D2.2

Scenario definitions and modelling requirements

Project Acronym	TransAID
Project Title	Transition Areas for Infrastructure-Assisted Driving
Project Number	Horizon 2020 ART-05-2016 – GA Nr 723390
Work Package	WP2 Scenarios, Use cases and Requirements
Lead Beneficiary	MAPtm (MAP)
Editor / Main Author	Anton Wijbenga MAPtm
Reviewer	Evangelos Mintsis CRT
Dissemination Level	PU
Contractual Delivery Date	First iteration: 28/02/2018 (M1); Second iteration 28/02/2019 (M18)
Actual Delivery Date	Second iteration 28/02/2019 (M18)
Version	v2.0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723390.

Document revision history

Version	Date	Comments
v0.1	2018-03-20	Initial draft version consolidated from different inputs
v0.7	2018-04-18	Updated timelines, updated chapter 3, harmonisation of decriptions
v0.8	2018-04-30	Chapter 2 intro updated, scenario 3 and 4 updated, reviews processed, glossary updated, chapter 4 added.
v0.9	2018-05-03	Processed review from CRT
v1.0	2018-05-04	Final version (first iteration)
v1.1	2019-01-17	Initial draft version for second iteration
v1.5	2019-02-25	Updated draft, most of the scenarios and vehicle modelling aspects completed (second iteration)
v1.6	2019-02-26	Communication sections added to scenarios; service 1.3 updated; SUMO factsheets updated
v1.7	2019-02-28	Review processed; Service 1.3 added; Survey added
v2.0	2019-02-28	Final version

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Dissemination level:

■ PU : Public

☐ RE : Restricted to a group specified by the consortium (including the Commission Services)

☐ CO : Confidential, only for members of the consortium (including the Commission Services)

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1. Introduction

1.1 About TransAID

As the introduction of automated vehicles (AV) 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, when automated vehicles of different 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 examine efficient 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 at a test track and during the second iteration possibly 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.

1.1.1 Iterative project approach

The infrastructure-assisted management solutions are developed and tested in two iterations, each taking half of the project total duration. During the first iteration, the focus is on studying aspects of transition of control (ToC) and transition areas (TAs) through basic scenarios. This implies that realistic models for automated driving (AD) and ToC need to be developed and/or adopted. Using the basic scenarios, it is possible to run many simulations and focus in detail on the relatively new aspects of ToC, Transition Areas (TAs) and measures mitigating negative effects of TAs. The goal of the first iteration is to gain experience with all aspects relevant to TAs and the mitigating measures.

During the second iteration, that experience is used to improve/extend the measures while at the same time increasing the complexity/realism of the scenarios and/or selecting different (more complex) scenarios. Moreover, it is used to enhance AV and driver models to accurately capture the effects of ToCs/MRMs on safety, traffic efficiency and the environment.

1.2 Purpose of this document

In D2.1 five services have been described encompassing multiple use cases and scenarios. For a selection of these scenarios, the **expected sequences of traffic situations** (or scenes), which must be resembled by the simulation models (that is a “storyline”), are specified such that a common understanding is ensured across the work packages 3-6. This is accomplished by creating a timeline illustrating the relevant events during evolution of the scenario to be modelled. From such a representation, the functional requirements on modelling can be derived and provided in an explicit form.

In general, each step in the timeline poses requirements on the models and the simulation. Thus, the timelines together with explicitly listed requirements form **a catalogue of functional requirements needed** as input to WPs 3-6.

1.2.1 Stakeholder survey

There is still a large number of unanswered questions within the realm of connected and automated driving. This is even more true when considering proper traffic management. One way to answer these questions is via simulations and corresponding real-life validations by field trials as is done in TransAID.

To support the results from those simulations and field trials, it is necessary to get a good grasp on certain issues that require an understanding of how connected and/or automated vehicles operate on the one hand, and what the policy makers allow or require on the other hand. This forms a cornerstone to support TransAID's goal, i.e. achieve a library with applicable and scrutinised measures for transition areas.

To that end, we will pose various questions to several stakeholders and experts. The goal is to gain insights into legal implications, (expected) driver and/or automated vehicle behaviour and infrastructure specific aspects with respect to automated vehicles.

The answers will provide some feedback on the work done so far, some of which is based on views from experts within the project consortium, and collect insights for future work.

The execution of the survey will be in line with the ethics aspects as covered in D10.1. Moreover, the template for the *information and consent form* in Appendix A of D10.1 will be adapted in line with the setup of the survey. The target audience, as well as setup and questions of the survey can be found in Appendix C.

1.3 Structure of this document

Each of the subsequent chapters is split into two sections, one for the first iteration and one for the second. The general descriptions, timelines and SUMO networks for the different scenarios are provided in Chapter 2. Next, Chapter 3 provides additional choices and requirements on the vehicle capabilities, traffic demand and traffic compositions used in the simulations. Finally, Chapter 4 describes the next steps in TransAID. Note that Appendix A contains the detailed descriptions (fact sheets) of the networks corresponding to the scenarios that will be studied during the first project iteration. Appendix B contains the same for the second iteration. Finally, Appendix C contains the setup and questions for a survey among stakholders.

1.4 Glossary

Abbreviation/Term	Definition
ACC	Adaptive Cruise Control
AD	Automated Driving

ADAS	Advanced Driver Assistance Systems
AV	Automated Vehicles (without cooperation abilities)
C-ITS	Cooperative Intelligent Transport Systems
C2C-CC	Car2Car Communication Consortium
CAM	Cooperative Awareness Message
CAV	Cooperative Automated Vehicle
CPM	Collective Perception Message
CV	Cooperative Vehicle
DENM	Decentralised Environmental Notification Message
DX.X	Deliverable X.X
ERTRAC	European Road Transport Research Advisory Council
HMI	Human Machine Interface
ITS	Intelligent Transport System
ITS-G5	Access technology to be used in frequency bands dedicated for European ITS
LOS	Level Of Service (from Highway Capacity Manual)
LV	Legacy Vehicle
MCM	Manoeuvre Coordination Message
MRM	Minimum Risk Manoeuvre
RSI	Road Side Infrastructure
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SUMO	Simulation of Urban MObility
TA	Transition area
TCI	Task Capability Interface
TLC	Traffic Light Control
TM	Traffic Management

ToC	Transition of Control
TOR	Take Over Request
TransAID	Transition Areas for Infrastructure-Assisted Driving
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-anything
VMS	Variable Message Signs
WP	Work Package

2 Scenario definitions & networks

This chapter is divided into two sections, one for each iteration. The section for the first iteration was created during that phase of the project and has not been changed since. The section regarding the second iteration presents the newly selected use cases that will be examined henceforth.

2.1 First iteration

A selection of use cases / scenarios to be examined during the first project iteration has been conducted based on experts' intuition and rating. The rating has been made considering the limitations of each use case, its impacts on real-life traffic operations, and the requirements for the representation of use cases in a simulation environment from AV modelling, traffic management (TM) and communications perspective. Based on the results of this rating, scenarios from use cases 1.1, 2.1, 3.1, 4.2 and 5.1 (see D2.1) have been selected for examination during the first project iteration.

Below, each of these five scenarios is described in more detail. First a short summary of the scenario is given (mostly similar to what is described in D2.1) and possibly some additional considerations given the scenario. The description includes a figure showing a schematic layout of the scenario (note: blue vehicles are automated, others are non-automated). In addition, a timeline is given for each scenario from which WP3-6 can extract functional requirements in addition to those listed explicitly in this document. The detail of the timelines is partly dependent on the type of scenario. In some scenarios the sequence of events is clearer than others, in part because the sequence of events is dependent on work to be done in subsequent work packages (mainly WP4). For example, it is not yet always clear if cooperative lane changes (i.e. CAV working together to change lanes) are beneficial. Another example is whether to provide one collective advice for all vehicles, an advice per vehicle type or targeted individually calculated advices.

Finally, as a starting point for WP3-6, each scenario description finishes with an overview of the initial SUMO simulation network for which the full details are available in Appendix A. The simulation network files themselves are part of this deliverable and are available separately.

2.1.1 Scenario 1.1: Provide path around road works via bus lane

2.1.1.1 General description

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 (appropriate) logic to determine whether such an action is tolerated in the given situation (i.e. unable to detect the situation and corresponding correct lane markings) and need to perform a ToC. 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 (RSI), CAVs can drive around the road works and maintain their automated driving (AD) mode (and thus preventing a ToC). That way, it is clear where the CAV is allowed to break the traffic rules and drive across the bus lane.

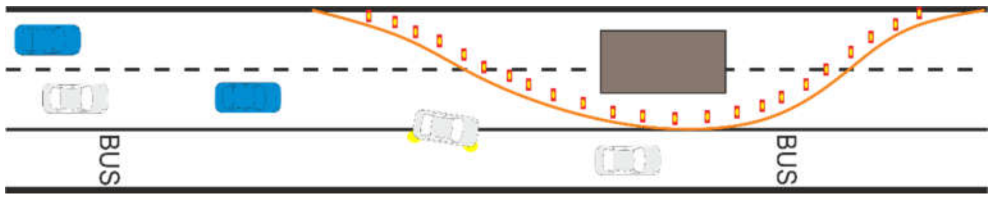


Figure 1: schematic overview of Scenario 1.1

In this scenario, there are road works on a two-lane road with a bus lane next to it. The RSI has planned a path and is distributing it. Approaching CAVs receive the path from the RSI and use the path to drive around the road works.

The way the path is provided is to be determined in WP4. However, at the time of writing, the path is defined as a line with a starting point somewhere upstream of the road works, following the bus lane to the end point somewhere downstream of the road works. The RSI advices vehicles to start merging (find a gap) from the starting point onward. The distance (time) between the starting point and beginning of the road works can be updated based on the Level of Service (LOS). When vehicles reach the end point, normal traffic operations can be resumed (i.e. merge back to the rightmost non-bus lane).

