs receive, process, and follow that path. ToCs/MRMs are prevented.
Background	In most situations where there is a stopped vehicle (e.g. breakdown, accident) and the normal lanes are blocked and there is bus lane, drivers will use that lane to circumvent the stopped vehicle. Automated vehicles might not have the (correct) logic to determine such an action is tolerated in the given situation. By explicitly providing a path around the stopped vehicle from the road side infrastructure, CAVs can drive around the stopped vehicle and maintain their automated driving mode.
Objective	Prevent the CAVs performing a ToC/MRM and enable the CAVs to drive around the stopped vehicle.
Desired behaviour	CAVs use provided path information to circumvent the stopped vehicle via the bus lane while maintaining their automated driving mode.
Expected benefits	The CAVs can keep their automated driving mode and the drivers do not need to interfere. Other vehicles are not delayed because of ToCs/MRMs by the CAVs or impacted otherwise as a result of those. As a result, travel times are improved, and safety is not negatively impacted.
Use case description	
Situation(s)	1. An urban two-lane road with to the right a bus lane. The normal lanes are blocked by a stopped vehicle (accident, breakdown) and there is <u>no bus</u> approaching. 2. An urban two-lane road with to the right a bus lane. The normal lanes are blocked by a stopped vehicle (accident, breakdown) and there <u>is a bus</u> approaching.
Actors and relations	<u>Stopped Vehicle:</u> Vehicle forms a blockage on the normal lanes. <u>RSI:</u> Detects the stopped vehicle via collective perception (i.e. road sensors, other vehicles, etc.) and determines its location. Then, the RSI determines a path around the stopped vehicle via the bus lane which is provided to the CAVs including the indication that the bus lane is allowed for driving. <u>CAV:</u> Receives the path from the RSI, processes it, and drives along the path around the stopped vehicle. The driver responds or doesn’t respond to ToC requests when CAV has no path information. V2V communications could help coordinating the manoeuvres of the vehicles, if needed. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs

	unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV drives around the stopped vehicle. <u>CV:</u> Also receives the path from the RSI and possibly a (road works) warning message. Drives around the stopped vehicle possibly affected by supportive measures individually. <u>LV:</u> Drives around the stopped vehicle possibly affected by supportive measures as a group. <u>BUS:</u> The bus drives along the bus lane according to the maximum speed.
Scenario(s)	<u>Scenario 1, based on situation 1, No bus</u>  On a two-lane road with a bus lane next to it, a vehicle stops, blocking the normal lanes. The RSI detects the stopped vehicle and determines a path around the stopped vehicle via the bus lane. That path is provided by the RSI to approaching CAVs which use the path to drive around the Stopped Vehicle. <u>Scenario 2, based on situation 2, Approaching bus</u>  This scenario is like Scenario 1, but a short while (a minute or so) after the RSI detects the stopped vehicle, a bus approaches on the bus lane driving at the maximum speed. CAVs take the Bus into account by getting in front of it, provided they can do so without slowing down the bus, or slow down to switch lanes to get behind the bus.
Functional constraints / dependencies	The RSI must be able to detect the Stopped Vehicle. The RSI must be able to determine a path around the Stopped Vehicle via the bus lane. The RSI must be able to distribute the path to CAVs. CAVs need to be able to receive and understand the path information. CAVs need to be capable of driving along the path. CAVs need to understand that they are allowed to drive on the bus lane via the path. CAVs need to be able to merge before or behind the approaching Bus.

Use case 1.3: Provide path to end of queue on motorway exit

Use case introduction	
Summary	The path to the end of a queue on a motorway exit is provided. The RSI detects the queue and a path to the tail is determined which is distributed to approaching CAVs. CAVs receive, process, and follow that path. ToCs/MRMs are prevented.
Background	The exit of a motorway might be fully blocked by a queue of vehicles because of a traffic light or blockage downstream of the exit. Drivers exiting the motorway see the queue and line up at the end of the queue. Automated vehicles might not detect the queue in time and subsequently cannot move to the exit lane because of the queue. They perform a stop next to the queue on the outermost lane and perform a ToC (or the stopping behaviour is an MRM).
Objective	Prevent the CAVs performing a ToC/MRM and enable the CAVs to join the queue at the end possibly on the emergency lane.
Desired behaviour	CAVs use provided path information to move to the end of the queue on the exit lane (and possibly on the emergency lane) while maintaining their automated driving mode.
Expected benefits	The CAVs can keep their automated driving mode and the drivers do not need to interfere. The risk of collision with stopped CAVs on the rightmost lane is reduced or eliminated. Other vehicles are not delayed because of stopped CAVs on the rightmost lane. As a result, travel times and safety are improved.
Use case description	
Situation(s)	A two-lane motorway with an exit and emergency lane. The exit interrupts the emergency lane. There is traffic of some service level on the main carriageway and there is a queue covering the entire exit.
Actors and relations	<u>Vehicles in Queue:</u> Slowly moving/standstill traffic on the exit lane. <u>RSI:</u> Detects the queue and the end of it through collective perception. Then, a path to the end of the queue from some generic point upstream on the rightmost lane of the main carriageway is determined. The RSI distributes that path to the CAVs including the indication that the emergency lane is allowed for driving. <u>CAV:</u> receives the path from the RSI, processes it, and drives along the path to the end of the queue. The driver responds or doesn't respond to ToC requests when the CAV has no path information. V2V communications could help coordinating the manoeuvres of the vehicles, if needed. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV drives to the end of the queue.

	CV: Also receives the path from the RSI and possibly a warning message. Drives to the end of the queue possibly affected by supportive measures individually. LV: Drives to the end of the queue possibly affected by supportive measures as a group.
Scenario(s)	 CAVs are driving along a two-lane motorway approaching an exit. This exit is blocked by traffic and the tail of the queue is covering the emergency lane with some vehicles. The queue is detected by the RSI which determines the location of the end of the queue. The RSI then determines a path from a point upstream of the queue on rightmost lane of the main carriageway to the end of the queue and provides the path to approaching CAVs. The CAVs follow the path to the end of the queue. Note that some vehicles might add to the queue while a path is being provided to the CAVs. The end of the path then becomes invalid because there are already vehicles there. The provided path takes the CAVs to the emergency lane some distance upstream of the tail of the queue. It is then assumed the CAVs simply stop before those extra vehicles in the queue while maintaining its level of automation.
Functional constraints / dependencies	The RSI must be able to detect the queue. The RSI must be able to determine a path from the rightmost lane of the main carriageway upstream of the queue to the end of the queue. The RSI must be able to distribute the path to CAVs. CAVs need to be able to receive and understand the path information. CAVs need to be capable of driving along the provided path. CAVs need to understand that they are allowed to drive on the emergency lane via the path. CAVs need to be able to consider vehicles that have already connected to the end of the queue and stop before those (assumed as normal AD functions but superseding the ‘follow path instruction’).

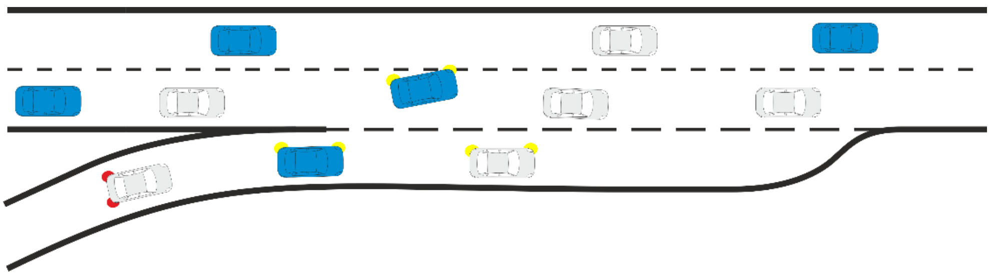
5.3.2 Service 2: Prevent ToC/MRM by providing speed, headway and/or lane advice

Service Introduction	
Summary	This service provides speed, headway and/or lane advice to vehicles to prevent the initiation of ToC/MRM due to complex traffic situations emerging from either planned or unpredictable events.
Background	Vehicles might be impeded or involved in safety critical situations under specific traffic conditions (e.g. incidents) or automated driving operations (e.g. platooning at motorway merge/diverge segments). Under these circumstances automated vehicles might request ToCs or execute MRMs for safety reasons. RSI will be able to predict, detect or become informed (via collective perception: i.e. road sensors, cooperative vehicles, etc.) of such conditions and provide optimal speed and/or lane advice to increase safety, traffic, and energy efficiency.
Objective	Provide speed and/or lane advice to CAVs and CVs to prevent CAVs and AVs from initiating ToC/MRM and level off traffic turbulence and decrease the number of safety critical situations.
Expected benefits	RSI-assisted optimal speed and lane selection advice is expected to prevent or dampen shockwaves, thus smoothing traffic flow and leading to safe and efficient traffic operations. Also, the measures will decrease the chance of CAVs and AVs having to quickly deal with unexpected situations.
Notable use case variables	The characteristics of the measures of this service are relatively generic and therefore applicable to many different situations. Most variables are relevant for use cases of this service. Notably more significant, are those variables affecting the time and space of implementing speed, headway and/or lane advice and the predictability of the critical situations. In addition, since this service aims for harmonizing traffic, supportive measures affecting other vehicle types (CV, AV, and LV) are important for successful implementation.
Selected use cases	2.1 Prevent ToC/MRM at motorway merge segments 2.2 Prevent ToC/MRM at motorway merge segments (CAV Platoon) 2.3 Intersection handling due to incident 2.4 Intersection handling due to road works *Note: Use cases 2.1 and 2.2 can be combined to form a new use case.*

Use case 2.1: Prevent ToC/MRM at motorway merge segments

Use case introduction	
Summary	Provide speed and lane advice to mainline and on-ramp CAVs and CVs to facilitate smooth merging into mainline traffic.

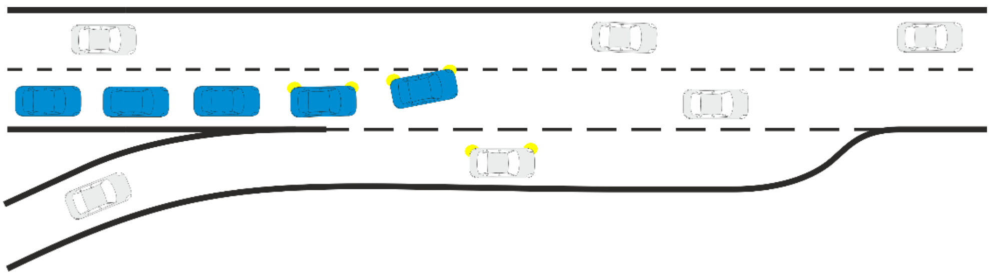
Background	The number of vehicle interactions is increased along motorway merge segments. Merging traffic forces mainline vehicles to either change lane (to maintain speed) or adjust their speed to facilitate merging operations. On the other hand, mainline traffic might impede merging vehicles due to dense traffic conditions or aggressive driving. Traffic instability along motorway merge segments due to increased lane change activity and shockwaves might result in merging and/or mainline CAVs performing ToCs/MRMs. Thus, the provision of RSI-assisted speed and lane advice to mainline and merging CAVs based on the available gaps on the mainline traffic and the arrival rate of merging vehicles is expected to prevent CAVs from initiating ToC/MRM.
Objective	Enable mainline and on-ramp CAVs to drive automated through motorway merge segments without initiating ToC/MRM by coordinating their actions.
Desired behaviour	CAVs and CVs use provided information to adjust their speed to approach the gap. If the available gaps on the mainline traffic are not large enough to ensure the safe merging of on-ramp traffic, CAVs and CVs use provided information to adjust their speed and/or lane so that sufficient gaps are created for merging traffic.
Expected benefits	Merging operations become smooth and thus the probability of a disruption on the motorway merge segment decreases. As a result of the measures, merging CAVs avoid ToC/MRM due to increased traffic instability or inability to merge into the mainline traffic and mainline CAVs avoid ToC/MRM due to cut-in situations or merging traffic.
Use case description	
Situation(s)	Dual lane motorway with single lane on-ramp entry. There is heavy traffic on the motorway partly preventing on-ramp vehicles from merging to the motorway.
Actors and relations	<u>RSI:</u> Monitors traffic operations along a motorway merge segment through collective perception resulting in vehicle positions, directions and speeds. Using that information, the RSI estimates available gaps on the mainline traffic and provides speed and lane advice to on-ramp CAVs and CVs. If available gaps are insufficient, the RSI provides speed or lane advice to mainline CAVs and CVs to create gaps for on-ramp merging traffic. <u>Mainline CAV & CV:</u> Receives advice from RSI and adjusts speed or changes lanes to enable smooth merging of on-ramp traffic. Could additionally cooperate through V2V with on-ramp CAV & CV if needed. <u>On-ramp CAV & CV:</u> Receives speed and lane advice from RSI to merge smoothly into the mainline. Could additionally cooperate through V2V with mainline CAV & CV if needed. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving.

	LV: Normal driving and merging operations possibly affected by supportive measures as a group.
Scenario(s)	 CAVs, AVs, CVs, and LVs drive along a motorway merge segment or enter the mainline motorway lanes through an on-ramp. RSI monitors traffic operations along the motorway merge segment (CAVs and CVs update speed and lane information to RSI) and detects the available gaps on the right-most mainline lane to estimate speed and lane advice for merging CAVs and CVs coming from the on-ramp. If available gaps on the right-most mainline lane are not large enough to allow the safe and smooth merging of on-ramp vehicles, speed and lane advice is also provided to mainline CAVs and CVs, thereby creating the necessary gaps in mainline traffic to facilitate the smooth merging of on-ramp vehicles.
Functional constraints / dependencies	The RSI must be able to detect the position, direction and speed of vehicles through collective perception. The RSI must be able to detect gaps in mainline traffic. The RSI must be able to estimate the optimal speed and lane advice for on-ramp merging CAVs and CVs and distribute that advice. The RSI must be able to estimate optimal speed and/or lane advice for mainline CAVs and CVs and distribute that advice. CAVs must be able to receive, process and execute speed advice and lane change requests. CVs must be able to receive and convey speed advice and lane change requests to drivers.

Use case 2.2: Prevent ToC/MRM at motorway merge segments (CAV Platoon)

Use case introduction	
Summary	Provide speed, headway, or lane advice to mainline CAV Platoon to prevent ToC/MRM for merging CAVs and support merging CVs.
Background	CAV Platoons approaching motorway merge segments limit the entrance of merging traffic due to driving cooperatively with limited spacing. Since merging on-ramp CAVs cannot enter the mainline traffic, they will initiate ToC/MRM on the merging lane. As a result, on-ramp traffic might be impeded leading to long on-ramp queues. Moreover, merging into the mainline traffic after a full stop will generate safety-critical conditions and

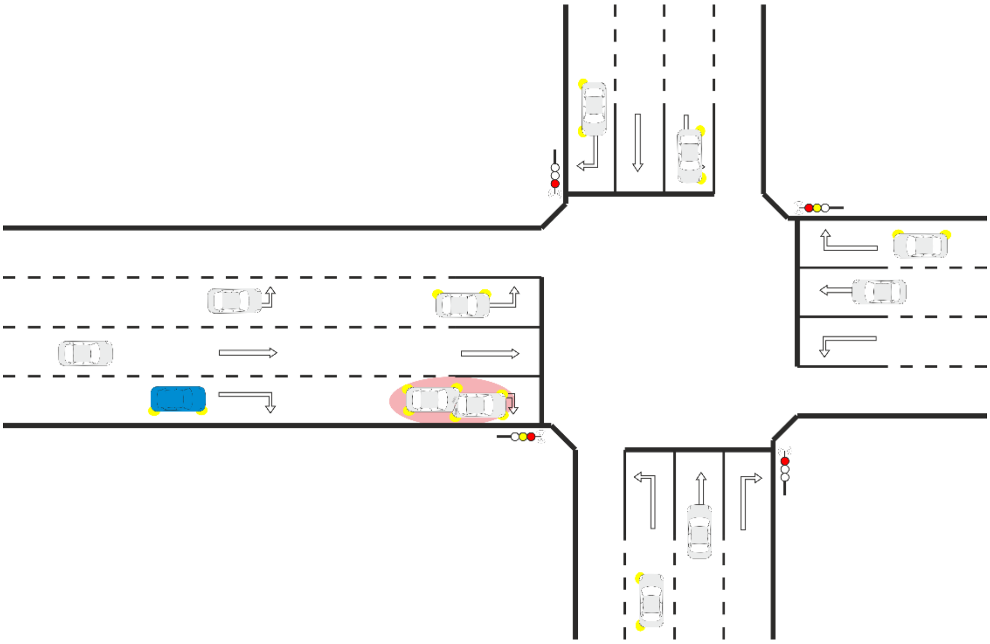
	might impede mainline traffic as well. The provision of infrastructure-assisted speed, headway and/or lane advice to CAV Platoons to either slow down, speed up, disperse or shift to other than the right-most mainline lane can prevent on-ramp CAVs from initiating ToC/MRM.
Objective	Enable on-ramp CAVs to merge smoothly into the mainline traffic while a CAV Platoon is approaching a motorway merge segment. Prevent CAVs from initiating ToC/MRM on the merging lane.
Desired behaviour	The mainline CAV Platoon slows down, speeds up, disperses (drive with larger headways) or changes lanes to a lane other than the right-most lane in response to provided information (a request). CAVs and CVs use provided information to adjust their speed to approach the gaps emerging on the mainline.
Expected benefits	Merging operations are smooth and thus the probability of a vehicle stopping on the merging lane decreases. On-ramp CAVs avoid ToC/MRM due to the inability to merge into the mainline traffic. Moreover, mainline traffic is not disrupted from stopped vehicles on the merging lane that attempt to enter the motorway. As a result, safety, traffic, and energy efficiency are increased.
Use case description	
Situation(s)	Dual lane motorway with single lane on-ramp entry. There is heavy traffic on the motorway partly preventing on-ramp vehicles from merging to the motorway.
Actors and relations	<u>RSI:</u> Monitors traffic operations along a motorway merge segment through collective perception resulting in vehicle positions, directions, and speeds, including those of platoons. Using that information, gaps for merging are determined. If available gaps are insufficient, the RSI provides speed and/or lane advice to the mainline CAV Platoon to create gaps for on-ramp merging traffic. Additionally, the RSI provides speed and lane advice to on-ramp CAVs and CVs to merge smoothly. <u>Mainline CAV Platoon:</u> Receives advice from RSI and adjusts vehicle speeds, headways or changes lanes. Could additionally cooperate through V2V with other CAVs if needed. <u>Mainline CAV & CV:</u> Normal driving based on vehicles' capabilities, possibly affected by individual supportive measures (e.g. see use case 2.1). Could additionally cooperate through V2V with other CAVs if needed. <u>On-ramp CAV & CV:</u> Receives speed and lane advice from RSI to merge smoothly into the mainline. Could additionally cooperate through V2V with other CAVs if needed. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. <u>LV:</u> Normal driving and merging operations possibly affected by supportive measures as a group.