Note that a ToC will still occur since AVs cannot receive the path from the RSI (since AVs by definition are lacking the ability of cooperative behaviour using communication) and must give control to human drivers.

In general, all vehicles must be informed (through conventional signalling or ITS-G5) about the road works in advance to ensure there is enough time to execute lane changes and/or transitions of control without negatively affecting the traffic flow or safety.

2.1.1.2 Timeline of actions

1. Demarcate spatial action horizon (i.e. How far upstream do we start managing traffic? How far downstream do we stop? LOS is a prerequisite in this case)
2. Define general strategy for mitigation (i.e. open bus lane for use by other (non-priority) vehicles)
3. Define traffic management scenario for dealing with the situation → in this case, merge all traffic onto the bus lane before the road works
4. Communicate with traffic stream (all vehicles/drivers are alerted about the road works)
    a. Via conventional signalling (e.g. VMS)
        i. AV and LV drivers will be informed using conventional signalling.
    b. Via ITS-G5 communications (the RSI provides a path around the road works) CAVs and CVs receive the path around road works (this step and sub-steps are frequently repeated to adapt to the LOS).
        i. Is the LOS above a specific threshold?
            1. If <u>yes</u> → move starting point of the path upstream and provide the update to CAVs and CVs on the general-purpose lanes. Those vehicles:
                a. Estimate the gap for merging
                b. If gap is large enough, initiate lane change
                c. If gap is not large enough:
                    i. CAVs might cooperate with other CAVs

                1. Generate gap on the target lane by longitudinal or lateral manoeuvre of CAVs on the target lane.
                2. When the gap is created execute the lane change
            ii. Non CAVs or CAVs driving in an area without other CAVs:
                1. Continuously estimate gaps.
                2. Once the gap is available perform the lane change
    2. If <u>no</u> → starting point of the path around the road works is close to the road works to ensure 'keep-your-lane' policy (cf. efficiency policy)
        a. At the merging point
            i. Left-most vehicles merge into the adjacent right lanes, giving priority to the right lanes. Right-most vehicles are advised to leave space gaps (preferably, alternating)
                1. Estimate the gap for merging
                2. If gap is large enough initiate lane change
                3. If gap is not large enough:
                    a. CAVs might cooperate with other CAVs
                        i. Generate gap on the target lane by longitudinal manoeuvre of CAVs on the target lane.
                        ii. When the gap is created execute the lane change
                    b. Non CAVs or CAVs driving in an area without other CAVs:
                        i. Continuously estimate gaps.
                        ii. Once the gap is available perform the lane change

5. Vehicles move along the road works driving on the bus lane.
6. Once vehicles have passed the road works and reach the end of the provided path → move towards the right-most non-bus lane and continue traffic operations normally.

Note: In case vehicles still need to perform a ToC because they still cannot cope with the situation, the ToC might fail and result in an MRM. This might be supported by Service 4 (e.g. Scenario 4.2 below) to minimize the impact of the MRM.

2.1.1.3 SUMO network

The figure below shows the SUMO network used for studying Scenario 1.1. The full details of this network can be found in Appendix A.

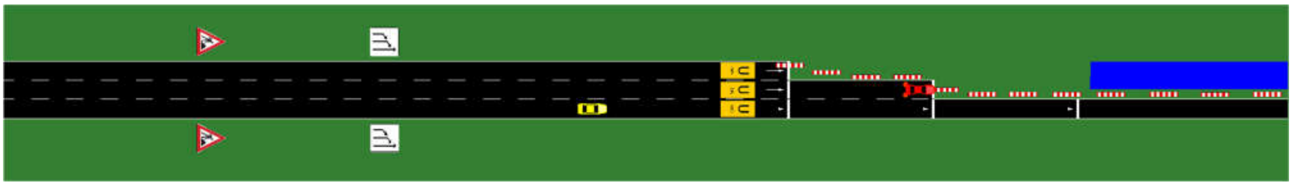
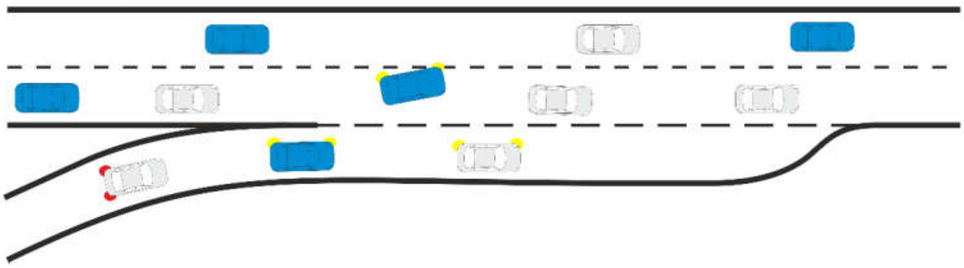


Figure 2: SUMO network for Scenario 1.1

2.1.2 Scenario 2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice

2.1.2.1 General description



CAVs, AVs, CVs, and LVs drive along a motorway merge segment or enter the mainline motorway lanes through an on-ramp. The RSI monitors traffic operations along the motorway merge segment 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. The scenario assumes that CAVs and CVs continuously update their speed and lane information to the RSI (in a near-real-time fashion). In addition, the RSI also fuses this information with measurements obtained via available road-side sensors. The speeds and locations of AVs and LVs can be estimated based on the information gathered via the latter sensors and the location (and available sensing information) of the other vehicles (being CAVs or CVs). This scenario necessitates the exchange of the required types of messages (i.e. CPM/CAM/DENM).

The central core of this scenario is the creation of gaps in the motorway's right-most lane (that is not part of the on-ramp). If the available gaps there are not large enough to allow the safe and smooth merging of on-ramp vehicles, speed and lane advices are also provided to the CAVs and CVs driving there, thereby creating the necessary gaps in traffic to facilitate the smooth merging of on-ramp vehicles. Thus, gaps are created by the exchange of suitable lane change advices to these two kinds of vehicles; AVs and LVs do not receive information. Note that we do not adopt explicit ramp-metering algorithms to control the in-flow of vehicles to the motorway. In addition, advice to vehicles is only given within a certain action-zone, i.e. upstream of and at the merge location. Beyond that, further downstream, vehicles can default back to their previous own behaviour.

Without the aforementioned measures 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.

Note: aggressive lane changes of human drivers can disturb traffic flow and cause emergency breaks or high decelerations. These do not pose great risks in free-flowing traffic, as the traffic streams remain locally and asymptotically stable (initial finite disturbances exponentially die out, even along CAV platoons). However, the more congested traffic becomes, the higher the instability of a traffic stream gets. Hence, such local disturbances are not smoothed out anymore, resulting in sudden and drastic changes in the speed profiles of upstream vehicles. Similarly, lane changes of *slow vehicles (e.g. trucks) have a higher impact, since they require larger gaps and can force other vehicles to suddenly break. Compared to cars, truck lane changes are minor in occurrence (if not forbidden by traffic law). However, in case they do occur, they typically lead to 'moving bottlenecks' due to their lower average speeds, especially in free-flow and synchronised traffic flows. Another situation, in which truck lane changes are more frequent, is when a truck enters the motorway via an on-ramp and trucks on the main motorway provide spacing by moving out of the way, creating again the aforementioned moving bottleneck.*

2.1.2.2 Timeline of actions

1. Estimate flow rates and densities upstream and at the main road and on-ramp.
    a. All road sensors send information to the RSI about the detected vehicles on the road.
    b. All CAVs and CVs broadcast information about themselves and the environment to the RSI and surrounding vehicles (CAVs and CVs).
    c. Calculate the level of congestion based on measured/estimated densities and flow rates.
2. The RSI combines all the previously collected and calculated information:
    a. To estimate the required gaps on the motorway's right-most lane.
    b. To estimate the available gaps on the motorway's right-most lane.
3. If the level of congestion is deemed high enough (which is a setting of the traffic management), and the required gaps outnumber the available gaps, then:
    a. Convert the gap-information into speed and lane advice for on-ramp CAVs and CVs.
        i. CAVs and CVs receive the speed and lane advice.
        ii. CAVs and CVs acquire their target speeds and implement the requested lane changes.
        iii. Determine the possibility for vehicle cooperation, depending on the vehicle mix.
            a. CAVs can cooperate with other CAVs:
                1. CAVs receive speed/headway advice.
                2. Create the gap by adjusting speed and headway of motorway CAVs.
                3. CAVs receive lane change advice.
                4. Create the gap by letting the motorway's CAVs change lanes.
            b. CAVs driving in an area without other CAVs perform lane changes once required gaps (given by the RSI) are available.

2.1.2.3 SUMO network

The figure below shows the SUMO network used for studying Scenario 2.1. The full details of this network can be found in Appendix A.

Figure 3: SUMO network for Scenario 2.1

2.1.3 Scenario 3.1: Apply traffic separation before motorway merging/diverging

2.1.3.1 General description

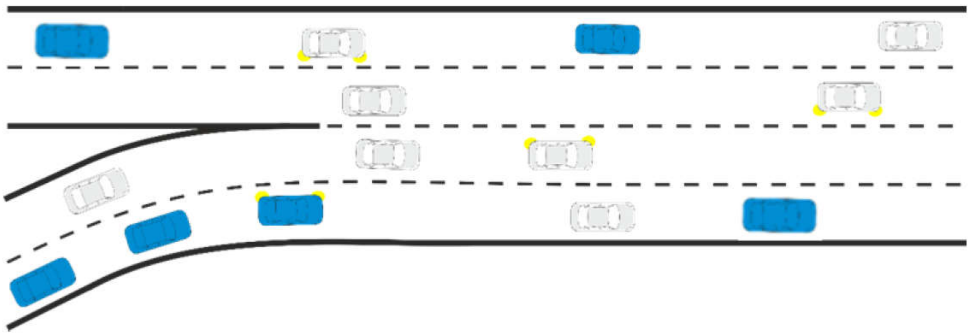


Figure 4: schematic overview of Scenario 3.1

CAVs, CAV platoons, CVs and LVs drive along two 2-lane motorways that merge into one 4-lane motorway. After the merging point, vehicles will drive to their target lane. RSI monitors the amount of different types of vehicles upstream through collective perception but also via CAM receptions, and infra sensors.

Based on the 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 at some point upstream of the merging point (where merging usually starts). CVs move to the other lanes not allocated to CAVs and CAV platoons. CAVs and CAV platoons thus enter the 4-lane section on the outer lanes, giving space to manually driven vehicles (CVs and LVs) to occupy the central lanes (where human driving still may generate risky situations).

Following this approach, the overall number of risky situations will be reduced which will positively affect the number of ToCs in this area.

At some point downstream of the merging point, the traffic separation is disabled, and all vehicles can gradually start changing lanes to reach their target destination.

2.1.3.2 Timeline of actions

1. Under the assumption that, as required by law, after the merging point all vehicles shall drive outermost right with normal traffic overtaking operations, the RSI setups the context for policy application:

    a. Identify/calculate a traffic separation area where the policy shall be applied. The traffic separation area is bounded by spatial policy horizons (i.e. point from which traffic separation shall be requested) and the point to which traffic separation shall be kept. In other words, the horizons are the point from which CAVs shall start occupying the lanes requested by the policy on the upstream motorways, and the point from which CAVs can merge towards their target lanes downstream the motorway merging point. The extension of the traffic separation area will be influenced by RSI technology availability (Road Side Units (RSUs), infrastructure sensors) and prevailing traffic conditions (esp. traffic density that directly impact the possibility to perform the lane changes needed to separate traffic upstream and let traffic merge again downstream).

   b. For the calculation of the traffic separation area, determine/receive flow rates at main road and on-ramp, as well as traffic stream composition.
      i. All cars coming from the 2-lane motorways upstream of the merging point and road sensors from that area send information to the RSI about the vehicles detected on the road. Depending on their cooperative capabilities, these vehicles will transmit either information about themselves (using Cooperative Awareness Message (CAM)/Manoeuvre Coordination Message (MCM) or information about other vehicles using Collective Perception Messages (CPMs). The RSI will combine this information with that received from the road sensors. The RSI shall be able to identify the share of different vehicle types on the motorway lanes. This share information can be used by the RSI to drive policy decisions (e.g. apply the policy much earlier upstream if there are a lot of CAVs to move from one lane to the other).
2. Before the merge point the RSI communicates advices to all vehicles.
   a. RSI combines all the information and decides the parameters (e.g. the previously mentioned horizons) of the traffic separation policy.
   b. All vehicles receive the traffic separation policy and parameters.
      i. Instruct all CAVs and CAV platoons to move towards outer lanes (i.e. left-most lane for the left group and right-most lane for the right group)
         a. If a lane change is required at CAVs:
            1. Estimate the time gap with vehicle coming from behind on the target lane for lane changing
            2. If the gap is large enough, perform the lane change
            3. If the gap is not enough, CAVs can cooperate with other CAVs coming from behind by always considering presence of additional non-CAV vehicles:
               i. Generate gap on the target lane by longitudinal manoeuvre of CAVs on the target lane.
               ii. When the gap is created execute the lane change.
            4. Non-CAVS vehicles or CAVS driving in an area without other CAVs:
               i. Continuously estimate gaps.
               ii. Once the gap is available perform the lane change.
            5. If gap cannot be created, then make (advice) ToC. When a ToC fails, the vehicle might be supported by Service 4 (e.g. Scenario 4.2) to minimize the impact of the MRM.
      ii. Instruct all LVs and CVs (via VMS, HMI, V2X, …) to move to the inner lanes.
         a. If a lane change is required:
            1. Estimate the gap with vehicle coming from behind on the target lane for merging lane changing.
            2. If there is enough gap, perform the lane change.
            3. Otherwise, continuously estimate gaps.
            4. Once the gap is available perform the lane change.
      iii. Instruct all vehicles to keep their speed ranges at a prespecified setpoints (depending on the TM context as determined before) as much as possible.
3. After the merge point (downstream, at the designated spatial action horizon).

a. Communicate to vehicles to resume normal operations (i.e. adopt the keep-right rule with overtaking if needed/wanted).

2.1.3.3 SUMO network

The figure below shows the SUMO network used for studying Scenario 3.1. The full details of this network can be found in Appendix A.

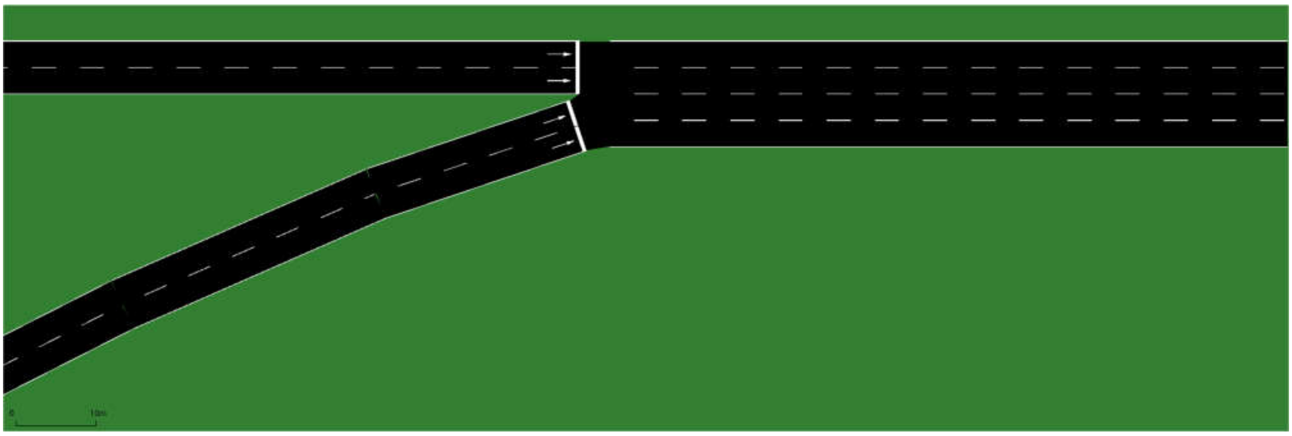


Figure 5: SUMO network for Scenario 3.1

2.1.4 Scenario 4.2: Safe spot in lane of blockage

2.1.4.1 General description

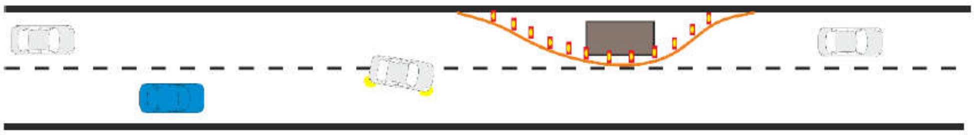


Figure 6: schematic overview of Scenario 4.2

There is a construction site covering one lane of the motorway road. The deployed RSI has information about the construction area and the vicinity of it and provides this information to the approaching CAVs.

Some CAVs are not able to pass the construction site without any additional guidance. Therefore, they need to perform a ToC. A ToC might be unsuccessful, so the respective CAV must perform an MRM. Without additional measures, the CAV would simply brake and stop on the lane it is driving, most likely disrupting the traffic flow when happening on the right lane (see figure),

To avoid this, the RSI also monitors the area just in front of the construction site and offers this place as a safe stop to the vehicle, if free. The CAV uses the safe spot information just in front of the construction site to come to a safe stop in case of an MRM.

Note: Service 4 basically is an additional measure to the other services, used when any ToC is about to fail (see D2.1 for details) and the impact of MRMs should be reduced. In this specific case of Scenario 4.2, it can be seen as an extension to Scenario 1.1.

2.1.4.2 Timeline of actions

As introduced, this specific scenario is an extension to Scenario 1.1. Therefore, all measures of Scenario 1.1 can also be applied here. The following will only describe the timeline in case of a (failed) ToC.

1. Incident (road works) zone is challenging for AD driving and specific CAVs cannot handle the situation being in AD mode.
    a. RSI knows that area around the construction site is challenging.
    b. RSI monitors the area in front of the construction site, especially on the lane which is about to close. This area is stored in the RSI as potential safe spot. According to the situation, there can be more than one safe spot.
        i. If the safe spot is not reserved by a CAV, or blocked by any vehicle, RSI communicates the position of the safe spot.
        ii. If it is reserved by a CAV, another safe spot is suggested (if any).
        iii. If all safe spots are reserved or blocked no action is taken.
    c. The CAVs receive the safe spot information.
    d. In case a CAV needs to trigger a ToC, it reserves the safe spot by communicating this to the RSI.
        i. The RSI receives the request and reserves the safe spot for this CAV.
        ii. From now on, the RSI also monitors the current position of the CAV and the surrounding traffic.
        iii. RSI provides time headway and lane advices in order to free the way of the CAV to the safe spot. Those advices are provided for other CAVs and CVs in the vicinity. This also includes the suggestions of cooperative lane changes, if needed.
    e. When the ToC fails and the MRM is started, the CAV tries to reach the safe spot. In case it needs to do a lane change, RSI is supporting this by providing cooperative lane change and CPM information.
    f. The CAV reaches the safe spot.