Scenario(s)	 A CAV Platoon approaches a merge segment on a two-lane motorway. The CAVs comprising the platoon drive with limited spacing that prevents on-ramp traffic from merging unimpeded into the mainline lanes. RSI detects an approaching CAV Platoon through collective perception and provides speed, headway and/or lane advice to speed up, slow down, disperse the platoon (increase headways) or shift it to the left lane thus generating gaps for on-ramp vehicles to merge unimpeded. RSI also estimates speed and lane advice for merging CAVs and CVs to facilitate merging based on the created gaps on the mainline traffic.
Functional constraints / dependencies	The RSI must be able to detect the position, direction and speed of vehicles, including platoons, through collective perception. The RSI must be able to detect gaps in mainline traffic using the speed, position and direction of vehicles and platoons. The RSI must be able to estimate optimal speed, headway and/or lane advice for mainline CAV Platoon (vehicles) and distribute that advice. The RSI must be able to estimate the optimal speed and lane advice for on-ramp merging CAVs and CVs and distribute that advice. CAVs and CAV Platoons must be able to receive, process and execute speed advice and lane change requests. CVs must be able to receive and convey speed advice and lane change requests to drivers.

Use case 2.3: Intersection handling due to incident

Use case introduction	
Summary	Provide lane advice to CAVs and CVs to proactively avoid a blocked lane due to an incident.
Background	The right-most lane of a 3-lane signalised intersection approach is blocked due to an unpredictable event (i.e. incident). Automated vehicles unfamiliar with the incident would come to a stop before the incident instead of using other lanes to circumvent it. To support CAVs and CVs, the RSI detects the event and implements a traffic management scheme, which encompasses suggestion of designated lane changes (spatially and temporally) to CAVs and CVs to shift to the open lanes and avoid a full stop.

Objective	Prevent CAVs and AVs from initiating ToC/MRM due to an incident (e.g. head-tail collision), by increasing anticipation of the unpredictable event (enhanced situation awareness) and providing optimal lane advice.
Desired behaviour	CAVs and CVs receive lane advice from the RSI and change lanes upstream of the incident's influence zone. From the middle lane they turn right. CAVs maintain automated driving mode by avoiding blocked lanes and/or irregular traffic patterns.
Expected benefits	Lane advice is distributed spatially and temporally upstream of the incident influence zone to CAVs and CVs. Vehicle interactions will be minimised, and ToCs/MRMs are prevented in CAVs. CVs have more time to gradually change lanes. As a result, traffic stability, energy efficiency, and safety will increase.
Use case description	
Situation(s)	A 4-armed signalised intersection with 3-lane approaches and turning lanes for all manoeuvres. The right-most lane of an approach is blocked by an incident.
Actors and relations	RSI: Detects the incident that blocks the right-most lane of the intersection through collective perception and estimates the optimal lane advice for CAVs and CVs. The RSI distributes that advice to CAVs and CVs. Optionally provides the information that it is allowed to turn right from the middle lane. CAV: Receives the lane change advice from the RSI and performs a lane change manoeuvre upstream of the blocked lane to avoid ToC/MRM. Could coordinate with other CAVs through V2V for the lane change if needed. CV: Receives the lane advice from the RSI and performs a lane change manoeuvre upstream of the blocked lane to prevent traffic turbulence. AV: Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. LV: Normal driving and merging operations possibly affected by supportive measures as a group.

<table>
<tr><td>Scenario(s)</td><td>
CAVs, CVs are driving on a 3-lane signalised intersection approach. A rear-end accident occurs on the right-most lane of the intersection approach which is then blocked. RSI detects the incident through collective perception. RSI provides designated lane change advice to CAVs and CVs. CAVs and CVs change lanes in a spatially and temporally distributed way. CAVs maintain their automated driving mode and avoid ToC/MRM because they use the middle lane to turn right.</td></tr>
<tr><td>Functional constraints / dependencies</td><td>The RSI must be able to detect the unpredictable event (i.e. incident).
The RSI must be able to detect CAVs and CVs speed, position, and direction.
The RSI must be able to estimate the optimal lane changes (spatially and temporally).
The RSI must be able to provide a warning and a lane advice to CAVs and CVs.
CAVs must be able to receive, process and execute lane change requests.
CAVs must be able/allowed to make a right-turn from the middle approach lane.
CVs must be able to receive and convey speed advice and lane change requests to drivers.
Time and space constraints must not limit the implementation of distributed lane changes.</td></tr>
</table>

Use case 2.4: Intersection handling due to road works

Use case introduction

Summary	Provide lane advice to vehicles to proactively avoid a blocked lane due to road works.
Background	The right-most lane of a 3-lane signalised intersection approach is blocked due to road works (planned event). Automated vehicles unfamiliar with the incident would come to a stop before the incident instead of using other lanes to circumvent it. To support CAVs and CVs, the RSI implements a traffic management scheme based on known road works information, which encompasses suggestion of designated lane changes (spatially and temporally) to CAVs and CVs to shift to the open lanes and avoid a full stop.
Objective	Prevent CAVs and AVs from initiating ToC/MRM due to road works, by increasing anticipation of road works (planned event) (enhanced situation awareness) and providing optimal lane advice.
Desired behaviour	CAVs and CVs receive lane advice from the RSI and change lanes upstream of the road works influence zone. From the middle lane they turn right. CAVs maintain automated driving mode by avoiding blocked lanes and/or irregular traffic patterns.
Expected benefits	Lane advice is distributed spatially and temporally upstream of the road works relevance zone to CAVs and CVs. Vehicle interactions will be minimised, and ToCs/MRMs are prevented in CAVs. CVs have more time to gradually change lanes. As a result, traffic stability, energy efficiency, and safety will increase.
Use case description	
Situation(s)	A 4-armed signalised intersection with 3-lane approaches and turning lanes for all manoeuvres. The right-most lane is blocked by road works.
Actors and relations	<u>RSI:</u> Knows the event (road works) that blocks the right-most lane of the intersection approach, estimates the optimal lane advice, distributes that advice to CAVs and CVs. Optionally provides the information that it is allowed to turn right from the middle lane. <u>CAV:</u> Receives the lane change advice from the RSI and performs a lane change manoeuvre upstream of the blocked lane to avoid ToC/MRM. Could coordinate with other CAVs through V2V for the lane change if needed. <u>CV:</u> Receives the lane advice from the RSI and performs a lane change manoeuvre upstream of the blocked lane to prevent traffic turbulence. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. <u>LV:</u> Normal driving and merging operations possibly affected by supportive measures as a group.

<table>
<tr><td>Scenario(s)</td><td>
CAVs, CVs are driving on a 3-lane signalised intersection approach. The right-most lane of the intersection approach is blocked due to road works which are planned and known before hand by the RSI. RSI provides designated lane change advice to CAVs and CVs. CAVs and CVs change lanes in a spatially and temporally distributed way. CAVs maintain their automated driving mode and avoid ToC/MRM because they use the middle lane to turn right.</td></tr>
<tr><td>Functional constraints / dependencies</td><td>The RSI must have the road works information (position, scope, duration, lane configuration, etc.).
The RSI must be able to detect CAVs and CVs speed, position, and direction.
The RSI must be able to estimate the optimal lane changes (spatially and temporally).
The RSI must be able to provide a warning and a lane advice to CAVs and CVs.
CAVs must be able to receive, process and execute lane change requests.
CAVs must be able/allowed to make a right-turn from the middle approach lane.
CVs must be able to receive and convey speed advice and lane change requests to drivers.
Time and space constraints must not limit the implementation of distributive lane changes.</td></tr>
</table>

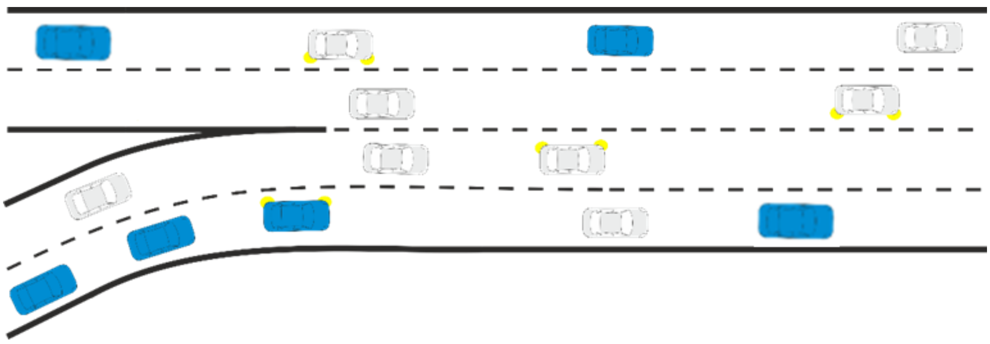
5.3.3 Service 3: Prevent ToC/MRM by traffic separation

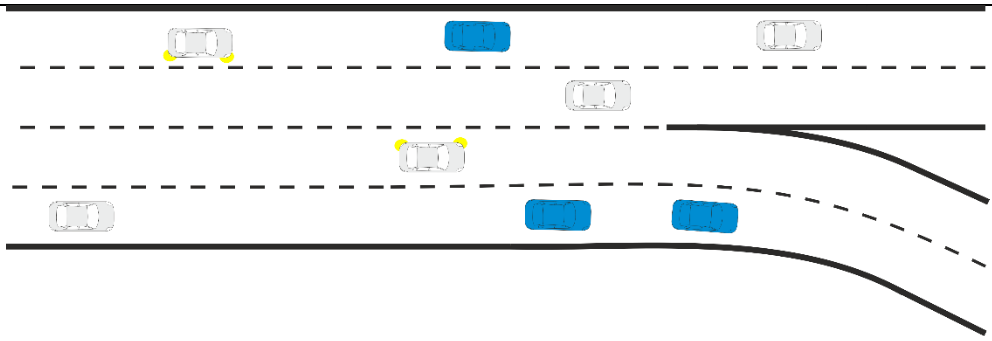
Service introduction	
Summary	Different vehicle types (CAV, AV, CV, LV) are separated by giving lane advice per type before critical situations. Vehicle interactions are reduced to reduce the chance of ToCs/MRMs and thus prevent those.
Background	In certain situations, the interactions between automated and non-automated vehicles might become critical (e.g. motorway merging sections, roadworks areas). Especially non-automated vehicles can create dangerous situations (sudden/delayed merging, cut-offs, quick take overs, etc.). Due to such situations automated vehicles might perform a ToC/MRM for safety reasons. To manage the coexistence of automated and non-automated vehicles in such critical situations a possible solution can be to separate automated and non-automated vehicles over dedicated portions of the road network. One way is to dedicate, where possible, one or more lanes for CAVs (which are optionally able to drive at close distances) while other types drive on other designated lanes. CAVs are assigned to lanes where the chance of a ToC is smallest.
Objective	Separate CAVs from non-automated traffic to support the CAVs in keeping their automation level thus preventing ToC/MRM.
Expected benefits	The measures will decrease the chance of CAVs having to quickly deal with unexpected situations. An increase of the overall traffic flow and an improvement of the safety are expected due to a reduced amount of interactions between automated and non-automated vehicles. Moreover, CAVs will be able to continue driving without having to perform a ToC/MRM. As a result, the driver will not have to intervene.
Notable use case variables	Type of critical situation: Traffic separation requires some space and time to implement. Therefore, compared to other variables, the type of critical situations and if there is more or less time and space for implementing the traffic separation measure have significant impact. Other aspects could vary as well, like the length of the critical situation. In addition, since this service aims to affect all vehicle types, supportive measures affecting other vehicle types (CV, AV, and LV) are important for successful implementation.
Selected use cases	3.1 Apply traffic separation before motorway merging/diverging 3.2 Apply traffic separation before motorway on-ramp 3.3 Apply traffic separation before roadworks areas

Use case 3.1: Apply traffic separation before motorway merging/diverging

Use case introduction	
Summary	To avoid ToCs and MRMs, instructions to apply traffic separation before motorway merging are provided.

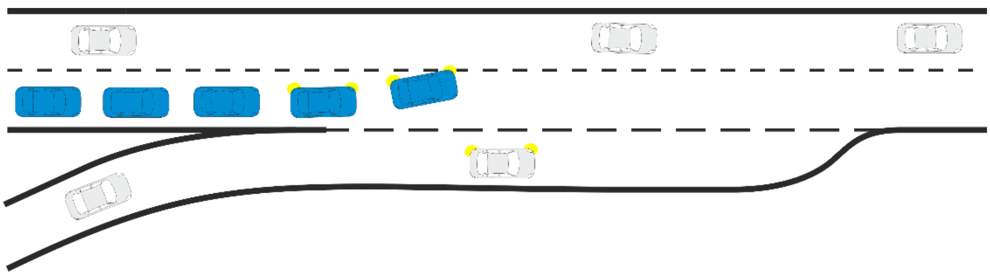
Background	Automated vehicles and platoons driving on a motorway heading towards a motorway merging section where two motorways merge or diverge, will face situations in which the other merging vehicles, especially non-automated vehicles can create dangerous situations (sudden/delayed merging) and disrupt traffic flow. To handle these situations one solution could be a proactive ToC to manual driving before the merging (e.g. via geo-fencing - conservative approach, see Service 6) or reactive ToC to manual driving in case the dangerous situation is sudden. In the first case, a more relaxed MRM can be needed if the driver is not responding. In the second case, the ToC itself can be dangerous if the risk is not detected early enough and a MRM would be problematic. In case a CAV Platoon approaches the merging/diverging point, the situation is even more complex: on the one hand, a ToC/MRM in/of any platoon vehicle has a direct impact on the others. On the other hand, merging vehicles need gaps to merge into, which the platoon might not allow. For these reasons, separating CAVs and CAV Platoons to motorway lanes away from the merging/diverging one can make sense, because a limited interaction between automated and non-automated vehicles will reduce the occurrence of the above situations.
Objective	Separate CAVs and CAV Platoons from non-automated traffic before the merging/diverging point to prevent CAVs performing a ToC/MRM in the merging area.
Desired behaviour	CAVs and CAV Platoons not needing to use the merging lane(s), gradually move to lanes away from the merging lane(s). CVs move from the lanes designated for CAVs to the other lanes, possibly merging to other directions. CAVs needing to change lanes for other directions do not use the designated CAV-lane(s) and drive as they would without measures.
Expected benefits	CAVs and CAV Platoons are separated from other vehicle types before the merging/diverging area. That means merging is spread out over a larger distance and the number of interactions between CAVs, AVs, CVs, and LVs are minimised. As a result, the risk of ToCs/MRMs is significantly reduced. Consequently, traffic flow, efficiency, and safety are improved.
Use case description	
Situation(s)	Two motorways, both with two lanes, converge and form a 4-lane motorway section. Blocked lane marking separates the left two lanes from the right two lanes in the merging section. After approximately 1.3 km, the merging section splits up into two motorways again, both with 2 lanes. There are merging CAVs and other vehicles looking to overtake or get in the correct lane.
Actors and	<u>RSI:</u> Monitors traffic operations along a motorway merge segment and the roads up- and downstream through collective perception resulting in vehicle

relations	positions, directions, and speeds, including those of platoons. Using that information, the RSI establishes the most suitable traffic separation policy, which holds preferred lanes for driving for the different sections and provides that policy to CAVs, CAV Platoons, and CVs. <u>CAV and CAV Platoon:</u> receives traffic separation policy (and optionally automated driving support information) from RSI. Optionally implement V2V for manoeuvring coordination. <u>CV:</u> receives traffic separation policy and manual driving support information (e.g. drive left/right indication) from RSI. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. <u>LV:</u> Normal driving and merging operations possibly affected by supportive measures as a group.
Scenario(s)	<u>Scenario 1: merging</u>  CAVs, CAV Platoons, and CVs drive along two 2-lane motorways that merge into one 4-lane motorway. Vehicles are merging to find their lane of preference. RSI monitors traffic operations along the motorway merge segment and the roads up- and downstream through collective perception. Based on the RSI provided traffic separation policy, CAVs and CAV Platoons move to the left lane of the left 2-lane motorway and to the right on the right 2-lane motorway some point upstream of the merging point (before where merging usually starts). CVs move to other lanes than the CAVs and CAV Platoons. CAVs and CAV Platoons thus enter the 4-lane section on the outer lanes, giving space to other vehicle types to merge. At some point downstream of the merging point, CAVs, CAV Platoons and CVs gradually start merging to their preferred lane. For the execution of the policy, CAVs and CAV Platoons optionally exchange V2V for manoeuvring coordination. <u>Scenario 2: diverging</u>