Note: for the simulation the time and location (parking spot) of the ToC/MRM must be defined explicitly and deterministically.

2.1.4.3 SUMO network

The figures below show the SUMO networks used for studying Scenario 4.2 in urban and motorway conditions. The full details of these networks can be found in Appendix A.

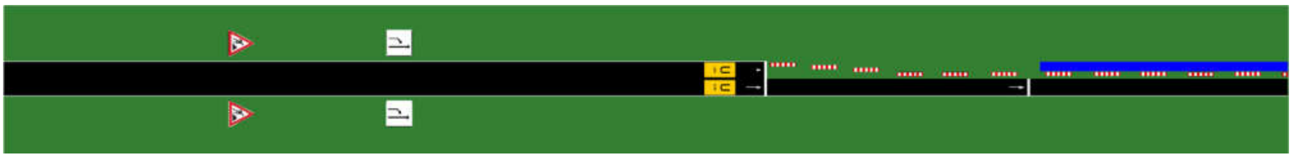


Figure 7: SUMO network for Scenario 4.2 in urban conditions

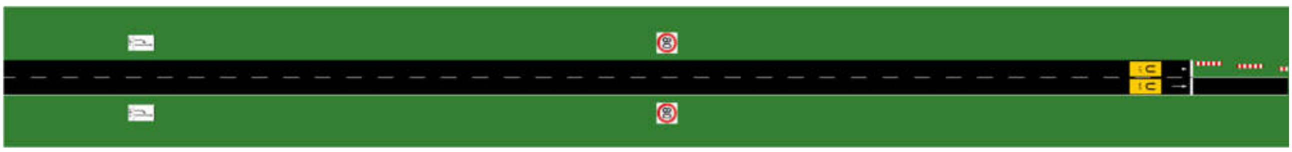


Figure 8: SUMO network for Scenario 4.2 in motorway conditions

2.1.5 Scenario 5.1: Schedule ToCs before no AD zone

2.1.5.1 General description

After a transition of control (ToC) from automated to manual mode, an automated vehicle is expected to behave more erratically. The driving characteristics 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).

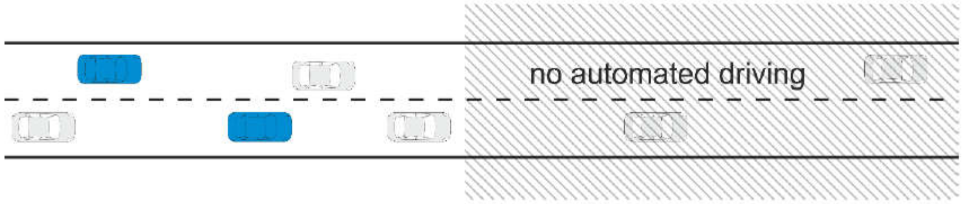


Figure 9: schematic overview of Scenario 5.1

Figure 9 shows the Scenario 5.1 where CAVs and other traffic are approaching a no AD zone with 2 lanes. Starting at some point upstream of 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. 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.

2.1.5.2 Timeline of actions

1. Under the assumption that all vehicles must drive in manual mode in the no AD zone, the RSI setups the context for policy application:
    a. Identify/calculate a transition area where the policy shall be applied. The transition area is bounded by spatial policy horizons (i.e. point from which transition of control shall be requested and point to which manual driving mode shall be kept.) The extension of the transition separation area will be influenced by RSI technology availability (RSUs, infrastructure sensors) and prevailing traffic conditions (esp. traffic density that directly impact the possibility to perform the ToCs needed).
    b. Obtain traffic stream information (composition, (average) speeds, …)
        i. All connected cars send information about themselves and other detected vehicles or obstacles.
        ii. All road sensors send information to the RSI about the detected vehicles on the road.
2. Communicate with traffic stream. That is, all vehicles/drivers are alerted about no AD-zone and ToC to manual mode is mandatory. Optionally include also TM measures to prevent traffic breakdown and increase traffic safety):
    a. Via conventional signalling (e.g. VMS).
    b. Via V2X communications.

3. RSI creates a virtual queue to store vehicle rank numbers at the RSI and decides the places where CAVs must do a ToC:
    a. On a per-CAV basis:
        i. Instruct vehicles with TM measures to ensure the safe execution of ToC or to prevent the traffic breakdown (i.e. maintain a constant speed, increase the security distance, etc.).
        ii. Determine ranked order of the CAV as it enters the action zone.
        iii. Depending on the rank / location of the CAV.
            1. CAVs and CVs receive the information about transitions.
            2. CAVs perform the ToC. When the ToC fails, the vehicle might be supported by Service 4 (e.g. Scenario 4.2) to minimize the impact of the MRM.
        iv. When it reaches the end of the action zone, remove it from the virtual queue.
    b. After a while, all CAVs left in the action zone will have had a ToC:

    Restart the process – once the virtual queue spans the entire action zone – by clearing the virtual queue so it can repeat.

    All cars continue driving in manual mode inside the no AD-zone.

2.1.5.3 SUMO network

The figure below shows the SUMO network used for studying Scenario 5.1 (the network is just a long stretch of road with a trigger for the no AD-zone). The full details of this network can be found in Appendix A.

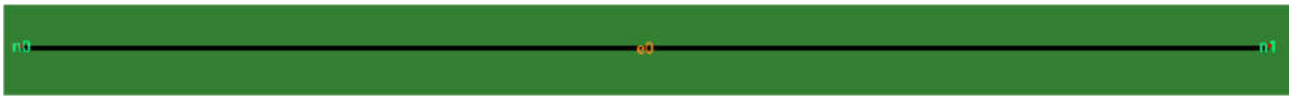


Figure 10: SUMO network for Scenario 5.1

2.2 Second iteration

2.2.1 Overall findings first iteration

Relevant findings form the first iteration which influenced the choice of scenarios for the second iteration are discussed below. A full evaluation of the results of the first iteration so far (which are written in D4.2) is not in scope of this deliverable and will be done at a later stage in WP6 and especially WP8.

Studying the five scenarios selected for the first iteration, we found that, in general, the idea of providing information to CAVs (Service 1 & 2), be it a path around an obstacle (e.g. road works), or speed and/or lane advice to prevent a ToC, mitigates the negative impacts of downward ToCs. In addition, when prevention is not feasible, distributing ToCs in time and space (Service 5) showed to be a very effective measure. As failsafe measure, Service 4, also seems promising.

The results of Service 3 (traffic separation) were mixed and highlighted some issues that also exist in the other scenarios. CAVs need time and space to implement the requested manoeuvres and without coordination the advised manoeuvres might impact traffic in a negative way thereby negating the expected positive effect of the request.

Another observation is that the advices cannot always be followed by all vehicles. This is either due to local traffic conditions, or in practice because of communication issues. Thus, it is meaningful to combine the services and implement a hierarchical approach as proposed by the TransAID project. Hence, for example, some CAVs can perform distributed ToCs while others are provided with information to keep their automation. In the case of incidental failure, the automated vehicle can also be guided to a safe spot.

Based on these findings, and the proposed work for the TransAID project, we selected 5 scenarios for the second iteration and overall improvements/extensions regarding vehicle modelling and cooperation. These vehicle modelling aspects and improvements/extensions, including for example CACC and dynamic ToC triggering, are described in Chapter 3.

2.2.2 Second iteration scenario selection

Looking at the scenarios from the first iteration, we found that scenario 1.1 (Provide path around road works via bus lane) showed significant improvements in traffic safety and marginal improvements in traffic efficiency and CO_2 emissions. The scenario includes road works, thus allowing for elaborate preparations of measures, including a temporary MAP message depicting the new road layout. Because of that, vehicles have all the needed information to cope with the situation. An improvement of the scenario would be to add cooperative manoeuvring, but that aspect can be studied in the other scenarios as well. Given the results and the limited options for improvement, it was decided not to continue studying this scenario in the second iteration.

It was also decided to stop studying scenario 3.1 (Apply traffic separation before motorway merging/diverging). While the idea of separating traffic upstream of a merging/diverging area to limit vehicle interactions which might induce complex traffic situations in these areas seems promising, most of the results so far were negative. The number of ToCs/MRMs did decrease due to the measurements, but improvements were not observed since the effects of ToCs/MRMs in the baseline scenario were not detrimental to traffic flow and lane change advices resulted in condensed lane changing activity in the entry and exit of the traffic management areas where traffic disruption migrated. Several ideas exist to improve the scenario (e.g. distributed and coordinated lane changes, cooperative manoeuvring for more efficient merging behaviour; improve lane change behaviour of LVs), but it remains to be seen if those would be enough. In addition, facts are lacking that detail the ‘problem’ in this scenario, i.e. ToCs as a result of increased vehicle interactions and due to erratic behaviour of LVs in particular. It is unclear how (C)AVs would exactly handle the situation, which is something that is better defined in the other scenarios.

Given the above and the fact that TransAID’s focus is primarily on urban situations, it would be inefficient (i.e. it makes more sense to focus resources in a different direction) to continue studying the scenario.

Note: TransAID proposes ‘Service 3 Prevent ToC/MRM by traffic separation’ as a mitigating measure for transition areas. In retrospect the merging/diverging scenario was perhaps not the best situation to apply this service to. There might be other situations where traffic separation as a measure is beneficial. In addition, traffic separation to support or enable automated driving, for example, through dedicated lanes for (C)AVs, is a different concept which TransAID has not evaluated.

The remaining scenarios, 2.1, 4.2 and 5.1, all showed promising results and additional ideas exist to improve on these scenarios. Moreover, results warranted a more detailed examination of the events in these scenarios. TransAID will therefore continue studying these scenarios. The details on the approach are described below in the descriptions of the scenarios.