	 CAVs, CAV Platoons, and CVs drive along a 4-lane motorway segment which diverges into two 2-lane motorways. Vehicles are merging to find their lane of preference. RSI monitors traffic operations along the motorway merge segment and the roads up- and downstream through collective perception. Based on RSI advice, CAVs and CAV Platoons move to the left-most lane or right-most lane of the 4-lane motorway some point upstream of the merging point (before where merging usually starts). CVs move to other lanes than the CAVs and CAV Platoons. CAVs and CAV Platoons thus enter the left 2-lane motorways on the left and the right 2-lane motorway on the right, giving space to other vehicle types to merge. At some point downstream of the diverging point, CAVs, CAV Platoons, and CVs gradually start merging to their preferred lane. For the execution of the policy, CAVs and CAV Platoons can optionally exchange V2V for manoeuvring coordination. Note that CAVs, CAV Platoons, or CVs move to different lanes depending on their destination.
Functional constraints / dependencies	The RSI must be able to detect CAVs, CAV Platoons, and CVs speed, position, and direction in the merging section and up- and downstream. The RSI must be able to determine the traffic separation policy, which includes the preferred lanes for the different vehicle types for the different sections of the motorway(s). The RSI must be able to provide the traffic separation policy to CAVs, CVs and CAV Platoons. CAVs and CAV Platoons must be able to receive, process and execute the traffic separation policy and optionally support V2V manoeuvring coordination. CVs must be able to receive and convey the traffic separation policy to drivers. Time and space constraints must not limit the implementation of the traffic separation policy.

Use case 3.2: Apply traffic separation before motorway on-ramp

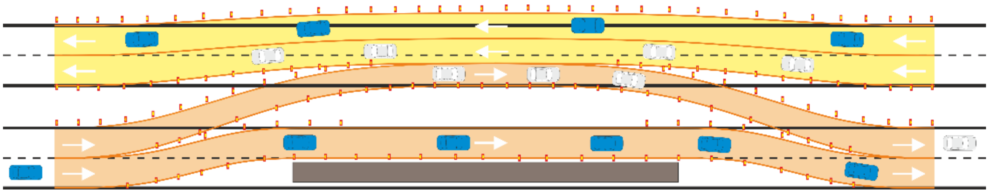
Use case introduction	
Summary	To avoid ToCs and MRMs in mainline traffic or on the on-ramp, instructions to apply traffic separation before motorway on-ramp are provided.
Background	Automated vehicles and platoons driving on a motorway heading towards an on-ramp, will face situations in which the other merging vehicles, especially non-automated vehicles can create dangerous situations (sudden/delayed merging) and disrupt traffic flow. To handle these situations one solution could be a proactive ToC to manual driving before the merging (e.g. via geo-fencing - conservative approach, see Service 6) or a reactive ToC to manual driving in case the dangerous situation is sudden. In the first case, a more relaxed MRM can be needed if the driver is not responding. In the second case, the ToC itself can be dangerous if the risk is not detected early enough and a MRM would be problematic. In case a CAV Platoon approaches the merging/diverging point, the situation is even more complex: on the one hand, a ToC/MRM in/of any platoon vehicle has a direct impact on the others. On the other hand, merging vehicles need gaps to merge into, which the platoon might not allow (also see use case 2.2). For these reasons, separating CAVs and CAV Platoons to motorway lanes away from the right-most lane can make sense, because a limited interaction between automated and non-automated vehicles will reduce the occurrence of the above situations.
Objective	Separate CAVs and CAV Platoons from non-automated traffic before the on-ramp to prevent CAVs performing a ToC/MRM in mainline traffic or on the on-ramp.
Desired behaviour	CAVs, CAV Platoons, and CVs move to lanes other than the right-most lane. Where possible CVs use other lanes than the CAVs or CAV Platoons.
Expected benefits	CAVs and CAV Platoons are separated from other vehicle types before the on-ramp. That means merging is spread out over a larger distance and the number of interactions between CAVs, AVs, CVs, and LVs are minimised. On-ramp CAVs and AVs avoid ToC/MRM due to the inability to merge into the mainline traffic. Moreover, mainline traffic is not disrupted from stopped vehicles on the merging lane that attempt to enter the motorway. Consequently, traffic flow, efficiency, and safety are improved.
Use case description	
Situation(s)	Dual lane motorway with single lane on-ramp entry. There is heavy traffic on the motorway partly preventing on-ramp vehicles from merging to the motorway.
Actors and	<u>RSI:</u> Monitors traffic operations along a motorway on-ramp through

relations	collective perception resulting in vehicle positions, directions, and speeds, including those of platoons. Using that information, the RSI establishes the most suitable traffic separation policy, which holds preferred lanes for driving for the different sections and provides that policy to CAVs, CAV Platoons, and CVs. Mainline CAV and CAV Platoon: receives traffic separation policy (and optionally automated driving support information) from RSI. Optionally implement V2V for manoeuvring coordination. Mainline CV: receives traffic separation policy and manual driving support information (e.g. drive right indication) from RSI. On-ramp CAV & CV: Normal driving based on vehicles capabilities, possibly affected by supportive measures individually. AV: Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. LV: Normal driving and merging operations possibly affected by supportive measures as a group.
Scenario(s)	 CAVs, CAV Platoon, and CV, approach an on-ramp on a two-lane motorway. The CAV Platoon drives with limited spacing that prevents on-ramp traffic from merging unimpeded into the mainline lanes. RSI monitors traffic operations along the motorway through collective perception. Based on the traffic policy from the RSI, CAVs and CAV Platoons move to the left lane of the left 2-lane motorway some point upstream of the on-ramp (before where merging usually starts). CVs move to the right lane. CAVs and CAV Platoons thus drive to the left while passing the on-ramp and CVs to the right. At some point downstream of the on-ramp, CAVs, CAV Platoons and CVs gradually start merging (back) to their preferred lane. For the execution of the policy, CAVs and CAV Platoons can optionally exchange V2V for manoeuvring coordination.
Functional constraints / dependencies	The RSI must be able to detect CAVs, CAV Platoons, and CVs speed, position and direction in the merging section (on-ramp) and up- and downstream. The RSI must be able to determine the traffic separation policy, which includes the preferred lanes for the different vehicle types for the different sections of the motorway(s).

	The RSI must be able to provide the traffic separation policy to CAVs, CVs and CAV Platoons. CAVs and CAV Platoons must be able to receive, process and execute the traffic separation policy and optionally support V2V manoeuvring coordination. CVs must be able to receive and convey the traffic separation policy to drivers. Time and space constraints must not limit the implementation of the traffic separation policy.

Use case 3.3: Apply traffic separation before roadworks areas

Use case introduction	
Summary	To avoid ToC and MRM, instructions to apply traffic separation before roadworks areas are provided.
Background	Automated vehicles heading towards or driving in roadworks areas potentially face dangerous situations caused by the presence of non-automated vehicles (e.g. sudden brakes on narrow sections). To handle these situations one solution would be proactive ToC to manual driving before the roadworks zone (e.g. via geo-fencing - conservative approach) or reactive ToC to manual driving in case the dangerous situation suddenly happens. In the first case, a more relaxed MRM can be needed if the driver is not responding. In the second case the ToC itself can be dangerous if the risk is not detected early enough. In addition, an eventual MRM would be more critical in roadworks areas. Also, inefficient situations can happen due to common behaviour of non-automated vehicles (not overtaking in sections with two adjacent narrow lanes even if possible; driving in the middle and preventing overtaking, etc.). Automated vehicles might better handle these situations if separated from non-automated vehicles. For these reasons, separating CAVs and CAV Platoons to dedicated lanes, where chances of a ToC are smallest, can make sense, because a limited interaction between automated and non-automated vehicles will reduce the occurrence of the above situations.
Objective	Prevent the CAVs performing a ToC/MRM in the road works zone and enable the CAVs to keep their automation level.
Desired behaviour	CAVs and CAV Platoons gradually move to designated lane(s) separated from other traffic.
Expected benefits	CAVs and CAV Platoons are separated from other traffic. As a result, the number of interactions between CAVs, CAV Platoons and other traffic are minimised. Consequently, the chance of ToCs/MRMs is significantly reduced. Traffic flow, efficiency and safety are improved.

Use case description	
Situation(s)	A 2-lane motorway. Before the right lane is closed due to road works, the left lane diverges to the opposite direction carriageway. There it continues as one narrower lane. At the same divergence point, the right lane diverges to the left lane. After the road works, the situation returns to 'normal' (i.e. lane on the other carriageway diverges back to the left lane and the left lane diverges back to the right lane).
Actors and relations	RSI: Monitors traffic operations along a road works and the roads up- and downstream through collective perception resulting in vehicle positions, directions, and speeds, including those of platoons. Using that information, the RSI establishes the most suitable traffic separation policy, which holds preferred lanes for driving for the different sections and provides that policy to CAVs, CAV Platoons, and CVs. CAV and CAV Platoon: receives traffic separation policy (and optionally automated driving support information) from the RSI. Optionally implement V2V for manoeuvring coordination. CV: receives traffic separation policy and manual driving support information (e.g. drive left/right indication) from the RSI. AV: Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. LV: Normal driving and merging operations possibly affected by supportive measures as a group.
Scenario(s)	 CAVs, CAV Platoons, and CVs drive along two 2-lane motorways with road works where the two lanes are splitting. The RSI monitors traffic operations along the road works and up- and downstream through collective perception. Based on the RSI provided traffic separation policy, CAVs and CAV Platoons move to the left lane, while CVs move to the right lane of the left 2-lane motorway some point upstream of the roadworks (before where merging usually starts). CAVs and CAV Platoons thus drive in their own lane on the other carriageway, while CVs remain on the original carriageway. After the road works, CAVs, CAV Platoons and CVs come together again and gradually start merging to their preferred lane. For the execution of the policy, CAVs, CAV Platoons and CVs can optionally exchange V2V for manoeuvring coordination.

Functional constraints / dependencies	The RSI must have the road works information (position, scope, duration, lane configuration, etc.). The RSI must be able to detect CAVs, CAV Platoons, and CVs speed, position and direction before and along the road works. The RSI must be able to determine the traffic separation policy, which includes the preferred lanes for the different vehicle types for the different sections of the motorway(s) (i.e. before, during and after road works). The RSI must be able to provide the traffic separation policy to CAVs, CVs and CAV Platoons. CAVs and CAV Platoons must be able to receive, process and execute the traffic separation policy and optionally support V2V manoeuvring coordination. CVs must be able to receive and convey the traffic separation policy to drivers. Time and space constraints must not limit the implementation of the traffic separation policy.

5.3.4 Service 4: Manage by guidance to safe spot

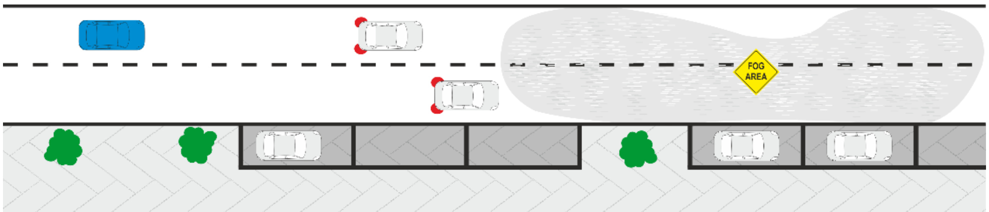
Service introduction	
Summary	In case a vehicle is going to perform a MRM, infrastructure helps by providing detailed information about possible safe stops.
Background	When vehicles need to perform a MRM, in most cases it will be a stopping on the ego lane. This would have a bad impact on traffic flow and efficiency and can also be dangerous for the performing vehicle and upcoming vehicles, esp. when occurring in areas of high complexity or high speeds, e.g. motorways. Upstream vehicles will possibly not be able to pass the stopped vehicle, leading to accidents or traffic jams. RSI can help by providing detailed information about areas in the vicinity where a safe stop is possible and whether this spot is occupied or not.
Objective	Have the CAV stop at an area where traffic flow and safety are minimally impacted.
Expected benefits	The CAVs needing to perform a MRM will be guided to safe spots. The vehicles will come to a halt there with heavily reduced risk of an accident and without blocking the following vehicles. Traffic jams are prevented. Traffic flow and efficiency are kept at the former level.
Notable use case variables	MRM can occur in numerous situations and there can be many types of 'safe spots' (e.g. before road works on blocked lane, bus lanes, safe havens, parking areas, etc.). The type and position of safe spot therefore characterises the different use cases the most and is the most important variable for this service.
Selected use cases	4.1 Safe spot outside carriageway 4.2 Safe spot in lane of blockage

Use case 4.1: Safe spot outside carriageway.

Use case introduction	
Summary	An area is on the road where automated driving is challenging and ToCs are necessary which might fail. Just in front of this area, there is another area (parking area, emergency lane) available which could be used as a safe spot. Infrastructure knows about this safe spot and provides information about it to the CAVs. A CAV which needs to execute a MRM is using this information and stops at the provided safe spot instead of in the carriageway.
Background	Whenever there is an area on the road where automated driving is challenging, non-automated vehicles are able to pass this area, but automated vehicles might need to perform a ToC when approaching. In some situations, the ToC fails and the vehicle must perform a MRM. As the normal MRM procedure most likely is stopping at the current lane,

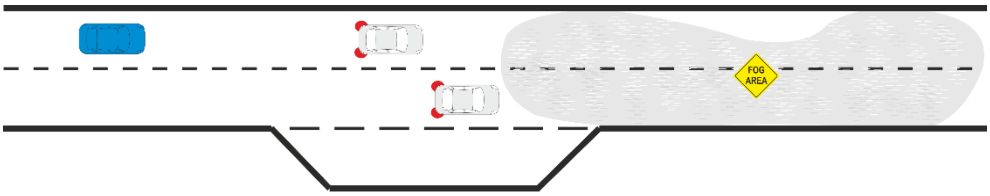
	this would cause dangerous situations and traffic jams. RSI can identify possible areas for safe stops outside the carriageway where ToCs are likely. When CAVs use these safe stops for MRMs instead of just stopping on the ego lane, the situation is less critical and traffic efficiency is impacted minimally.
Objective	Help CAVs to perform MRMs ending outside the carriageway.
Desired behaviour	RSI is detecting safe spots and providing related information about the safe spot and the area where automated driving is challenging. CAVs receive the information and some perform ToCs. One CAV which needs to perform a MRM after a ToC failure uses the provided safe spot to come to a safe stop outside the carriageway.
Expected benefits	The CAV is reaching a safe spot in the area outside the carriageway which is less dangerous than just stopping on the driving lane. As a result, traffic flow, efficiency and safety are not reduced since other vehicles can still pass the area.
Use case description	
Situation(s)	1. An urban two-lane road with an area where automated driving is challenging and a free parking area some point upstream. 2. A two-lane motorway with an area where automated driving is challenging without an emergency lane, but with a safe haven either left or right of the carriageway.
Actors and relations	RSI: Detects safe spots (parking spaces/safe havens) and their occupancy upstream of the area where automated driving is challenging and distributes the location of the safe spots to CAVs. Also, the RSI provides information about the area where automated driving is challenging for CAVs. MRM CAV: Receives the challenging area provided by the RSI and processes it. A ToC to the driver is initiated. In addition, a safe spot position is received from the RSI. The driver does not respond in time and an MRM is executed, and the safe spot is reached. CAV: Receive the challenging area provided by the RSI and processes it. A ToC to the driver is initiated. Driver resumes control. AV: Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. CV: Also receives the challenging area from the RSI and alerts the driver about possible ToCs/MRMs. Normal driving otherwise possibly affected by additional supportive measures individually. LV: Normal driving and merging operations possibly affected by supportive measures as a group.