Dropping scenarios 1.1 and 3.1 freed up some capacity to study two new scenarios. For those new scenarios we looked at D2.1 where we listed 14 use cases. Based on the experience gained during the first iteration, scenarios 1.3 and 2.3 were selected. Details are below.

2.2.3 Communications

As of writing, WP6 is running for the first iteration where the impact of using V2X communications to implement the measures is being evaluated by building upon the iTetris framework (see D6.1). Much effort is being put into the technical challenges and integrating V2X into the traffic management measures. When completed, the work will provide insight into how far the desired behaviour can be achieved using V2X message sets. Currently, the focus is on the message flows (i.e. timing, sequences) and architecture.

Evaluating the possible congestion of the communication channels is not one of the primary goals of the first iteration. However, eventually, that aspect is important to evaluate as it impacts whether a vehicle will receive a message (in time) or not. Therefore, the congestion rate of the channels directly impacts desired changes in driving behaviour of CVs and CAVs.

To have a more realistic evaluation of the possible congestion of the communication channels, (V2X capable) traffic surrounding the proposed situations also needs to be simulated, because that will increase the channel loads. Therefore, all scenarios (except for 2.3 which already includes surrounding traffic) have been extended with two lanes in the opposite direction.

2.2.4 Scenario 1.3: Queue spillback at exit ramp

2.2.4.1 General description

CAVs, AVs, CVs, and LVs approach an exit on a motorway. There is a queue on the exit lane that spills back onto the motorway. We consider a queue to spill back on the motorway as soon as there is not enough space on the exit lane to decelerate comfortably (drivers will start decelerating upstream of the exit lane). Vehicles are not allowed to queue on the emergency lane, but queuing on right-most lane of the motorway will cause: a) a safety risk due to the large speed differences between the queuing vehicles and the regular motorway traffic and b) a capacity drop for all traffic (including vehicles that do not wish to use the exit). This scenario assumes that the RSI will allow (and facilitate) vehicles to queue on a section of the emergency lane to avoid this capacity drop and safety risk.

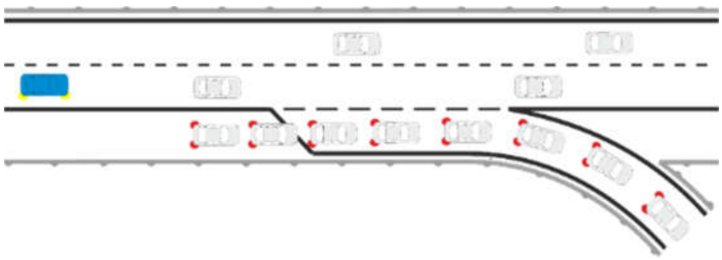


Figure 11: schematic overview of Scenario 1.3

The RSI will monitor the off-ramp and exit lane, and when a queue is detected, a section of the emergency lane will be opened. Vehicles that wish to exit the motorway will be able to decelerate and queue safely without interfering with the regular motorway traffic. The length of the section of the emergency lane that is opened for traffic will be determined dynamically by the RSI.

Traffic managers will try to avoid queuing on an exit ramp, usually by taking measures to improve the outflow of the exit. This use case looks into the behaviour of the RSI and the vehicles when the spillback of a queue on the motorway actually occurs. It does not discuss if, when, or how the traffic manager can avoid the spill-back of the queue on the motorway.

The RSI monitors traffic operations along the motorway and the exit ramp and detects the queue spillback. In order to ensure traffic safety, the speed limits of the different lanes are changed by the RSI as follows:

- The speed limit in the section of the motorway between the upstream end of the queue and the end of the off-ramp is reduced to 20 km/h above the speed limit of the adjacent lane to the left, while maintaining a minimum speed limit of 50 km/h.
- Upstream of this section, the speed limit is gradually reduced to improve safety and to avoid shock waves in the traffic flow. CVs and CAVs receive lane change advices, according to their desired route. Vehicles that intend to use the off-ramp are advised to use the right-most lane, the other vehicles are advised to use the other lane.

The vehicles that wish to use the exit lane will be allowed to use the emergency lane at some distance upstream of the queue. The RSI will dynamically determine the length of the section where this is allowed, such that the vehicles leaving the motorway can safely and comfortably decelerate on the emergency lane (without disturbing the traffic that remains on the motorway).

It is possible that LVs and/or AVs will not use the emergency lane to decelerate and queue. In that case, the CVs and CAVs on the emergency lane should allow the LVs and AVs to merge into the queue on the exit lane.

If an AV or CAV does not manage to change into the exit lane, a TOR is offered (not forced) to the driver (more correctly, the driver should receive a signal that the vehicle cannot take the exit lane on its own). The driver can choose whether or not to accept the TOR, if the TOR is not accepted, the AV or CAV will keep on trying to merge into the exit lane for a short while (e.g. 10 seconds) and finally continue driving and change its route (it is assumed to reroute and use another exit).

2.2.4.2 Timeline of actions

1. Detection of queue spillback on the exit ramp.
2. RSI continuously monitors the queue (possibly supported by V2X).
3. Demarcate spatial action horizon upstream of the exit lane

4. The RSI communicates with the traffic stream about the adapted speed limits (dependent on lane and the upstream distance from the tail of the queue) and preferred lane advice (dependent on the vehicle's route/destination) to upstream vehicles:
    a. Via conventional signalling (e.g., VMS) to inform LV drivers and AVs.
    b. Using V2X to inform CV drivers and CAVs.
2. Desired behaviour of vehicles using exit lane:
    a. Within the spatial horizon determined by the RSI, the vehicles leaving the motorway are advised to use the emergency lane for decelerating and queuing.
    b. While in the queue: leave a gap for a vehicle that still wants to merge if it did not queue at the end of the queue.
3. Desired behaviour of vehicles not using exit lane:
    a. Slow down to max{50 km/h, 20 km/h faster than the vehicles in the adjacent lane to the left}
4. If the vehicle does not manage to merge into the exit lane:
    a. Offer a TOR (or signalling mechanism to the driver), if the driver does not accept within a short time period (e.g., 30 sec), reroute the vehicle using another exit ramp.
5. Once vehicles have passed the off-ramp continue traffic operations normally.

2.2.4.3 Communications requirements

The execution of this service requires the exchange of information between vehicles and between vehicles and the infrastructure. The exchange of information is based on the V2X message set defined in Deliverable 5.1. Thus, CAM and CPM messages will be employed to increase the environmental perception of the traffic stream while the MCM is employed to send advices from the infrastructure (i.e. speed or lane change advices). Similarly, the new speed limits will be disseminated to the traffic using the IVIM. The use of the part of the emergency lane by vehicles will require that the infrastructure sends to the vehicles which part of the emergency lane can be used. This case has not been taken into account in the definition of the V2X message set of the first iteration of the project. During the second iteration of the project, WP5 will take into account this requirement (along with the requirements of other services) to extend the definition of the V2X message set.

2.2.4.4 SUMO network

The figure below shows the SUMO network used for studying Scenario 1.3. The full details of this network can be found in Appendix B.

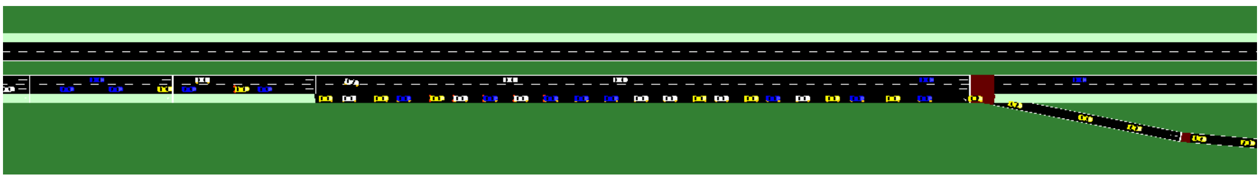


Figure 12: SUMO network for Scenario 1.3

2.2.5 Scenario 2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice

2.2.5.1 General description

CAVs, AVs, CVs, and LVs drive along a motorway merge segment or enter the mainline motorway lanes through an on-ramp. The RSI monitors traffic operations along the motorway merge segment 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. The scenario assumes that CVs continuously update their speed and position information to the RSI (in a near-real-time fashion), while CAVs also update their current lane and share perception information of other vehicles around them. In addition, the RSI also fuses this information with measurements obtained via available road-side sensors. The speeds and locations of AVs and LVs can be estimated based on the information gathered via the latter sensors and the location (and available sensing information) of the other vehicles (being CAVs or CVs).

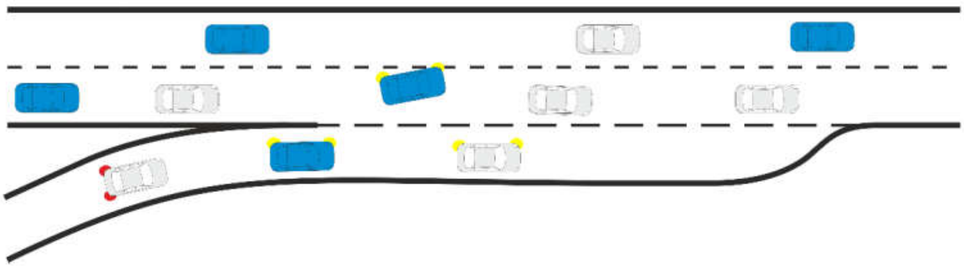


Figure 13: schematic overview of Scenario 2.1 (2nd Iteration)

The core of this scenario is finding gaps in the motorway's right-most lane (that is not part of the on-ramp). C(A)Vs are guided to these gaps with speed advice, because even with very low traffic volume they could arrive right next to other vehicles in the merging area by chance in the absence of guidance. If the available gaps are not large enough to allow the safe and smooth merging of on-ramp vehicles, speed and lane advices are also provided to the CAVs and CVs driving on the main road, thereby creating the necessary gaps in traffic to facilitate the smooth merging of on-ramp vehicles. Thus, gaps are created by the exchange of suitable lane change advices to these two kinds of vehicles; AVs and LVs do not receive information. In addition, advice to vehicles is only given within a certain action-zone, i.e. upstream of and at the merge location. Beyond that, further downstream, vehicles can default back to their previous own behaviour. Combining this with ramp-metering algorithms to control the in-flow of vehicles to the motorway, will open more possibilities for traffic management as the inflow can temporally be halted when the gap creation measures would be too disruptive.

Without the aforementioned measures 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.

2.2.5.2 Timeline of actions

1. Estimate flow rates and densities upstream and at the main road and on-ramp.
    a. All road sensors send information to the RSI about the detected vehicles on the road.
    b. All CAVs and CVs broadcast information about themselves and the environment to the RSI and surrounding vehicles supporting wireless communications.
    c. Calculate the level of congestion based on measured/estimated densities and flow rates.
2. The RSI combines all the previously collected and calculated information:
    a. To estimate the required gaps on the motorway's right-most lane.
    b. To estimate the available gaps on the motorway's right-most lane.
3. Convert the gap-information into speed and lane advice for on-ramp CAVs and CVs.
    a. CAVs and CVs receive the speed and lane advice.

   b. CAVs and CVs acquire their target speeds and implement the requested lane changes.
4. If the level of congestion is deemed high enough (which is a setting of the traffic management algorithm), and the required gaps outnumber the available gaps, then:
   a. Identify the optimal locations to create the missing gaps and send the speed advice to CAVs and CVs on the main road and on the on-ramp.
      i. CAVs and CVs receive the speed and lane advice.
      ii. CAVs and CVs acquire their target speeds and implement the requested lane changes.
      iii. Determine the possibility for vehicle cooperation, depending on the vehicle mix. CAVs could cooperate with other CAVs by receiving additional detailed advice from the RSI.
5. If the level of congestion is even higher, ramp metering should be added to the strategy to at least hold traffic temporally when gap creation would be too disruptive for the main road traffic.

2.2.5.3 Communications requirements

The execution of this service necessitates the exchanges of messages between vehicles and between vehicles and the infrastructure. Following the definition of the message set in Deliverable 5.1, CAM and CPM messages will be employed by the RSI to estimate flow rates and densities upstream of the merge area. The speed and lane advices computed by the RSI can be disseminated to vehicles employing the MCM. Similarly, CAVs can employ the MCM to define cooperative manoeuvres. At this point of the project no further extensions of the required messages are foreseen in order to execute this service. However, the definition of the traffic management procedures in WP4 can introduce new requirements for the TransAID message set.

2.2.5.4 SUMO network

The figure below shows the SUMO network used for studying Scenario 2.1. The full details of this network can be found in Appendix B.

Figure 14: SUMO network for Scenario 2.1

During the first iteration it was concluded that the approaches towards the merging area in the SUMO network were too short for the model to acquire data on the possible merge locations. Therefore, an extra 500 meter approach was added to let the traffic harmonize after injection into the simulation. This way, traffic was in its free flow state when it passed the first infrastructure detectors.

2.2.6 Scenario 2.3: Intersection handling due to incident

2.2.6.1 General description

CAVs, AVs, CVs, and LVs are driving towards a 3-way signalised intersection. Each arm of the intersection consists of two entry lanes and one exit lane. The following describes the entry lanes of each arm. The east approach (A) has one lane for through traffic (1) and one lane for let turning traffic (2). The south approach (B) has one lane for right turning traffic (3) and one lane for left turning traffic (4). The west approach (C) has one lane for right turning traffic (5) and one lane for through traffic (6).

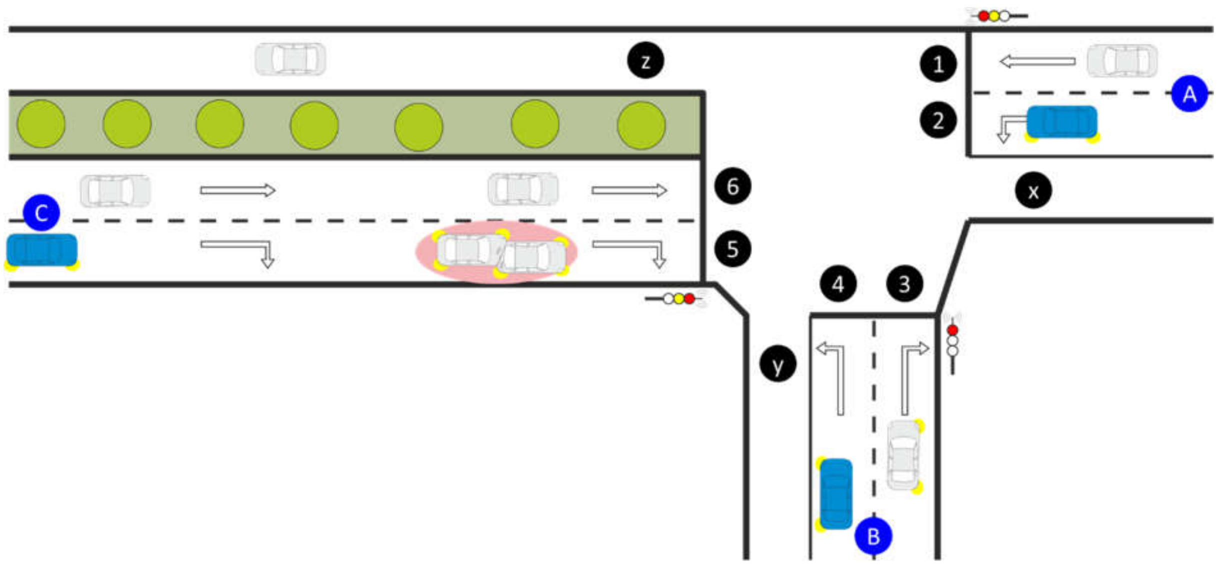


Figure 15: schematic overview of Scenario 2.3

An incident occurs just before the stop line of the right turning traffic lane on the west approach (approach C, lane 5). The incident is blocking lane 5 and therefore vehicles driving on this lane will need to use the through traffic lane (approach C, lane 6) to drive around the incident. Vehicles driving to the south also need to make their right turn from lane 6 to the exit lane of the south arm (lane y).

Vehicles approaching on lane 5 or lane 6, heading to the south arm of the intersection, will prepare for a right turn from lane 5 to the south arm of the intersection. Without measures a CAV:

A. approaching on lane 5 will come to a stop in lane 5 before the incident. Depending on whether the CAV can recognise the situation, either a TOR is issued (CAV is able to identify the incident but has no solution) or the CAV will simply wait as if the incident is the end of a queue.
B. approaching on lane 6 will try to merge to lane 5 and succeed (situation A is applicable) or cannot move to lane 5, because it is blocked by the incident or queuing vehicles before it. The CAV will inform the driver it cannot make the right turn an continue straight ahead to lane x and follow an alternate route.

When the RSI receives information about an incident it will deploy all the following four counter measures. CAVs and CVs:

A. will receive information about the incident itself (position, type, etc.).
    i. In addition, CAVs and CVs will receive information to support (allow/enable) the right turn from lane 6 to the south arm of the intersection.

Note: Normally, vehicles at this intersection are not allowed to make a right turn from lane 6. Therefore, the MAP and SPAT messages do not facilitate such a manoeuvre. CAVs and CVs might require information to support this manoeuvre. How to facilitate this manoeuvre will be subject for study in WP4 and WP5.

B. will receive a reduced speed advice.
C. are advised to use lane 6 to prepare for the right turn to the south arm of the intersection. The lane advice will help CAVs to make the right turn while maintaining their automated driving (AD) mode (and thus preventing a ToC).
    i. In case CAVs cannot cope with the situation they will drive straight ahead to find an alternate route.
    Note: they will most likely not trigger a ToC in this situation, possibly resulting in an MRM, because a ToC when driving near or on the intersection is dangerous.

The traffic light control (TLC) program might also be updated to further support the measures in case of the incident. For example, the TLC-program could switch to a program with:

- an arm-by-arm control logic, or
- a combined straight and right turn control logic.

Note that AVs and LVs will not receive any information. Therefore, ToCs will occur for AVs.

2.2.6.2 Timeline of actions

This scenario will be a combination of:

- CAVs passing the incident and making the right turn without a TOR, ToC or MRM.
- CAVs passing the incident, not being able to make the right turn and continue straight ahead.
- CAVs performing ToC as no solution for turning is found.
- CAVs with a failing ToC which results in an MRM.

Timeline:

1. RSI detects the incident on lane 5 (possibly supported by V2X).
2. Demarcate spatial action horizon (i.e. How far upstream do we start managing traffic? How far downstream do we stop?).
3. Define general strategy for mitigation (i.e. allow right turn from lane 6 to lane y; change TLC program or not).
4. Define a traffic management scenario for dealing with the situation:
    a. keep all traffic on lane 6.
    b. merge all traffic from lane 5 to lane 6.
    c. (optionally) activate TLC-control-scenario (i.e. different TLC program) to handle the incident.
    d. monitor the area upstream of the incident, especially on the lane of the incident. This area will be allocated as a potential safe spot. According to the situation, there can be more than one safe spot. See use case 4.2.
5. Communicate to CAVs and CVs about the incident using V2X:
    a. provide lane advice.
    b. provide speed advice.
6. Desired behaviour of vehicles driving along lane 5:
    a. Slow down to max 30 km/h.
    b. Merge into lane 6.