<table>
<tr><td>Scenario(s)</td><td>
<u>Scenario 1, based on situation 1, free parking area</u>



On an urban two-lane road, CAVs are approaching an area where automated driving is challenging. RSI is aware of this area and consecutively monitors the vicinity in upstream of this area. Upstream is a row of parking spaces with some free space which can be used as safe spot. Information about the area where automated driving is challenging, and the corresponding position of the safe spot is sent to the CAVs. The CAVs receive this information and initiate ToCs to the drivers. For one CAV, the ToC is not successful, thus an MRM is executed. This CAV is driving to the safe spot and stops there.

<u>Scenario 2, based on situation 2, motorway with safe haven</u>



On a two-lane motorway, CAVs are approaching an area where automated driving is challenging, but where a safe haven is available. RSI is aware of this area and consecutively monitors if the safe haven is still available and can be used as safe spot. Information about the area where automated driving is challenging, and the corresponding position of the safe spot is sent to the CAVs. The CAVs receive this information and initiate ToCs to the drivers. For one CAV, the ToC is not successful, thus an MRM is executed. This CAV is driving to the safe spot and stops there.
</td></tr>
<tr><td>Functional constraints / dependencies</td><td>
RSI must be able to detect free safe spots and whether they are still available.

RSI must be able to provide information of the areas where automated driving is challenging to CAVs.

RSI must be able to distribute the position of the safe spot to the CAVs.

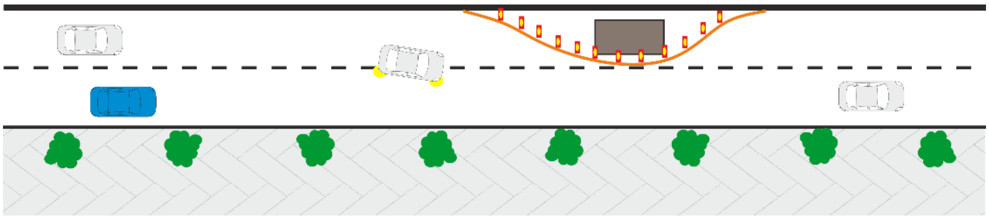
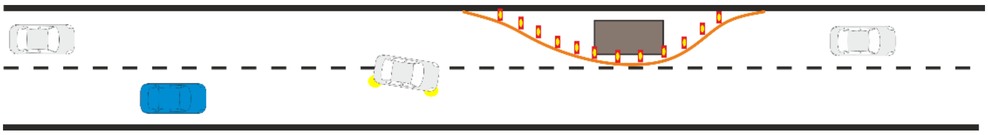
CAVs and CVs need to be able to receive and understand the information.

CAVs need to be capable of reaching the safe spot automatically.
</td></tr>
</table>

Use case 4.2: Safe spot in lane of blockage

Use case introduction	
Summary	A blockage (e.g. construction site, broken vehicle) is on the road. RSI is aware of the blockage and provides safe spot information just in front of it to avoid negative impacts on traffic efficiency. A CAV which needs to execute an MRM is following the advice and stops at the provided safe spot.

Background	When there is a challenging situation for automated driving, vehicles might need to perform ToCs. When these ToCs fail, the vehicles perform an MRM, and the vehicle most likely stops on the ego lane. That would be dangerous to the vehicle and upcoming vehicles and disrupt traffic flow. When there is also some kind of blockage on the road, this could be a broken-down vehicle or a construction site or any other obstacle which is blocking this lane, it is better if the vehicle stops just in front of the blockage. Therefore, the RSI is monitoring the area and provides information about a possible safe spot position in front of or behind the obstacle.
Objective	Help CAVs to perform less dangerous MRMs by stopping in front of a blockage.
Desired behaviour	RSI is – in case of a non-static blockage, e.g. a broken-down vehicle – detecting the obstacle. Furthermore, it needs to detect safe spots and provide related information about the safe spot and the area where automated driving is challenging. CAVs receive the information and some will perform ToCs. A CAV which needs to perform a MRM uses the provided safe spot to come to a safe stop in front of the blockage.
Expected benefits	The CAV is reaching a safe spot in front of the blockage, which is less dangerous than just stopping on the driving lane. Traffic flow, efficiency, and safety is not reduced, other vehicles can still pass the blockage.
Use case description	
Situation(s)	1. An urban two-lane road with a construction site blocking one lane 2. A two-lane motorway with a construction site blocking one lane, and no emergency lane.
Actors and relations	<u>RSI:</u> Detects a blockage on the road. This service is only needed when the blockage is not static. The RSI provides information about the area where automated driving is challenging for the CAVs. Also, the RSI detects free safe spots in front of the blockage and provides this information to CAVs and CVs. <u>MRM CAV:</u> Receives the challenging area provided by the RSI and processes it. A ToC to the driver is initiated. In addition, a safe spot position is received from the RSI. The driver does not respond in time and an MRM is executed, and the safe spot is reached. <u>CAV:</u> Receive the challenging area provided by the RSI and processes it. A ToC to the driver is initiated. Driver resumes control. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. <u>CV:</u> Also receives the challenging area from the RSI and alerts the driver about possible ToCs/MRMs. Normal driving otherwise possibly affected by

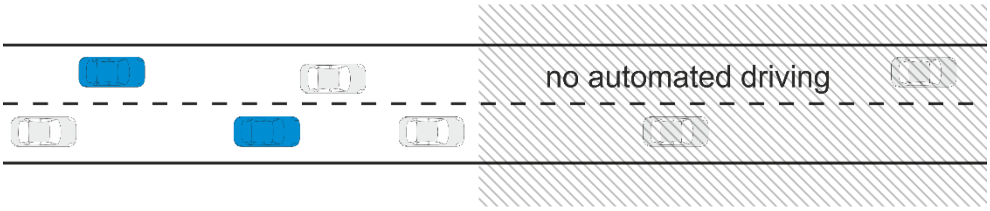
	additional supportive measures individually. LV: Normal driving and merging operations possibly affected by supportive measures as a group.
Scenario(s)	Scenario 1, based on situation 1, urban construction site  There is a construction site covering one lane of the urban road. The RSI knows about it and provides this information to the approaching CAVs. Some CAVs are not able to pass the construction site and perform a ToC. Some of the ToCs are unsuccessful, so the respective CAV must perform a MRM. It uses the safe spot information just in front of the construction site to come to a safe stop. Scenario 2, based on situation 2, motorway construction site  This situation is the same as Situation 1, but on Motorways. Speeds are higher, and more space and time are needed to execute the measures of this service.
Functional constraints / dependencies	RSI must be able to detect non-static blockages or know about static blockages (i.e. position, range, duration, etc.). RSI must be able to detect free safe spots and whether they are still available. RSI must be able to provide information of the areas where automated driving is challenging to CAVs. RSI must be able to distribute the position of the safe spot to the CAVs. CAVs and CVs need to be able to receive and understand the information. CAVs need to be capable of reaching the safe spot automatically.

5.3.5 Service 5: Distribute ToC/MRM by scheduling ToCs

Service introduction	
Summary	Whenever multiple ToCs need to be executed in the same area, this service distributes them in time and space to avoid collective ToCs and possibly MRMs in a small area.
Background	When automated vehicles switch to and from automated mode, those are expected to behave more erratically. Also, after the transition, driving parameters are different (e.g. different headway, different lateral movement variation, different overtaking behaviour, etc.). Because the driving behaviour during transitions and driving behaviour shortly thereafter are different, traffic flow and safety are disturbed. This effect is amplified when there are many ToCs in the same area. To prevent that amplification in mixed traffic scenarios, ToCs are distributed in time and space upstream (for downward transitions) or downstream (for upward transitions) of an area where there is no or limited automated driving.
Objective	Distribute ToCs by scheduling them in time and space to prevent collective ToCs/MRMs thereby preventing a disturbance of traffic flow.
Expected benefits	Because collective ToCs and possibly MRMs are prevented, there is a more harmonised traffic flow. Vehicle behaviour changes more gradually instead of in a concentrated area. As a result, less vehicles need to slow down, and the risk of accidents is reduced. Traffic flow, efficiency, and safety are increased.
Notable use case variables	This service can be applied to many different situations, if the location and timing of the ToCs cause can be predicted. Wherever and whenever there is a situation causing ToCs and it is plannable or detectable vehicles can be managed up- and downstream. As a result, there are many types of situations where this service can be applied. Causes could be a blockage (e.g. road works, accident), merging sections (on- offramp, motorways converging/diverging, etc.), geo-fences restricting automated driving (from OEM or road authority). In other words: any situation that limits or prevents automated driving. Also, this service supports managing upward transitions in addition to downward transitions. There can be ToCs towards an area limiting or preventing automated driving (vehicles transitioning from automated to manual mode) or there can be ToCs leaving such area (vehicles transitioning from manual to automated mode).
Selected use cases	5.1 Schedule ToCs before no AD zone 5.2 Schedule ToCs after no AD zone *Note: use cases 5.1 and 5.2 could be combined to form one larger use case / scenario. The described situations could be 'stitched'.*

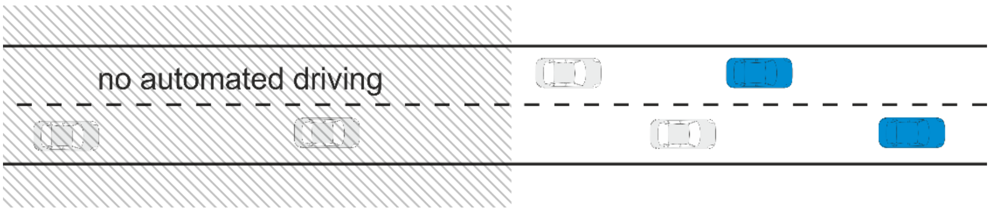
Use case 5.1: Schedule ToCs before no AD zone

Use case introduction	
Summary	Approaching an area where automated driving is not possible (no AD zone) on a two-lane road, ToCs are scheduled (in time and place) upstream of the no AD zone.
Background	When automated vehicles from automated mode to manual, those are expected to behave more erratically. Also, after the transition, driving parameters are different (e.g. different headway, different lateral movement variation, different overtaking behaviour, etc.). Because the driving behaviour during transitions and driving behaviour shortly thereafter are different, traffic flow and safety are disturbed. This effect is amplified when there are many ToCs in the same area. To prevent that amplification in mixed traffic scenarios, downward ToCs are distributed in time and space upstream of an area where there is no or limited automated driving (e.g. tunnel, geofence, complicated road works).
Objective	Prevent disturbance of the traffic flow due to collective ToCs and possibly MRMs by distributing ToCs upstream of the no AD zone.
Desired behaviour	Approaching the no AD zone, CAVs subsequently perform ToCs geographically spread out.
Expected benefits	Traffic disturbance due to collective ToCs are minimised. As a result, negative impact on the traffic situation is expected to be minimal. For all vehicles, traffic flow, efficiency, and safety are improved.
Use case description	
Situation(s)	A two-lane road with an area downstream where automated driving is not possible. This can be either an urban road or a motorway.
Actors and relations	<u>RSI:</u> Monitors traffic operations along the road through collective perception resulting in vehicle positions, directions, and speeds, including those of platoons. Using that information, the RSI establishes the most suitable position and moment for each CAV (including those in a platoon) to perform a ToC. Those ToC requests are provided to CAVs and CAV Platoons. <u>CAV and CAV Platoon:</u> receive ToC requests from RSI and performs ToCs in accordance with the request. Optionally, V2V could be used to coordinate different vehicle manoeuvres, if needed. <u>CV:</u> Receives ToC warnings from CAVs and alerts the driver about possible ToCs/MRMs. Normal driving otherwise possibly affected by additional supportive measures individually. <u>AV:</u> Possibly affected by supportive measures as a group. Still doing MRMs unless driver responds to a ToC request from the vehicle. If ToC is successful, the AV continues driving. <u>LV:</u> Normal driving operations possibly affected by supportive measures as

	a group.
Scenario(s)	 CAVs and other traffic are approaching a no AD zone with 2 lanes. Starting about 3 km upstream from the no AD zone, the RSI determines through collective perception the positions and speeds of vehicles and determines the optimal location and moment for CAVs to perform a downward ToC. Subsequently, ToC requests are provided to the corresponding CAVs. Based on the ToC Requests, the CAVs perform ToCs at the desired location and moment in time and transition to manual mode. CVs are warned about the ToCs and possible MRMs. In the no AD zone, the CAVs are in manual mode. *Note: the figure is schematic. The blue automated vehicles have performed ToCs further upstream than the picture might suggest.*
Functional constraints / dependencies	The RSI must be able to detect CAVs, CAV Platoons, and CVs speed, position, and direction along the road. The RSI must be able to determine the optimal position and moment for ToCs for each CAV. The RSI must be able to provide the ToC requests to CAVs and CAV Platoons. CAVs and CAV Platoons must be able to receive, process and execute the ToC requests. CVs must be able to receive ToC warnings from other vehicles and inform the driver. Time and space constraints must not limit the implementation of the ToC scheduling service. There must be enough time and space upstream of the no AD zone to apply the distribution of ToCs (and thus the ToCs themselves).

Use case 5.2: Schedule ToCs after no AD zone

Use case introduction	
Summary	Leaving an area where automated driving is not possible (no AD zone) on a two-lane road, ToCs are scheduled (in time and place) downstream of the no AD zone.
Background	When automated vehicles switch from manual to automated mode, driving parameters are different (e.g. different headway, different lateral movement variation, different overtaking behaviour, etc.). Because the driving behaviour during transitions and driving behaviour shortly thereafter are

	different, traffic flow and safety can be disturbed. This effect is amplified when there are many ToCs in the same area. To prevent that amplification in mixed traffic scenarios, upward ToCs are distributed in time and space downstream of an area where there is no or limited automated driving (e.g. tunnel, geofence, complicated road works).
Objective	Prevent disturbance of the traffic flow due to collective ToCs by scheduling ToCs in time and space downstream of the no AD zone.
Desired behaviour	Leaving the no AD zone, CAVs subsequently perform ToCs geographically spread out.
Expected benefits	Traffic disturbance due to collective ToCs are minimised. As a result, negative impact on the traffic situation is expected to be minimal. For all vehicles, traffic flow, efficiency, and safety are improved.
Use case description	
Situation(s)	A two-lane road with an area upstream where automated driving is not possible. This can be either an urban road or a motorway.
Actors and relations	RSI: Monitors traffic operations along the motorways through collective perception resulting in vehicle positions, directions, and speeds, including those of platoons. Using that information, the RSI establishes the most suitable position and moment for each CAV (including those in a platoon) to perform a ToC. Those ToC requests are provided to CAVs and CAV Platoons. CAV and CAV Platoon: receive ToC requests from RSI and performs ToCs in accordance with the request. Optionally, V2V could be used to coordinate different vehicle manoeuvres, if needed. CV: Receives ToC warnings from CAVs and alerts the driver about possible ToCs. Normal driving otherwise possibly affected by additional supportive measures individually. AV: Possibly affected by supportive measures as a group. Still doing ToCs in the same area. LV: Normal driving operations possibly affected by supportive measures as a group.
Scenario(s)	 CAVs and other traffic are leaving a no AD zone with 2 lanes. CAVs are driving in manual mode together with other vehicles. From the point where vehicles leave the no AD zone to a few kilometres downstream (e.g. 3 km), the RSI determines through collective perception the positions and speeds of vehicles and determines the optimal location and moment for CAVs to

	perform an upward ToC. Subsequently, ToC requests are provided to the corresponding CAVs. Based on the ToC Requests, the CAVs perform ToCs at the desired location and moment in time and transition to automated mode. CVs are warned about the ToCs. *Note: the figure is schematic. The blue automated vehicles perform ToCs further downstream than the picture might suggest.*
Functional constraints / dependencies	The RSI must be able to detect CAVs, CAV Platoons, and CVs speed, position, and direction along the road. The RSI must be able to determine the optimal position and moment for ToCs for each CAV. The RSI must be able to provide the ToC requests to CAVs and CAV Platoons. CAVs and CAV Platoons must be able to receive, process and execute the ToC requests. CVs must be able to receive ToC warnings from other vehicles and inform the driver. Time and space constraints must not limit the implementation of the ToC scheduling service. There must be enough time and space downstream of the no AD zone to apply the distribution of ToCs (and thus the ToCs themselves).