7. Desired behaviour of vehicles driving along lane 6:
    a. Stay in lane.
    b. Slow down to max 30 km/h.
    c. Create gaps for vehicles that want to merge from lane 5.
8. If vehicles driving on lane 5 do not manage to merge into lane 6 and come too close to the incident (distance to be defined):
    a. Advice the vehicle to issue a TOR.
        i. If the driver takes over, the vehicle merges into lane 6 when possible and continues downstream and makes the right turn from lane 6.
        ii. If the driver does not accept within a short time period (e.g., 30 sec), the vehicle performs an MRM and is guided to a safe spot on lane 5. See use case 4.2. After the MRM the driver takes over and proceeds as in the previous step.
9. If vehicles driving on lane 5 do manage to merge into lane 6, they continue driving in automated mode and make the right turn.
10. If the vehicle does not manage to make the right turn from lane 6 to the south arm of the intersection, vehicles continue driving along lane 6 to lane x of arm A (straight ahead).

Once vehicles have successfully passed the incident and have made the right turn onto the south arm of the intersection or drove straight ahead, then continue traffic operations normally.

2.2.6.3 Communications requirements

Different messages are needed to execute this service. On the one hand, CAM and CPM messages will be employed to increase the environmental perception of vehicles and the RSI. Vehicles will be informed about the accident through the DENM. MAPEM and SPATEM will be respectively include information of the road topology and about the traffic lights. Lane, speed and ToC advices are sent employing the MCM defined in Deliverable 5.1. This service introduces new requirements on the message set. The SPATEM has not been employed in the first iteration of the project, thus, this message will be included in the new definition of the message set. Further, as stated before, vehicles on lane 6 that desire to do a right turn may require to receive a confirmation that the turn is allowed. How to disseminate this information is one of the future topics of study in WP5.

2.2.6.4 SUMO network

The figure below shows the SUMO network used for studying Scenario 3.1. The full details of this network can be found in Appendix B.

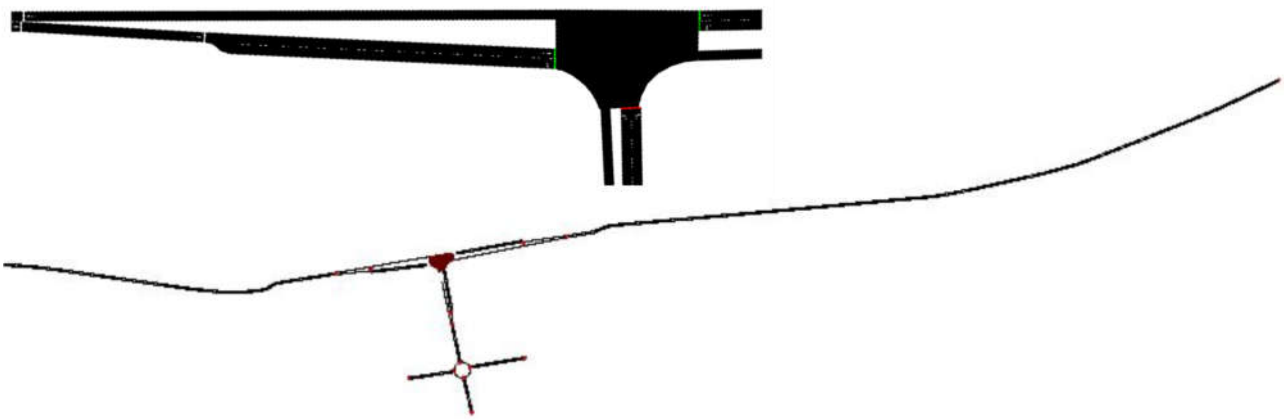


Figure 16: SUMO network for Scenario 2.3

2.2.7 Scenario 4.2: Safe spot in lane of blockage & Lane change Assistant

2.2.7.1 General description

A construction site is covering one lane of a road (urban or motorway). The deployed RSI continuously collects information about the construction area and the vicinity of it and provides it to the approaching CAVs.

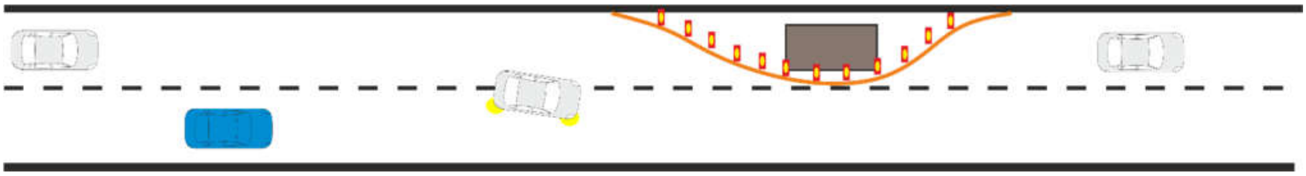


Figure 17: schematic overview of Scenario 4.2 (2nd Iteration)

Some CAVs are not able to pass the construction site without human intervention due to system limitations. Therefore, system-initiated ToCs take place somewhere upstream of the construction site. If any ToCs are unsuccessful, the respective CAVs perform MRMs. Without additional measures, the CAV would simply brake and stop on the lane it is driving. Thus, if it stops on the right free lane it will majorly disrupt the traffic flow, while if it stops further upstream of the work zone on the left lane it will essentially create a second lane drop bottleneck.

To avoid the latter situations, the RSI which is monitoring the area just in front of the construction site, offers pre-determined spaces as safe stops to the vehicle, if they are not occupied by surrounding traffic. The CAV uses the safe spot location information to come to a safe stop in case of an MRM.

Additionally, the RSI uses cooperative awareness and collective perception services along with data fusion to acquire accurate knowledge regarding prevailing traffic conditions, and thus facilitate early merging of CAVs on the right free lane (Lane Change Assistant Service). To ensure smoother merging of the CAVs on the right free lane, the RSI schedules lane change advices so that they are distributed in space and time to prevent any likely local turbulence of traffic. The Lane Change Assistant Service can be concurrently combined with cooperative manoeuvring to enhance its performance. Hence, the possibility that CAVs (which can overpass the work zone without disengagement of the driving automation system) stop in front of the work zone on the left lane and occupy safe spots that should be available for CAVs performing MRMs diminishes. Moreover, the average traffic flow performance is expected to improve in the absence of slow moving or stopped CAVs on the left lane in front of the work zone that attempt to merge onto the free right lane through cooperation.

2.2.7.2 Timeline of actions

1. The RSI monitors traffic in the area upstream of the work zone and is aware of the safe spot location information and reservation status.
    a. RSI uses cooperative awareness, collective perception, sensor data and data fusion to acquire precise knowledge regarding traffic status.
    b. RSI has information that the area around the construction site is challenging to AD.
        i. RSI schedules (distributes in time and space) lane changes for CAVs driving on the left lane to facilitate merging on the right free lane prior to arrival to the work zone. If the proposed lane changes are blocked by

surrounding vehicles, cooperative manoeuvring (centralized or decentralized) can be also implemented.

c. The safe spot areas are pre-determined and stored by the RSI (given the situation, there can be more than one safe spot).
    i. If the safe spot is not reserved by a CAV, or blocked by any vehicle, RSI communicates the position of the safe spot.
    ii. If it is reserved by a CAV, another safe spot is suggested (if any).
    iii. If all safe spots are reserved or blocked no action is taken.
d. The CAVs receive the safe spot information.
e. In case a CAV triggers ToC, it reserves the safe spot by communicating this to the RSI.
Note: the reservation of the safe spot occurs at the end of the available lead time to exclude cases when reservations might occur for successful ToCs.
    i. The RSI receives the request and reserves the safe spot for this CAV.
    ii. RSI provides time headway and lane advices to other CAVs and CVs in the vicinity in order to free the way for the CAV to the safe spot. *Note: These advices are only provided when conditions are safe for their execution.*
f. When the ToC fails and the MRM is started, the CAV tries to reach the safe spot.
g. The CAV reaches the safe spot.
h. After a while the driver of the CAV in the safe spot takes over and drives around the road works.

2.2.7.3 Communications requirements

This service employs the CAM and CPM messages to acquire accurate knowledge regarding prevailing traffic conditions. Moreover, it also employs the MCM to send headway and lane advices from the RSI and to coordinate the cooperative manoeuvres of vehicles. Additionally, this service introduces a mechanism for handling the safe spots where vehicles performing ToCs will be able to reserve a safe spot that will be employed if an MRM is needed. The current version of the message set does not allow the reservation of safe spots, hence, WP5 will define the appropriate message sets and flows needed based on the definition of the reservation mechanism of WP4.

2.2.7.4 SUMO network

The figures below show the SUMO networks used for studying Scenario 4.2 in urban and motorway conditions. The full details of these networks can be found in Appendix B.