6 Safety and efficiency metrics

Key Performance Indicators (KPIs) were adopted and developed for the assessment of traffic management strategies within the context of the aforementioned use cases. Earlier scientific work and relevant policy-driven projects were reviewed for the determination of existing KPIs definitions that would be relevant to the scope of TransAID. Additionally, new metrics were introduced for the assessment of traffic operations in Transition Areas. KPIs used within the context of TransAID pertain to traffic efficiency, safety, energy efficiency and the environment, and communications. Regarding traffic efficiency indicators, both aggregate (network-wide) and disaggregate (local) indicators were considered. Microscopic traffic characteristics relating to vehicle operations were also selected for the evaluation of the different vehicle type dynamics on Transition Areas. KPIs will be estimated both upstream, at, and downstream of Transition Areas and per vehicle type (to identify possible interactions between different vehicle types). With respect to safety metrics, ‘proxy’ measures such as the space gaps and speed differences between vehicles were used. Since evaluation of traffic safety with the use of microscopic traffic simulation software is directly infeasible, these “surrogate safety measures” are selected (based on results published in literature) to provide an indication of a safe or unsafe situation. Table 1 presents a comprehensive list of the projects and other scientific work that was reviewed for the identification of KPIs relevant to the scope of TransAID.

Table 1: List of reviewed projects and scientific work for the identifiaction of KPIs

Project Name	**Project Description**
PREVENT	Development and demonstration of preventive safety applications and technologies.
HAVEit	Focus on highly automated driving of individual vehicles and on automation level transitions.
INTERACTIVE	Introduction of safety systems that autonomously brake and steer.
AdaptIVe	Development of automated driving functions for daily traffic by dynamically adapting the level of automation to situation and driver status.
AUTOMATE	Development of a highly reliable automated driving system that users can understand, accept, trust and eventually will regularly use.
ADAS&Me	Develops ADAS that incorporate driver / rider state, situational / environmental context and adaptive HMI to automatically hand over different levels of automation and thus ensure safer and more efficient road usage for all vehicle types (conventional and electric car, truck, bus, motorcycle).
FOTsis	Analyzes the capabilities of the infrastructure to incorporate various functionalities of cooperative vehicles and traffic management centers and determines their impact on traffic and safety.

CARTRE – ITS JPO – SIP-adus	Conducted a questionnaire survey in search for a high-level impact assessment framework for automation in road transportation.
AECOM Study on KPIs for ITS (Payne, 2015)	Proposed a methodology for the definition of KPIs for ITS.
FOT-Net Data (Gellerman et al., 2017)	Compiled a comprehensive list of KPIs (Performance Index Matrix) for the impact assessment of field operational tests (Updated FESTA Handbook).
DRIVE C2X (Stahlmann, Festag, Tomatis, Radusch, & Fischer, 2011)	Addressed large-scale field trials of safety and traffic efficiency applications based on C2X communication under real-world conditions.
AutoNet2030 (Fortelle et al., 2014)	Developed and tested a co-operative automated driving technology, based on a decentralised decision-making strategy which is enabled by mutual information sharing among nearby vehicles.

The objective of TransAID is to manage connected and automated vehicles in a mixed traffic stream along Transition Areas so as to prevent, manage or distribute ToC/MRM. To this end a comparison of traffic conditions in terms of aggregate traffic performance measurements (Table 2) before and after the implementation of a traffic management scheme per use case is proposed to demonstrate the impacts of infrastructure-assisted traffic management on traffic efficiency along Transition Areas. TransAID encompasses vehicles of different automation and communication capabilities which co-exist and interact on the same network. The impacts of different vehicle types on the same traffic stream pertain to the aforementioned capabilities. TransAID proposes existing KPIs (Table 3) for the evaluation of vehicle operations (per vehicle type) to identify the contribution of each vehicle type on the prevailing traffic conditions. Moreover, the latter KPIs can be used for the assessment of vehicle behaviour under different traffic management strategies. Energy efficiency of infrastructure-assisted traffic management along Transition Areas is evaluated in terms of fuel consumption and CO_2 emissions (Table 4). The proposed energey efficiency related performance measurements can be accurately estimated during microscopic traffic simulation experiments.

Table 2: KPIs for the evaluation of network efficiency

No.	KPI Name	KPI Description
1	Mean time headway (THW)	The mean value of the time gap to an object (e.g. a lead vehicle (bumper to bumper) or pedestrian, which is travelling in the vehicle's path of travel).
2	Standard deviation of time headway	Defined as the standard deviation of the THW.
3	Average delay time (per distance)	Extra travel time due to negative deviation from the intended speed profile.
4	Average travel time (per distance)	Time required to travel from origin to destination for a vehicle.

5	Average stop time (per distance)	Average time at standstill per vehicle per kilometre.
6	Throughput	Total number of vehicles per hour through a particular road section or intersection approach, normalised to number of lanes and proportion of green time (where relevant).
7	Average network speed	Average space mean speed of the vehicular fleet on a specific road network.
8	Average density	Average number of vehicles per kilometre for a specified road segment.
9	Average flow rate	Average number of vehicles per hour that have passed through a specific location of the road network during the simulation period.
10	Number of stops	Average number of stops per vehicle per kilometre.
11	Number of lane changes	Total number of lane changes per kilometre.
12	Average queue length	Average queue in a specific road segment during the simulation period. It is measured in vehicles.
13	Maximum queue length	Maximum length of the queue in a specific road segment, expressed as number of vehicles per lane.
14	Total travelled distance	Total number of kilometres travelled by all the vehicles that have crossed a specific road segment.

Table 3: KPIs for the evaluation of vehicle operations (per vehicle type)

No.	KPI Name	KPI Description
1	Mean speed	Mean vehicle speed
2	SD speed	Standard deviation of vehicle speed
3	Maximum longitudinal acceleration	Peak level of longitudinal acceleration achieved during a scenario.
4	Maximum lateral acceleration	Peak level of lateral acceleration achieved during a scenario.
5	Frequency of left lane changes	Time frequency of performed left lane changes (either time or distance based).
6	Frequency of right lane changes	Time frequency of performed right lane changes (either time or distance based).
7	Deviation from desired lane	Number of lanes from the current lane to the desired lane (0 if driving in the desired lane).
8	Frequency of active overtaking	Time frequency of active overtaking (i.e. overtaking conducted by the subject vehicle), either time or distance

		based.
9	Frequency of passive overtaking	Time frequency of passive overtaking (i.e. overtaking in which the subject vehicle is overtaken), either time or distance based.
10	Frequency of lane exceedances	The number of times per a certain distance or time the vehicle leaves the own lane boundaries.
11	Minimum accepted gap in lane changes	Minimum space or time gap accepted by a driver or vehicle to perform a lane change.

Table 4: KPIs for the evaluation of energy and environmental impacts

No.	KPI Name	KPI Description
1	Average fuel consumption (l/km)	Fuel consumed per road-km for a vehicle's trip from origin to destination.
2	Total fuel consumption (l)	Total fuel consumed by all vehicles on the road network during the analysis time-frame.
3	Average CO_2 emissions (g/km)	CO_2 emitted per road-km for a vehicle's trip from origin to destination.
4	Total CO_2 emissions (g)	Total CO_2 emitted by all vehicles on the road network during the analysis time-frame.

Surrogate Safety Measures (SSMs) are events that can be correlated with crash rates. SSMs can be used as indicators of accidents in safety evaluations and are in particular useful when testing for situations where no real or not enough accident data is available (simulation studies). SSMs can be used in the development of intelligent driver support systems (such as collision avoidance systems) but also for more advanced systems such as Automated Vehicles. They can provide a very useful insight when mixed traffic occurs (as not all vehicles are CAVs), which is of particular interest in the envisioned scope of the scenarios within the TransAID project. SSMs function as indicators and are linked with associated likelihoods to have accidents (collision risk) and accident outcomes (collision severity). Thus, they are not direct accident measures, but they have to be proccessed and analyzed to indicate the probability of safety critical situations.

The calculation of the SSMs, aims to create and validate a methodology which allows for the comparison of safety-related aspects, such as the safe functioning (i.e. road safety), between automated vehicles and non-automated vehicles. Within TransAID, a specific set of infrastructure and incident configurations are tested, by means of dedicated scenarios. For each of these scenarios, corresponding experiments are carried out. Data logging during the simulation time-line enables the collection of the required information to estimate the following surrogate safety measures (Table 5). A comprehensive list of different SSMs and their use for assessing the likelihood of various crash types is presented in Appendix B.1. Thorough information with respect to the analysis of SSMs within the context of each use case for safety assesment will be provided in future deliverables.

Table 5: KPIs for the evaluation of traffic safety

No.	KPI Name	KPI Description
1	Mean of time-to-collision (TTC)	The mean time required for two vehicles (or a vehicle and a object) to collide if they continue at their present speed and on the same path. Measures a longitudinal margin to lead vehicles or objects.
2	Post Encroachment Time (PET)	Time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of collision.
3	Deceleration Rate to Avoid Collision (DRAC)	The rate at which a vehicle must decelerate to avoid a probable collision.
4	Time exposed Time to Collision (TET)	Summation of all time intervals that a vehicles experiences TTC values that are lower that a specific TTC threshold value.
5	Time integrated Time to Collision (TIT)	The difference between observed TTC and threshold TTC value for a given time interval cumulative to the time the vehicle traverses the study area.
6	Number of instances with hard braking	Number of instances that decelartion rate exceeds a minimum pre-determined threshold.

The proposed use cases within the context of TransAID entail traffic management schemes that aim to distribute ToC/MRM or lane changes in space and time upstream of Transition areas. Therefore, KPIs pertaining to the total number and density of ToC/MRM and lane changes upstream of the disruption areas (road works, accident, stopped vehicle after MRM, etc.) are introduced (Table 6). The proposed new KPIs can be correlated to average macroscopic traffic stream characteristics to verify the effect of the proposed traffic management schemes. With respect to the traffic separation use cases lane-based KPIs will be considered. KPIs pertaining to network efficiency, vehicle operations, energy efficiency, safety, and communications will be also used to assess traffic dynamics and operations along Transition Areas.

Table 6: New traffic dynamics metrics at Transition Areas

No.	KPI Name	KPI Description
1	Mean duration of the transfer of control	Mean duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle).
2	Maximum duration of the transfer of control	Maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle).
3	Total Number of ToCs	Number of ToCs performed in the whole network.
4	Number of ToCs (per distance)	Number of ToCs performed per kilometre.

5	Total Number of Lane Changes	Number of Lane Changes performed in the whole network.
6	Number of Lane Changes (per distance)	Number of Lane Changes performed per kilometre.
7	Total Number of MRMs	Number of MRMs performed in the whole network.
8	Number of MRMs (per distance)	Number of MRMs performed per kilometre.

The traffic management policies of the TransAID project for the prevention, management and distribution of ToC at transition areas require the communication among vehicles and among vehicles and the infrastructure. Therefore, communication KPIs have been introduced (Table 7). Those KPIs can be correlated with the efficiency of the communication scheme and with the availability of updated information. A more detailed description can be found in Appendix B.2.

Table 7: KPIs for the evaluation of communications

No.	KPI Name	KPI Description
1	Neighbourhood Awareness Ratio	The proportion of vehicles in a specific range from which a message was received in a defined time interval.
2	Neighbourhood Interference Ratio	The ratio between the number of vehicles outside the specified range from which the given vehicle received a message, and the total number of vehicles from which the given vehicle has received a message.
3	Latency	The time difference between the transmission and reception time of a packet.
4	Date age	The time interval between the instant when the data is generated in the source vehicle and the actual time.
5	Packet Delivery Ratio	The ratio of packet successfully received over the total number of packets transmitted.
6	Footprint	The total channel resources consumed by the radio of a single vehicle in time and space.
7	Channel Busy Ratio	The percentage of time that the channel is perceived as busy for a given time interval.
8	Messages received per vehicle	The number of messages of a specific type received by a vehicle in a determined time interval.
9	Inter Package Reception Time	The interval of time elapsed between two successful receptions of packets of the same type.

Finally, the developed measures will be prototypically implemented in real world prototypes. The main reason for this implementation is to get insight into its feasibility. As feasibility cannot be easily measured directly, the following KPIs (Table 8) have been defined. These are basically repitions of former mentioned KPIs, but they can only be measured in a dedicated area of the feasibility assessment, i.e. on the proving ground or on the limited segment of the public road used for implementation.

Table 8: KPIs for the evaluation of feasibility assessments of the real world implementations

No.	KPI Name	KPI Description
1	Mean duration of the transfer of control	Mean duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle).
2	Maximum duration of the transfer of control	Maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle).
3	Total Number of ToCs	Number of ToCs performed.
4	Total Number of Lane Changes	Number of Lane Changes performed.
5	Total Number of MRMs	Number of MRM performed.
7	Mean speed	Mean vehicle speed
8	SD speed	Standard deviation of vehicle speed
9	Maximum longitudinal acceleration	Peak level of longitudinal acceleration achieved during a scenario.
10	Maximum lateral acceleration	Peak level of lateral acceleration achieved during a scenario.

7 Conclusions

The main objective of this deliverable is to describe and identify the use cases where disruptions of traffic flow are expected to be most severe because of transitions between automation levels, and to identify KPIs to evaluate those use cases. For those identifications, TransAID has looked to state of the art literature (Chapter 3), held a workshop with road authority stakeholders (Appendix A), consulted advisory board members and interviewed experts.

The findings have been combined to identify the relevant aspects for TransAID scenarios and Transition of Control (ToC) in general (Chapter 3.5.12). The large number of aspects (or dimensions) affecting automated vehicle behaviour and possible trigger conditions in combination with the many uncertainties regarding those aspects and conditions (e.g. what exactly triggers a ToC or Minimum Risk Manoeuvre?), posed a challenge for the use case and scenario definitions.

Through brainstorming using a template based on above mentioned aspects and conditions, TransAID has identified five generic services that can be applied to many situations (see Section 4.3.4). Because of their generic characteristic, these services are expected to mitigate negative impacts resulting from vehicles in Transition Areas, regardless of the uncertainties (i.e. even if certain conditions are different, the solutions still apply).

As a result, an overview was created of the situations where transition of control occurs regularly and causes traffic flow disruptions. By means of detailed services and use case descriptions (Chapter 5), the deliverable gives a comprehensive overview on (negative) traffic safety and traffic efficiency impacts, for both urban, inter-urban and motorway situations, and proposes a preliminary set of (high-level) traffic measures.

Within the five services, the use cases and scenarios provide a specific set of examples for the abovementioned situations. These use cases provide a common basis for the next steps in TransAID (i.e. development of driver / vehicle models, traffic management (TM) procedures and communication / sensor models in the WPs 3-5).

In addition to the services and use cases, an extensive set of Key Performance Indicators (KPIs, see Chapter 6) has been identified to evaluate the use cases (later on in WP6). These KPIs are based on those found in literature and new KPIs identified by TransAID to specifically evaluate the vehicle behaviour (especially ToCs) in Transition Areas.

Given the work done for this deliverable, it contributes to the TransAID sub-objectives 1 and 6:

1) WP2 contributes to the evaluation and modelling of current automation prototypes and their drivers' behaviour (subobjective 1) by the identification and description of use cases.

6) Sub-objective 6 is addressed by the definition of safety and efficiency metrics for uniformed evaluation.

When, during the course of the project, new insights become available, the use case descriptions will be updated to support continuous progress which is also done for the WPs that depend on the output of WP2.

7.1 Next steps

Based on the use cases and scenarios provided as examples within the five services, simulation (SUMO) networks need to be created to study the Transition Areas and accompanying mitigating measures. This is the main objective of the next deliverable 2.2 where for each use case specific scenarios are devised, and corresponding network definition files and configuration files are provided in a suitable format (e.g., as a SUMO-net) as an input to the simulations in WPs 3-6.

These files include all necessary information on the road network (e.g. on the roads, traffic lights, locations of possible incidents, etc.). A simulation that uses these specifications and includes no traffic management procedures should expose the identified issues when it is run with the appropriate AV-models from WP3.

A report will be created describing the set of network definition files and configuration files to enable modelling activities in WP3-5 (fact sheets as well as network and configuration files loadable into the traffic simulation SUMO)[4].

Completing deliverable 2.2 will fulfil the second TransAID sub-objective:

2) Sub-objective 2 is addressed by the provision of the simulation scenarios, the network definition and configuration files and modelling requirements.

For milestone M18 a revised version of deliverable 2.2 will be created by updating that deliverable with insights gathered during the first TransAID iteration and needed information for the second one.

[4] WPs 3-5 already started their work based on preliminary work for D2.2 based on concept versions of this deliverable.

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Appendix A: CoEXist/MAVEN/TransAID workshop report

Vehicle automation: implications for city and regional authorities

Joint CoEXist/MAVEN/TransAID workshop

10 October 2017– Brussels

WORKSHOP NOTE

1. Scope and aims of workshop

The H2020 projects hosting this workshop, CoEXist, MAVEN and TransAID, are all exploring the implications of increasing vehicle automation on urban roads. They are mainly considering the traffic management and infrastructure aspects of connected and automated vehicles (CAVs). CoEXist is also exploring the transport planning and policy dimensions. Further information on each of these projects is provided in Appendix A.III.

Consultation with, and outreach, to local/regional authorities, especially city authorities and traffic managers, is important for each of these projects. Given the projects' synergies, in terms of content and timing, as well as the partnership overlap, the organisation of a joint workshop targeting local authorities offered a logical and efficient way to proceed. This workshop follows a successful workshop for local authorities organised by MAVEN in Barcelona in November 2016. Neither CoEXist nor TransAID had started at that time.

The primary aim of this workshop was to gather the views and requirements of local authorities and other urban transport stakeholder on various tasks underway or planned within the projects, specifically:

- the CoEXist automation-ready framework
- the MAVEN transition roadmap
- the TransAID list of situations for which automation is inappropriate or a threat

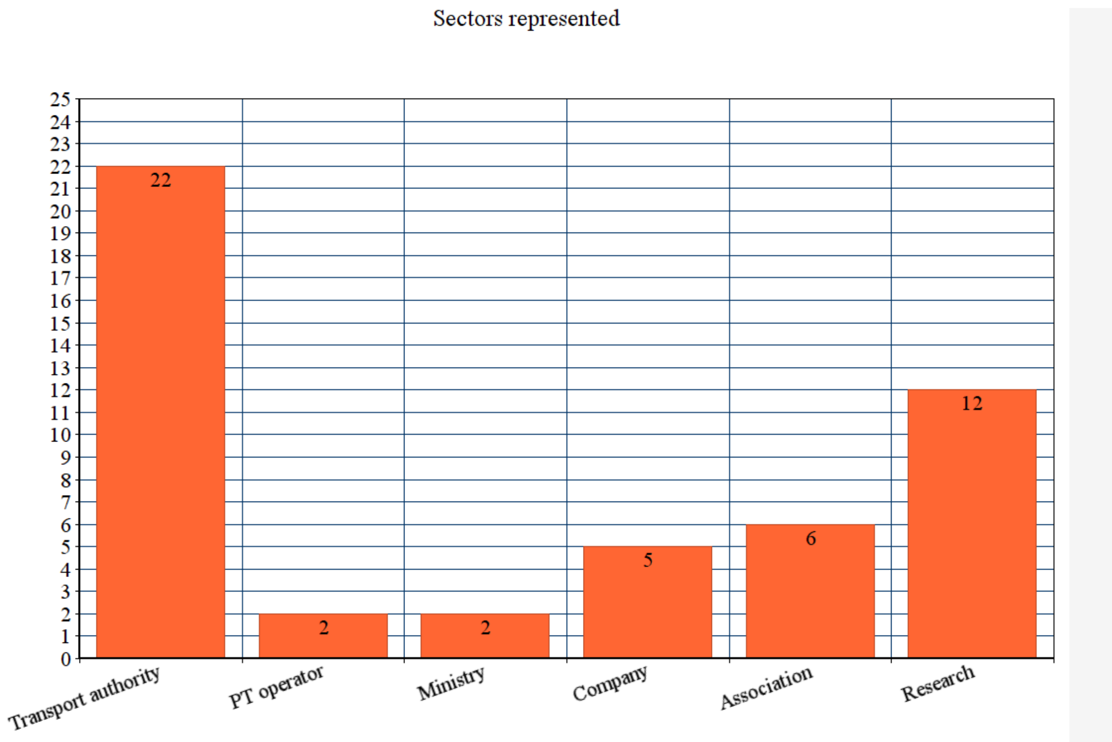
The workshop agenda was divided into two parts:

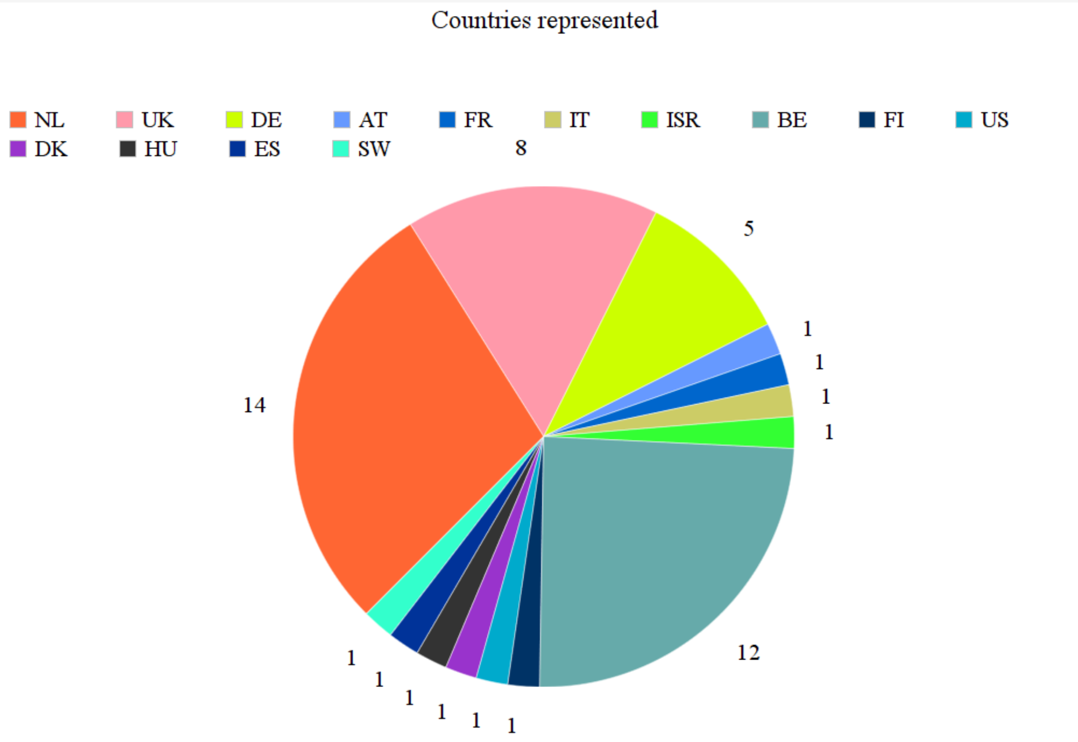
- the morning plenary session saw an introduction to the three projects, to the CAV activities of two projects' partner cities as well as insight to research in this field and the wider city/regional authority perspective on CAVs
- the afternoon session comprised project sessions in smaller groups to encourage interaction.

The full set of presentations is available for downloading from the following webpage: https://www.polisnetwork.eu/publicevents/481/36/Vehicle-automation-implications-for-city-and-regional-authorities-joint-CoEXist-MAVEN-TransAID-workshop

2. Workshop participants

The audience was targeted at urban transport stakeholders, with a particular emphasis on representatives of local and regional government. The following charts provide a breakdown of attendance by sector and by country. Given the high number of representatives from transport authority, the workshop met its target audience goal. The full list of participants can be found in Appendix A.II.





3. Plenary session

Following an introduction to the workshop' aims and audience and the complementarity of the CoExist, MAVEN and TransAid projects, Bip Radia from INEA[5]contributed a few words about the work of the agency on vehicle automation. While he acknowledged the value of bringing together representatives of city and regional authorities to talk about vehicle automation, he also stressed the importance of industrial policy as a key driver for this sector.

A quick overview of the CoExist, MAVEN and TransAid projects was given by the respective project coordinator or partner, as well as a brief introduction to the scope of the afternoon project breakout session - a short description of the projects can be found in Appendix A.III. These project overviews were complemented by a presentation from Bart van Arem (TU Delft) who pulled together the results from a wide variety of other projects and studies on the topic of vehicle automation and cities. Some highlights of these findings include the following:

- Until the driver is fully relieved of the driving task, automation technology can only serve safety and comfort purposes.
- Automation should not be assessed in just transportation terms (safety, efficiency, etc). The economics, for instance, are equally important, notably in relation to time spent in congestion doing more productive things.
- High income males are more interested in certain vehicle technologies, such as adaptive cruise control (a key enabler of vehicle automation) than other cohorts.

[5]EC agency implementing the CEF programme and parts of the H2020 programmes

- Level 4 automation vehicles will not be commercially available on the roads for another 10 years.

The session then moved onto the automated vehicle activities of two city councils which are part of MAVEN and CoEXist respectively:

- Greenwich: this London borough is very active in European and national-funded projects dealing with transport and smart city innovation. A key driver for these projects is finding solutions to respond to the demographic and social challenges that the borough is facing: notably (i) a substantial population growth and the mobility demands it will generate that will be difficult to accommodate on an already saturated public transport network and (ii) growing poverty. The CAV projects on which Greenwich is working include some related to data, notably understanding what would be the demands of CAVs on the digital infrastructure (and finding that the existing infrastructure is wholly inadequate), and some focusing on customer perception and acceptance of CAVs.
- Gothenburg: this Swedish city will undergo massive change in the next 15 years due to major urban developments and population growth. The city is exploring how innovation and new technology can help it reach its sustainable goals but admits that it’s not easy to establish longer-term goals due to the rapid pace of technological change. Gothenburg expects CAVs to help it achieve its policy goal of zero vision safety and also to reduce the cost and inconvenience of infrastructure measures designed to deliver a safer and calmer traffic environment, notably speed bumps and road signs. The city council also expects automated vehicles to use less space and views digitalisation as being a key enabler of automation, connectivity and electrification.

In the following discussion, a number of points were raised, notably:

1) City AV planning and policy will to some extent depend on the type of service that is offered by automation, i.e. automated private cars or automated shuttles.
2) The presentations during the morning session are missing a vision for the future. The focus has been on car. Is this the future we want for our cities?
3) There is a need for cities and regions to reflect on how they can use automation to serve their own transport and societal goals.
4) In order to be proactive as a city or region and to engage with politicians, more information is needed about vehicle automation, notably when it will be here and what are its capabilities.

The morning plenary terminated with an overview of the main themes and points that are emerging from the Polis paper on ‘AVs and cities and regions’.

4. Small group project sessions

During the afternoon session, the audience was invited to join two rounds of 3 project group discussions.

The CoEXist session conducted three exercises to elicit input from the workshop participants. Some of the key results are listed below:

1. Defining “Automation-ready”. The aim of the task was to discuss a definition of framework to enable cities to deal with the arrival of connected and automated vehicles (CAVs)
   - CoEXist initial definition: *“Automation-ready is defined as conducting transport and infrastructure planning for automated vehicles in the same comprehensive manner as for existing modes such as conventional vehicles, public transport, pedestrians and cyclists, while ensuring continued support for existing modes.”*
   - The initial definition will be modified
   - The definition is highly debatable
   - Can we even reach a definition which is “future-proof”?
   - Liveability remains the top priority
   - Digital infrastructure should be mentioned, also regarding connectivity
   - CAV is not necessarily a separate mode; rather automation will enable new functionalities in existing modes
   - Maintenance and operation should also be described
   - We need to have a limit, as we cannot cover everything
2. Vision/mobility goals. The main objective of this exercise was to ask cities about their vision and mobility goals and whether these align with the impacts brought by CAVs in cities
   - Priority remains with cyclists and pedestrians on top with the aim of reducing congestion and improving safety
   - In some cases, priorities or goals may change (e.g. where first- and last-mile services are more cost-effective)
   - Digitalisation and innovation in transportation should become a goal (e.g. modernisation of public transport to stay competitive)
   - Cities mentioned that the focus should perhaps be more on higher liveability goals (e.g. health, economy), or probably put the mobility goals into the context of these higher level ones
   - Open question of whether sharing becomes a mobility goal?
   - Mobility of the future will most likely be more multi-dimensional
3. Identifying “automation-ready” measures. The participants were asked to define measures cities need to take over three timespans: short (0-5 years), medium (5-10 years), long term (10-15 years).

   - 0-5 years: most measures identified

    - Awareness in general (also for decision makers)
    - Proactive rather than reactive solutions (e.g. pilots)
    - Prepare infrastructure, both physical and digital
- 5-10 years:
    - Reallocation of opened up road spaces and parking to green and public spaces
    - Back office for data exchange in traffic management
    - Road pricing for “SPAM” roaming cars
- 10-15 years: least measures.
    - Rethinking and prioritising investments
    - Taxation changes
    - Landuse changes

General comments about (C)AVs

Local authorities need to deal with the arrival of AVs. However, for year now cities have moved from car-centric transport planning towards sustainable mobility planning, so what now is perceived as promoting car use goes against what cities are aiming to achieve. Planning for integrating CAVs shall be part of a bigger picture, and AVs should be part of an integrated mobility plan which takes into account different cultural contexts.

AVs could work only if they provide real public service. Cities need to reduce traffic, but they do not necessarily have enough public transport (PT) capacity. Improving the efficiency of AV movements will add more traffic to streets, whereas the goal is to remove cars. This is a policy question: who do we want to prioritise? It’s highly unlikely that AVs will have priority over pedestrians, cyclists and PT users

There is uncertainty with regards to competition between **AVs and public transport**. AVs can have benefits compared to PT services (e.g. in suburban and rural areas and in feeding PT hubs). Automated mass transit is very different from conventional PT, but individual automated cars are not different from traditional cars. Investment costs in PT are important; infrastructure investment, eg, tramways, should typically last for 40 years. The same investment process will apply to automated public transport and it certainly should not cost more.

Ultimately, policy makers will decide on the modal split a city or region should aspire to in the future and that will determine policy on AVs. An evaluation of the AV evolution also depends on freedom of choice of users. Is it possible to offer tools to the public for co-modality? That has an impact on how we design system for AV.

Open questions

- AV plannings: who is responsible, who owns the fleet? What about parking, storage, charging (assuming they will be all electric vehicles)?
- AV operations: in case of an AV ride booking, who has priority? What is the order to deal with the requests? Who defines that order? There are lots of moral questions behind these aspects, e.g. wealthier AV users can go straight and less wealthy users will have to take diversions?

Comments about (C)AVs and traffic management

Traffic and data management. No special traffic rules for automated cars are envisaged: they will be treated in the same way as normal cars. However, it is expected that automated cars will make diverting traffic easier, specifically where there is vehicle-infrastructure communication (i.e., C-ITS). Connected and automated vehicles (CAVs) can support other measures, e.g. intersections could be managed in a more dynamic manner and traffic managers could envisage using the road in a more flexible way, such as using traffic lanes in one direction during the morning peak, and in the opposite direction during the evening rush hour. However, the mix with traditional cars will still be a challenge. CAVs can take the green wave strategy on congested roads to a new level. Depending on how a city is able to interact with AVs will to some extent determine the efficiencies that can be gained.

A world of (C)AVs will rely heavily on artificial intelligence. Yet AI struggles to make sense of traffic management plans given their diversity and cultural specificity. A way around this could be for traffic management centres/road-side units to communicate directly with vehicles, to control their movements for instance. However, today's centres simply do not have the capability to control such a large number of vehicles and it's unlikely that traffic managers will even want to do this. There is also the question of liability.

Open transport data is another way to have a well-connected system. There is a need to give information to cars to direct them. Traffic managers are in the best position to predict traffic, resulting for instances from big events. There is a need for sharing data between the appropriate players at the right moment: how to exchange information between the traffic manager and service providers will be key. On the contrary, a lack of data sharing will weaken the prediction of traffic flows and reduce traffic efficiency.

Responsibilities for traffic management vary from one city/region to the next and can even be shared between different agencies within a given city/region. For instance, in London, the task is shared between the boroughs and the strategic transport authority Transport for London.

Open questions:

- Who is responsible for the vehicle-generated and who has overall ownership of data?
- Will the traffic management be capable of dealing with the large amounts of data generated by tomorrow's vehicle?
- What is the procedure in case of system failure?
- How does an AV interact with a traffic management centre?

Specific feedback about MAVEN Transition roadmap:

- Do we need to adapt the infrastructure to AV or should it be the other way around?
- Public acceptance: is there enough trust in technology?
- How will liability be addressed in a future of CAVs?
- How to make systems sufficiently robust to prevent hacking?
- MAVEN should also look at use cases where people want to get out of an AV, eg, parking
- How scalable is the MAVEN approach?
- The project's roadmap should limit itself to traffic management only and go deeper in one topic
- Clarify the ICT infrastructure requirements: on the roads and underground (eg, 5G network)

TransAID break-out session

When cooperative automated vehicles (CAVs) emerge on urban roads, there will be areas and situations where all levels of automation can be granted, and others where highly automated driving will not be allowed or not feasible. Complex environments, missing sensor inputs or temporary road configurations are examples of such situations and at these locations CAVs are expected to degrade their level of automation. Such geographic areas are referred to as 'Transition Areas' and are associated with negative impacts on traffic safety and efficiency, in particular with mixed traffic. Therefore, the objective of TransAID is to add digital infrastructure (I2V support) to avoid transitions (i.e. to maintain the automation level) or to influence the timing of the transition (in time and/or space).

In the TransAID breakout session the concept of infrastructure assistance for CAVs was discussed. One of the aims was to identify circumstances and situation which require or justify the involvement of digital infrastructure and/or restrictions set by road authorities. In both rounds most of the debate focussed on the capabilities of CAVs (in general, by brand and by automation level), which seemed to result from a lack of facts on both the limitations of self-driving vehicles and their effects on traffic flow dynamics and traffic safety. This also includes our assumptions (and uncertainty) on how CAVs will behave under various conditions, as well as how drivers/monitors will behave. Without such facts a large part of this discussion remained and will remain hypothetical, which makes it hard to conclude on appropriate measures to achieve societal policy objectives.

Notably, it was acknowledged that the capabilities of AVs are often seen as intelligent property, which hinders sharing information. On the other hand, some participants argued that car manufacturers will ensure that their vehicles will be able to operate adequately, or will limit the use of certain functionality otherwise (e.g. by means of geo-fencing). Moreover, this might be true for the more predictable scenarios, which can be captured by maps, sensors, physical infrastructure, or machine learning, but does not explain how AVs will deal with dynamic expected scenarios and unpredictable scenarios.

Another on-going debate is the trade-off between safety requirements and system performance: a vehicle which preserves large safety margins will drive in a very conservative and therefore inefficient manner. To better understand the system boundaries, it was stated that the operational design domain (ODD) of CAVs should be better defined, also to inform the vehicle driver of the capabilities of his/her vehicle. This led to the question which variables must be used to classify an ODD for which a CAV is suited? Another perspective on this is a procedure for certification of roads for automated driving. Road authorities could have a huge role in this, in particular when it comes to policies and strategies.

Here the scope of the discussion became much broader than traffic operations and extended to urban mobility and land use. The presence of a control centre for automated vehicles was mentioned, one that is similar to air traffic control and may support automated vehicles depending on their capabilities and classification (certification) of the road. In addition, it was stated that decentralised control could assist and manage AVs in a more pro-active manner thereby improving their performance. This concept is very much related to the TransAID vision.

Related to this it was stated that also the coexistence of automated vehicles and manually driven vehicles should be assessed in more detail. Finally, the involvement of city representatives in the global CAV debate was stipulated: when CAVs will be introduced based on the needs of cities (cities pull) and not because of technology readiness (technology push), it will become a city-guided development which will lead to different requirements. Here we note that cities need to obtain a clear view on what they want to achieve, as they are more concerned with mobility in general rather than just CAVs.

In conclusion: it was not possible to identify specific circumstances and situations where infrastructure assistance for CAVs is most needed. Nevertheless, the need for some control function was acknowledged and therefore is worth exploring. This requires more evidence as well as a policy framework. These might be obtained/derived from modelling/simulation studies (involving academics) and field experience (involving car manufacturers).

Appendix A.I – Final workshop agenda

10.00	Welcome and introduction	*Suzanne Hoadley, Polis&Bernard Gyergyay, Rupprecht Consult*
10:15	Brief introduction to projects and small group activities: • Planning for automated vehicles (CoExist) • Automated vehicles, traffic management and infrastructure (MAVEN) • Situations in which automated vehicles should not be allowed (TransAID)	 *Bernard Gyergyay, Rupprecht Consult* *Meng Lu, Dynniq* *Jaap Vreeswijk, MapTM*
11:00	Self-driving Cities: Will we have them? Do we need them? Do we want them?	*Bart van Arem, TU Delft*
11:15	*Break*	
11.45	The automated vehicle activities of selected cities: • Greenwich • Gothenburg	 *Ben Dodds, Digital Greenwich* *Mikael Ivari, city of Gothenburg*
12.15	Automation in urban areas – Polis position paper	*Suzanne Hoadley, Polis*
12.30	*Lunch*	
13.15	Round I of parallel small group sessionsCoEXist, MAVEN and TransAID	
14.45	*Break*	
15.15	Round II of parallel small group sessions CoEXist, MAVEN and TransAID	
16.45	Wrap up	
17.00	Close of workshop	

Appendix A.II - Participants list

First Name	Last Name	Organisation
Adriano	Alessandrini	UNIFI
Ammar	Anwar	University of Cambridge
Sylvain	Belloche	Cerema
Gert	Blom	City of Helmond
Judith	Boelhouwers	City of Rotterdam
Florinda	Boschetti	Polis
Martijn	Bruil	Province of Gelderland
Matthias	Buelens	Flanders
Pasquale	Cancellara	Polis
Darren	Capes	City of York Council
Ian	Catlow	London's European Office
Matthew	Cockburn	Bristol City Council
Rosemarijn	de Jong	City of Rotterdam
Eric	de Kievit	City of Amsterdam
Antoine	de Kort	Ministry of Infrastructure and the Environment
Ben	Dodds	DG Cities Ltd/RBG
Mireille	Elhajj	Digital Greenwich
Pieter	Faber	Cities Northern Netherlands
Ulrich	Fastenrath	BMW AG
Sergio	Fernández Balaguer	EMT MADRID
Maxime	Flament	ERTICO-ITS Europe
Gisa	Gaietto	City of Stuttgart
Syrus	Gomari	Rupprecht Consult
Bernard	Gyergyay	Rupprecht Consult - Forschung & Beratung GmbH
Suzanne	Hoadley	Polis
Mikael	Ivari	City of Gothenburg
Eric	Kenis	Government of Flanders - Mobility & Public Works
László Sándor	Kerényi	BKK Centre for Budapest Transport

Johannes	Liebermann	AustriaTech
Meng	Lu	Dynniq
Sven	Maerivoet	Transport & Mobility Leuven
Marian	Marsh	Reading Borough Council
Edwin	Mermans	Province of Noord-Brabant
Rick	Meynen	STIB-MIVB
John	Miles	University of Cambridge Department of Engineering
Pieter	Morlion	City of Ghent
Thomas	Mourey	Polis
Johan	Olstam	VTI
Harold	Perik	Flanders Make
Bip	Radia	INEA
Pirkko	Rämä	VTT
Siegfried	Rupprecht	Rupprecht Consult GmbH
Georgios	Sarros	INEA
Steven	Schladover	UC Berkeley
Ebtihal	Shity	Technion
Kim	Smith	DG Cities Ltd
Jörg	Sonnleitner	University of Stuttgart
Eelko	Steenhuis	Cities Northern Netherlands
Bart	van Arem	TU Delft
Frank	van den Bosch	Gemeente Helmond
Françoise	van den Broek-Serlé	Emmen
Jaap	Vreeswijk	MAP traffic management
Ceri	Woolsgrove	European Cyclists' Federation

Appendix A.III – Project outlines

CoEXist

CoEXist (May 2017 – April 2020) aims at preparing for the transition phase during which connected automated (CAVs) and conventional vehicles (CVs) will co-exist on urban roads. Through a cross-disciplinary approach and the engagement of relevant stakeholders, CoEXist is developing an automation-ready framework for road authorities and is developing traffic simulation tools. The tools developed by CoEXist will be tested by road authorities in four cities with different urban structures and traffic compositions: Helmond (NL), Milton Keynes (UK), Gothenburg (SE) and Stuttgart (DE), in order to assess the "automation-readiness" of their locally-designed use cases.

The mission of CoEXist is to build the capacity of road authorities and other urban mobility stakeholders to prepare for the transition to a road network shared by CVs and an increasing number of CAVs. The results of the project will enable road authorities to understand in detail the impact of increasing numbers of CAVs and to plan accordingly.
www.h2020-coexist.eu

CoEXist has received funding from the European Union's Horizon 2020 Research and Innovation Framework Programme under grant agreement n° 635998.

MAVEN

MAVEN (September 2016-August 2019) is developing solutions for managing automated vehicles on urban roads with signalised intersections and mixed traffic. It is developing algorithms for organising the flow of infrastructure-assisted automated vehicles, and structuring the negotiation processes between vehicles and the infrastructure. The project expects to address a wide range of issues relevant to urban road authorities including the role of road side equipment (eg, traffic lights); interaction between the infrastructure and automated vehicle in terms of functions such as speed advisory, platooning or lane change advisory; and, the impact on vulnerable road users (pedestrians and cyclists), among others.

Furthermore, the project will contribute to the development of enabling technologies, such as telecommunication standards and high-precision maps. A roadmap for the introduction of road transport automation will be developed, to support road authorities in understanding potential future changes in their role and in the tasks of traffic management.

http://www.maven-its.eu

MAVEN has received funding from the European Union's Horizon 2020 Research and Innovation Framework Programme under grant agreement n° 690727.

TransAID

TransAID (September 2017-August 2020) is focusing on transition areas, i.e. those situations and locations where (high-level) automation is not possible or only possible with additional assistance. For these situations, TransAID will develop applicable (digital) infrastructure interventions. A preliminary list of situations and possible intervention strategies will be detailed and expanded in the early months of the project. During this phase, the project would like to receive input from local authorities, e.g. relevant situations for which they consider automation inappropriate/a threat/etc. as well as requirements.

TransAID is receiving funding from the European Union's Horizon 2020 Research and Innovation Framework Programme under grant agreement n° 723390.

Appendix B.1: Surrogate Safety Measures

Surrogate Safety Measures (SSMs) are events that can be correlated with crash rates and can be used as indicators of accidents in safety evaluations. SSMs are in particular useful when testing for situations where no real or not enough accident data is available. SSMs can be used in the development of intelligent driver support systems (such as collision avoidance systems) but also for more advanced systems such as Automated Vehicles. They can provide a very useful insight when mixed traffic occurs (when not all vehicles are AVs), which is of particular interest in the envisioned scope of the use cases within the TransAID project.

SSMs function as indicators and are linked with associated likelihoods to have accidents (collision risk) and accident outcomes (collision severity), given a number of assumptions (such as human driver, deceleration ratios, etc.).

B.1.1 Collision risk measures

Examples of SSMs as indicators for collision risk are presented subsequently (Behbahani & Nadimi, 2015; Gettman & Head, 2003). It should be noted that different indicators are suitable for different types of conflicts: head-on, rear-end, sideswipe, intersections/crossing traffic, etc. (Cunto, 2008) provides a detailed overview of existing SSMs which can be applicable.

B.1.1.1 Time-based measures

- Gap Time (GT):
    - Time lapse between completion of encroachment by turning vehicle and the arrival time of crossing vehicle if they continue with same speed and path.
    - Similar: Time to intersection (TTI), Time to stop line (TTS), Time to zebra (TZ), Time to line crossing (TLC).
- (Minimum) Time-To-Collision (TTC) (similar to GT, lower TTC indicates a higher probability of collision) (Vogel, 2003):
    - Time that remains until a collision occurrence between two vehicles if the collision course and speed difference are maintained constant. Threshold values 4 to 5 seconds (distinguishes between driver being in dangerous situation and driver actually being in control); or 3 seconds (higher values pose to many false alarms) (Hayward, 1971)
    - General Formulation for Time-To-Collision (GTTC) (Saffarzadeh, Nadimi, Naseralavi, & Mamdoohi, 2013)
    - Time-To-Collision for a moving line section and a point (Laureshyn, Svensson, & Hydén, 2010).
- Time to Accident (TTA)
    - Simplifies TTC measurement which only records the TTC value when an evasive action took place.
- Encroachment Time (ET)
    - Time duration during which the running vehicle infringes upon the right-of-way of the through vehicle.
- (Minimum) Post Encroachment Time (PET)
    - Time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of collision.

  - Lower PET indicates a higher probability of collision. Threshold values lie between 1 and 2 seconds (2 seconds is usually considered to be the time interval in which normal manoeuvres can be executed).
- Initially Attempted Post-Encroachment Time (IAPT)
  - Time lapse between commencement of encroachment by turning vehicle plus the expected time of the through vehicle to reach the point of collision and the completion time of encroachment by turning vehicle. The IAPT is almost equal to PET, but it does not use the real time of arrival at the conflict area by the vehicle on the major approach but uses the projected arrival time if no action was taken by the driver instead.
- Sideswipe Collision Risk (SSCR)

B.1.1.2 Required braking power measures

- (Initial) Deceleration Rate (DR)
- Deceleration Rate to Avoid Collision (DRAC)
  - The rate at which a vehicle must decelerate to avoid a probable collision (Archer, 2005). The measure would actually require a number of assumptions in relation to the vehicle that initiated the conflict to be correctly calculated (speed, trajectory). Higher DRAC indicates a higher probability of collision[6].
  - Five severity grades in function of deceleration ranges could be identified:
    - Severity grade 1: <1.5 m/s² DRAC
    - Severity grade 2: 1.5 < 3.0 m/s² DRAC
    - Severity grade 3: 3.0 < 4.5 m/s² DRAC
    - Severity grade 4: 4.5 < 6.0 m/s² DRAC
    - Severity grade 5: >6.0 m/s² DRAC
  - Conflict levels associated to DRAC
    - No conflict (DRAC 0m/s²): evasive action not necessary
    - No conflict (DRAC 0-1m/s²): adaptation necessary
    - Conflict level 1 (DRAC 1-2 m/s²): reaction necessary
    - Conflict level 2 (DRAC 2-4 m/s²): considerable reaction necessary
    - Conflict level 3 (DRAC 4-6 m/s²): heavy reaction necessary
    - Conflict level 4 (DRAC >6m/s²): emergency reaction necessary
- Proportion of Stopping Distance (PSD)
  - The ratio between the remaining distance to the potential point of collision and the minimum acceptable stopping distance.
- Crash Potential Index (CPI)

[6] Comments/critique related to these indicators are that DRAC, CPI, and PSD are not useful for all types of conflicts. They are mostly relevant for rear-end and head-on conflicts, but not for sideswipe accidents. Only TTC and PET consider the motion characteristics of both of the vehicles in a conflict and thus allow for some estimations of the risk of sideswipe collisions for example.

- The probability that the deceleration rate to avoid a collision (DRAC) exceeds the maximum available deceleration rate (depending on the vehicle, pavement skid resistance, etc.)

B.1.1.3 Safety indices

- Time exposed Time to Collision (TET)
  - Summation of all time intervals that a vehicles experiences TTC values that are lower that a specific TTC threshold value (Figure B1).
- Time integrated Time to Collision (TIT)
  - The difference between observed TTC and threshold TTC value for a given time interval cumulative to the time the vehicle traverses the study area (Figure B1).
- Difference between TET and TIT (Barmentlo, 2009)
  - TET only assesses the time a conflict is present.
  - TIT also incorporates the criticality of the conflict.
  - (presence of) Shockwaves.

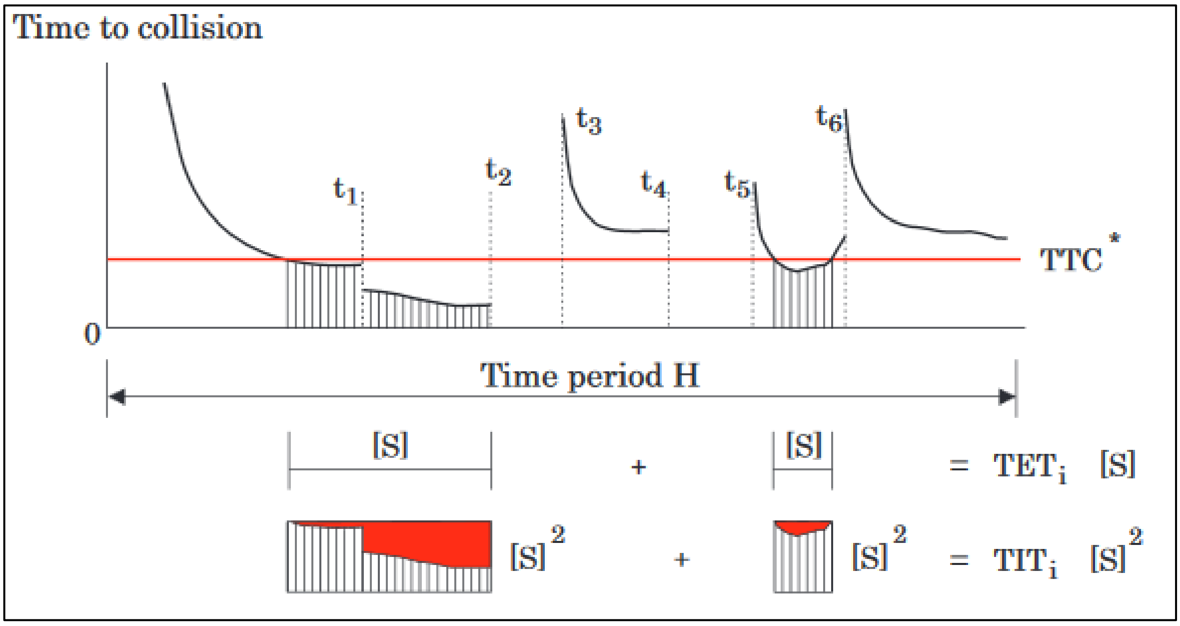


Figure B1 Illustration of TET and TIT surrogate safety measures (SSMs)

B.1.2 Collision severity measures

- Unsafety Density Parameter (UD**)**
  - In a car-following situation, UD considers the severity of a potential crash if the leading vehicle decelerates with maximum braking capacity (Barceló, Dumont, Montero, Perarnau, & Torday, 2003).
- Max Speed (MaxS)
  - The maximum speed of vehicles involved in a conflict (Gettman & Head, 2003).
  - Higher MaxS indicates a higher severity of the resulting collision.
- Relative Speed (DeltaS)
  - The relative speed of vehicles involved in a conflict (Gettman & Head, 2003).
  - Higher DeltaS indicates a higher severity of the resulting collision.

- Kinetic Energy (Sobhani, Young, & Logan, 2011).
- Maximum “post collision” DeltaV (MaxDeltaV)
  - The change in velocity between pre-collision and post-collision trajectories of a vehicle.

B.1.3 SSMs for specific conflict conditions

(Gettman & Head, 2003) provides a good description of what SSMs to use in order to monitor specific conflicts or conditions. Two types of conflicts can be described: on a single location in time and space (conflict *point*) or during a range of times and locations (conflict *line*). A special case is *rear-end* conflict lines. In addition, various types of conflicts can explicitly be defined (Figure B2):

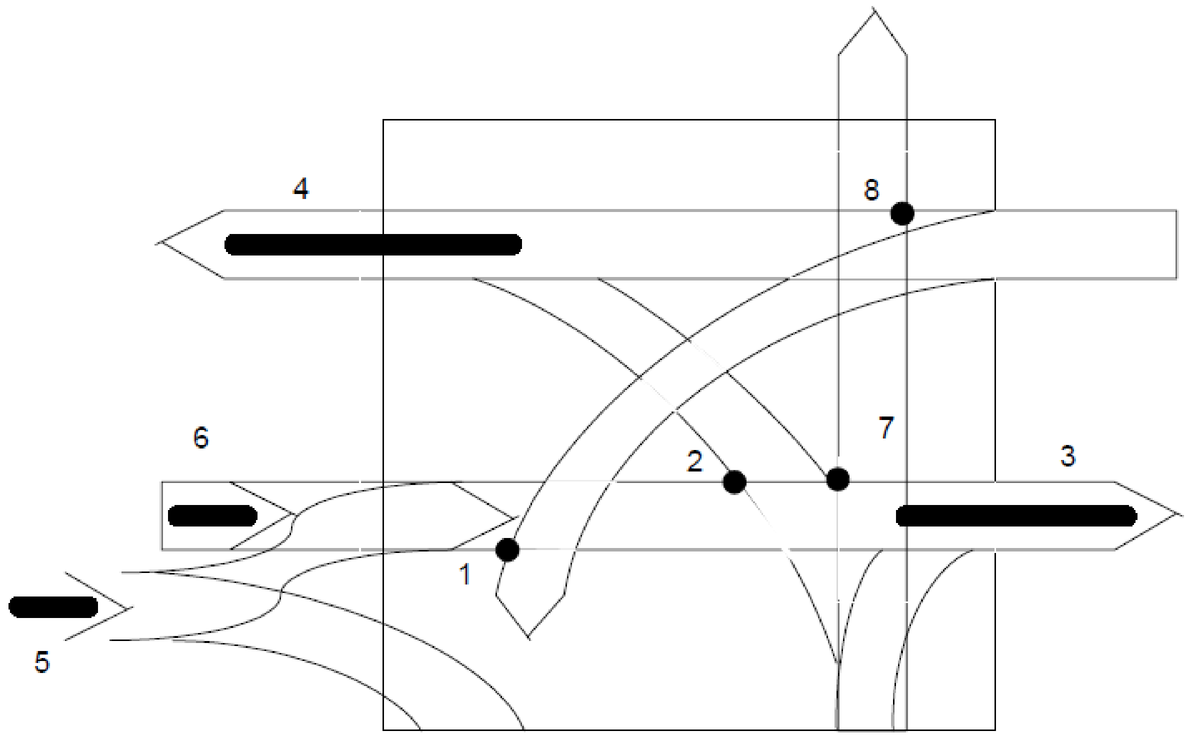


Figure B2 Conflict points and lines **(Gettman & Head, 2003)**

This allows for a clear grouping:

- Crossing flows – conflict point events (numbers 1, 2, 7 and 8 in Figure B2)
  - Number 2: Turning: left-turn from minor to major road, crossing traffic on major road, left-hand side (see also conflict number 4).
  - Number 1: Turning: left-turn from major to minor road, right-of way conflict with crossing traffic with other direction of travel on same major road.
  - Numbers 7 and 8: Crossing intersection: right-of-way conflict for minor road with traffic streams on major road.
- Merging crossing flows – conflict line events (numbers 3 and 4 in Figure B2)
  - Number 4: Turning: left-turn from minor to major road, crossing traffic on major road, right-hand side (see also conflict number 2)
  - Number 3: Turning: right-turn from minor to major road, crossing traffic on major road, left-hand side

- Adjacent flows – lane-changing conflict line events (number 6 in Figure B2)
    - Number 6: rear-end conflict with leading vehicle changing lane in front of follower vehicle
- Following flows – rear-end conflict line events (number 5 in Figure B2)
    - Number 5: read-end conflict with leader vehicle making a turn, causing following vehicle to decelerate do avoid conflict

However, some collision types are not represented in SSMs within the simulation structure presented by (Gettman & Head, 2003).

- Sideswipe collisions
- Head-on collisions
- Swerve-out-of-lane collisions

Some additional remarks on the use of SSMs:

- Additional collision types such as pedestrian collisions and U-turn related conditions do pose some difficulties for SSMs.
- Evasive manoeuvres are mostly not represented (changing lanes, swerving, accelerating).
- Not all conflict event contributors are directly integrated in the estimation of SSMs. However, the methodology to estimate SSMs can be adjusted up to a certain extent to allow for differences in these contributors:
    - Visual obstructions and occlusion
    - Sunlight blinding
    - Weather conditions
    - Road signage

B.1.4 Surrogate Safety (Assessment) Models

The Surrogate Safety Assessment Model (SSAM) is a technique that combines microsimulation and automated conflict analysis, which analyses the frequency and character of narrowly averted vehicle-to-vehicle collisions in traffic, and to assess the safety of traffic facilities without waiting for a statistically above-normal number of crashes and injuries to actually occur. A traffic facility is modelled in a microsimulation model.

Previous analyses (as evidenced from literature) have indicated that there are some correlations between (model-identified) conflicts and (registered) crashes, although these are different for arterial roads and intersections. Conflict based models provide better predictions at intersections than at arterial roads (Ariza, 2011). A possible explanation is that driving behaviour on arterial segments is not as detailed compared to the vehicular movements at intersections. Improvements to driver behaviour models, specifically the lane changing model, could be made to improve the performance of arterial conflict-based collision prediction models.

Appendix B.2: KPIs for Communications

Neighbourhood Awareness Ratio

The Neighbourhood Awareness Ratio (NAR) measures the reliability of a message dissemination. It is defined as the proportion of vehicles in a specific range from which a message was received in a defined time interval. That is, the ratio between the number of vehicles (N_r) inside the defined range of the transmitter from which a message was received in a time interval and the total number of vehicles (N_t) inside the defined range of the transmitter (white area in Figure B3) in the same time interval:

$$NAR = \frac{N_r}{N_t} \tag{1}$$

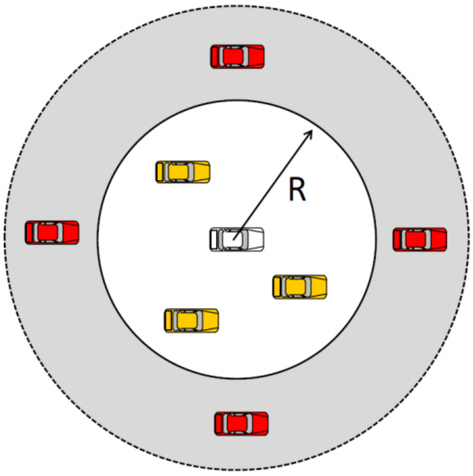


Figure B3 Communications range and defined range with ratio R (Boban & d'Orey, 2016)

The target range might depend on the vehicle's speed or the application requirements. It can be evaluated on a per packet basis or for a given time window. A similar KPI has been used in projects DRIVE C2X (Boban & d'Orey, 2016) and AutoNet2030 (Llatser, Festag, & Fettweis, 2016).

Neighbourhood Interference Ratio

The Neighbourhood Interference Ratio (NIR) measures the proportion of nodes outside certain range whose packet transmission may cause interferences. The NIR is defined as the ratio between the number of vehicles ($N_{r_{out}}$) outside the specified range (grey area in Figure B3) from which the given vehicle received a message, and the total number of vehicles from which the given vehicle has received a message ($N_{r_{tot}}$):

$$NIR = \frac{N_{r_{out}}}{N_{r_{tot}}} \tag{2}$$

It can be used to evaluate the unnecessary interference generated if the range is the target range of the application. Again, the target range might depend on the vehicle's speed or the application requirements. It can be evaluated on a per packet basis or for a given time window. A similar KPI has been used in project DRIVE C2X (Boban & d'Orey, 2016).

Latency

Latency measures the communications delay and it is defined as the time difference between the transmission (t_{Tx}) and reception time (t_{Rx}) of a packet. It is determined by the time required to encode, transmit and decode a packet:

$$latency = t_{Rx} - t_{Tx} \tag{3}$$

It is normally evaluated on a per-packet basis. It can be influenced by packet retransmissions at the lower layers (if needed) or the channel load.

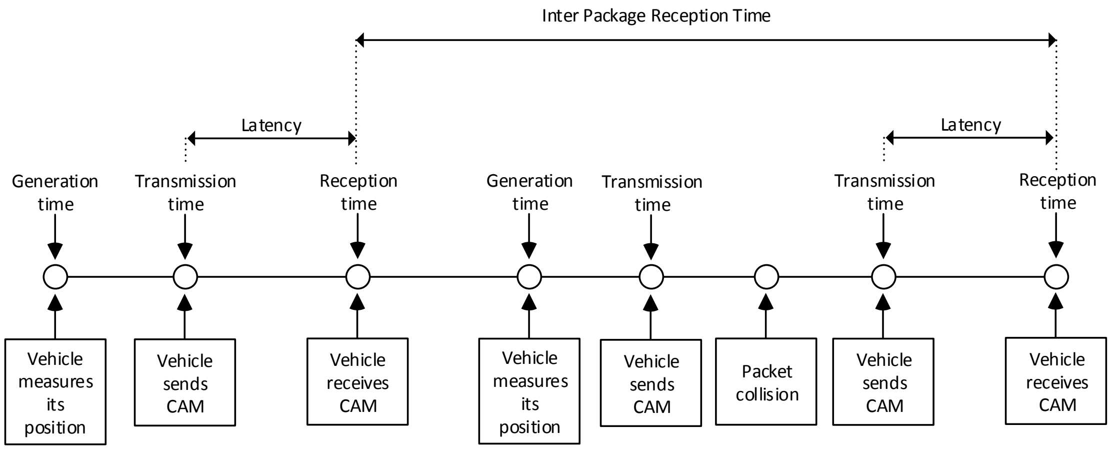


Figure B4 Inter Package Reception time and latency timeline example.

Inter Package Reception Time

The Inter Package Reception Time (IPRT) is defined as the interval of time elapsed between two successful receptions of packets of the same type, i.e. two CAM messages. It measures the awareness of a given type of message, that is, the update interval of a message. In the ideal case, the IPRT is equal to the transmission period. The IPRT is negatively influenced by packet collisions.

Date age

The data age metric measures the freshness of the information. It is defined as the time interval between the instant when the data is generated in the source vehicle (t_G) and the actual time (t_{Now}). The data age is mainly influenced by the latency, the transmission period and the number of lost packets.

$$data\ age = t_G - t_{Now} \tag{4}$$

A similar KPI has been used in project AutoNet2030 (Llatser et al., 2016).

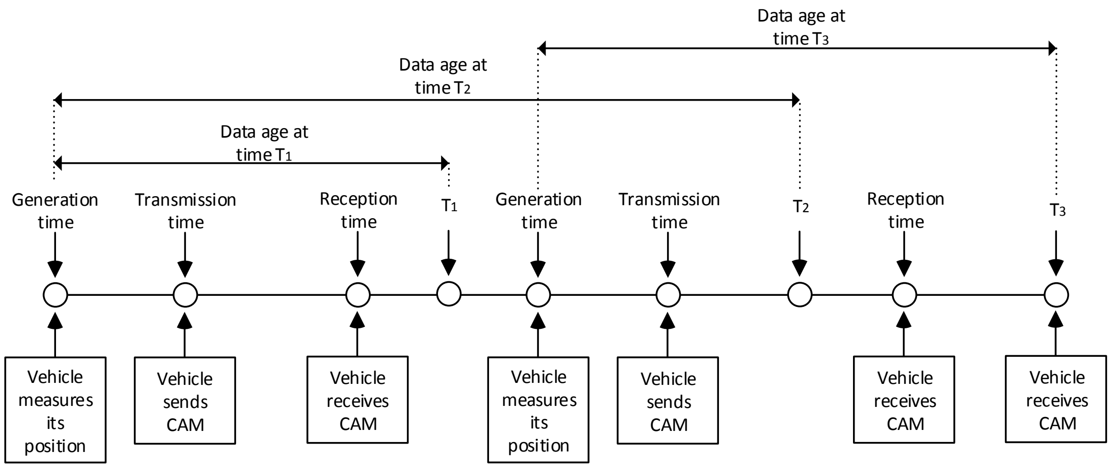


Figure B5 Data age timeline example

Packet Delivery Ratio

The Packet Delivery Ratio (PDR) measures the proportion of packets successfully received in a given time window. It is defined as the ratio of packet successfully received ($N_{packets_{Rx}}$) over the total number of packets transmitted ($N_{packets_{Tx}}$):

$$PDR = \frac{N_{packets_{Rx}}}{N_{packets_{Tx}}} \tag{5}$$

The PDR can be evaluated over short periods of time (e.g. every second) or can be evaluated over long periods of time to obtain average values.

Footprint

The footprint is defined as the total channel resources consumed by the radio of a single vehicle in time and space. To calculate the footprint of a vehicle, it is first necessary to compute its contribution to the channel load. This contribution is calculated by multiplying the packet transmission frequency (*F)*, the packet duration (*T)*, and the packet sensing ratio (PSR). PSR is defined as the probability of sensing a packet at a given distance. This probability can be computed as the probability that a given packet transmission produces a received signal power (P_r) higher than the carrier sense threshold (CS_{Th}). CS_{Th} is the minimum received signal strength needed to detect a packet and therefore senses the channel as busy. The footprint of a vehicle can be expressed as the spatial integral of the load it generates (Sepulcre, Gozalvez, & Coll-Perales, 2017):

$$footprint = \int_d F \cdot T \cdot \ Prob(P_r(d) > \ CS_{Th}) \tag{6}$$

Channel Busy Ratio

The Channel Busy Ratio (CBR) measures the percentage of time that the channel is perceived as busy for a given time interval. The CBR experienced by a vehicle in a road segment with p vehicles/km can be related to the footprint as follows:

$$CBR = footprint \ \frac{p}{1000} \tag{7}$$

This relation considers that all vehicles have the same footprint. This relation is only valid if the vehicles are uniformly distributed and there are not packet collisions. As a result, the previous CBR expression is particularly accurate for low channel load levels. In a practical scenario, this CBR estimation can be considered as an upper bound. This is the case because when packets collide the amount of time that the channel is sensed as busy is reduced compared to this upper bound (Sepulcre et al., 2017).

Messages received per vehicle

This metric is defined as the number of messages of a specific type received by a vehicle in a determined time interval.