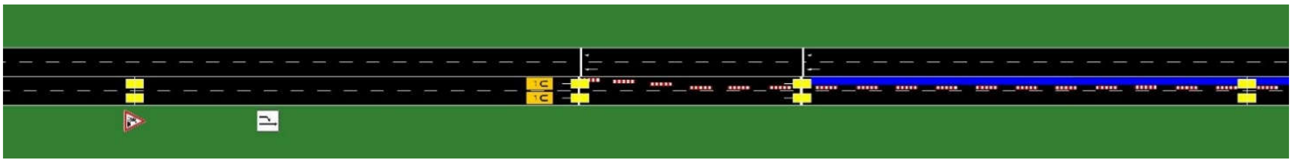


Figure 18: SUMO network for Scenario 4.2 in urban conditions (2nd Iteration)

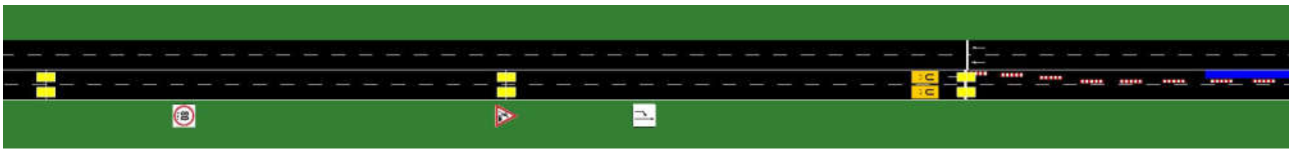


Figure 19: SUMO network for Scenario 4.2 in motorway conditions (2nd Iteration)

2.2.8 Scenario 4.1 + Service 5 (4.1-5): Distributed safe spots along an urban corridor

2.2.8.1 General description

On an urban two-lane road, LVs and C(A)Vs are approaching a No-AD zone, where manual driving is obligatory. Therefore, all C(A)Vs need to perform a transition, which occasionally may fail and lead to an MRM. Without further information, the vehicle would be expected to perform the MRM on the carriage way and interfere significantly with smooth and safe traffic operation.

However, upstream of the No-AD zone, several parking spaces are located on the road side, which could be used as safe spots. For the suitability of such a space it is assumed that the vehicle performing the MRM is able to enter it directly without further parking maneuvers.

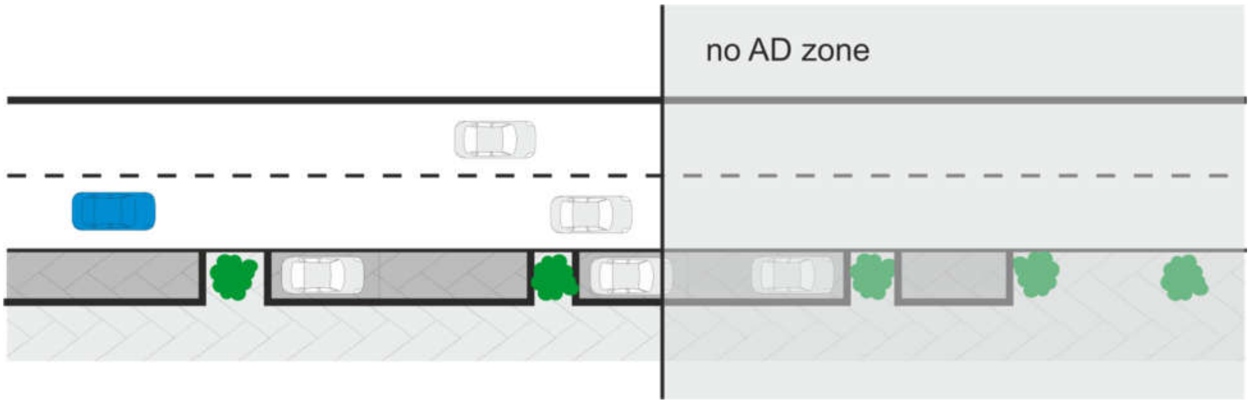


Figure 20: schematic overview of Scenario 4.1-5

The RSI monitors the position and speed of the approaching vehicles and the availability of the safe spots (parked vehicles) and provides information about which spot to use in case of an MRM to the CAVs. Further, to raise the probability that a vehicle, that needs to perform an MRM, does this when a safe spot is in range, the RSI schedules and sends ToC advice and safe spot assignments for individual CAVs likely to perform an MRM.

C(A)Vs that receive a ToC advice will initiate a takeover with a specified lead time. In case that the driver does not take over within this lead time the vehicle will try to steer towards its assigned safe spot and stop there.

2.2.8.2 Timeline of actions

1. CAVs send their state (position and speed) via V2X messages.
    a. RSI receives information on vehicle positions (from V2X or infrastructure) and integrates it into its internal representation of the traffic situation.
2. RSI broadcasts No-AD zone information.
    a. CAVs receive No-AD zone location and store it.
2. RSI determines occupancy of safe spots (parking places).
3. RSI internally calculates desirable hypothetic assignment of safe spots in case of MRMs and corresponding TOR positions for the detected CAVs.
    a. RSI sends safe spot assignments to all CAVs which are likely to initiate an MRM.
        i. CAV receives safe spot assignment, stores it, and sends an acknowledgement to the RSI.
        ii. RSI receives safe spot assignment acknowledgement and stops assignment messages.

   iii. RSI keeps sending assigned safe spot information to all CAVs, which did not acknowledge the assignment yet.

b. RSI sends ToC advices to all CAVs which have passed their assigned TOR positions.
   i. CAV receives ToC advice, initiates the downward transition and sends a corresponding announcement.

CAVs, which did not receive a ToC advice (due to transmission failures) and are close to the No-AD zone, initiate a takeover on their own.

2.2.8.3 Communications requirements

As the previous services, this service employs the CAM and CPM to enhance the environmental perception of vehicles and the RSI and the MCM to disseminate ToC advices to vehicles. The DENM message is employed to alert vehicles about the No-AD zone as defined in Deliverable 5.1. Similar to Service 4.2, this service also defines a reservation mechanism of safe spots. Hence, the message set defined in Deliverable 5.1 should be extended in order to accommodate the possibility of reservation of safe spots. Note that, the reservation mechanism of both services might not be equal. These mechanisms will be defined in WP4 while the appropriate message definition to allow the reservation will be defined in WP5. No further extensions of the message set are needed for the execution of this service.

2.2.8.4 SUMO Network

The figure below shows the SUMO network used for studying Scenario 4.1-5. The full details of this network can be found in Appendix B. In the figure below, only one set of parking spaces can be observed. However, the network contains five parking areas, equidistantly distributed at 150m, as is written in the full details.

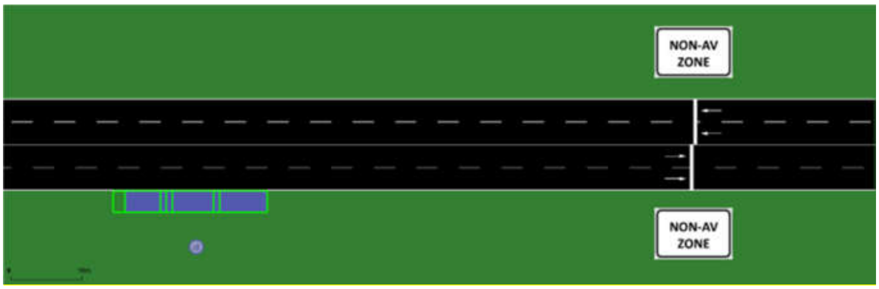


Figure 21: SUMO network for Scenario 4.1-5

3 Modelling requirements

This chapter is divided into two sections, one for each iteration. The section for the first iteration was created during that phase of the project and has not been changed since. The section regarding the second iteration provides updates on the vehicle modelling aspects (e.g. definition of actors and vehicle behaviours) as well as on the overall simulation parameters (e.g. vehicle mixes, LOS and fleet composition).

3.1 First iteration

In addition to the use case scenarios (timelines) and networks, other requirements and/or choices must be provided regarding simulation input (i.e. vehicle types and relevant characteristics, traffic demand, traffic composition, etc.). Below, the several actors are described with their capabilities and relevant models/algorithms. For the definition of the actors' communications capabilities, the Car2Car Communication Consortium roadmap overview (C2C-CC, "Vehicle manufacturers: C-ITS deployment plans and role in vehicle automation") was taken into account. Next, some models and algorithms are highlighted (lateral and longitudinal behaviour, ACC, lane change algorithms, etc.) and the way traffic measures (i.e. requests, advices, desired vehicle behaviour) are applied to the simulations. Moreover, an initial set of parameters regarding the traffic used in the simulation is provided (traffic demand, fleet composition and composition of actors).

3.1.1 Definition of actors

In the tables below, eight different actors are described. Each actor is a passenger vehicle type with specific capabilities. These vehicle types were carefully selected based on, on the one hand, roadmaps which predict which vehicle types become available in the coming years and, on the other hand, pragmatic reasons (e.g. limit the number of actors to have a manageable number of combinations and select those vehicle types that are most likely affected by TransAID measures).

For each vehicle type, the automated driving capabilities are defined and, if applicable, its ToC/MRM capabilities. Also, it is determined which kind of communication and/or messages the vehicle type supports. Finally, the algorithms and/or models to implement those capabilities are listed.

To what extent each of these actors take part in the simulations is described in section 3.2.5 where tables show the initial percentages for each of the actors.

Vehicle Type/Name	Legacy Vehicle (LV)
AD Capabilities	LVs are explicitly driven manually and are not equipped with any Advanced Driver-Assistance Systems (ADAS).
Communication Capabilities	LVs have no communication capabilities with the infrastructure (V2I) or other vehicles (V2V).
ToC/MRM Capabilities	LVs have no automated driving or communication capabilities. Thus, it is not required that they can execute ToCs or MRMs.
SUMO Driving Models	- Longitudinal Motion: Krauss Car-following Model - Lateral Motion: 2015 Sub-Lane Lane Change Model

Table 1: properties of Legacy Vehicle

Vehicle Type/Name	Legacy Vehicle – ADAS Equipped (LV-A)
AD Capabilities	LV-As are equipped with Level 1 & 2 ADAS (Adaptive Cruise Control, Lane Keep Assist, Forward Collision Warning, etc. according to SAE J3016) that assist drivers with the longitudinal and lateral vehicle control. However, drivers are responsible for the primary driving tasks and thus, they are continuously required to remain in the driving loop.
Communication Capabilities	LV-As have no communication capabilities with the infrastructure (V2I) or other vehicles (V2V).
ToC/MRM Capabilities	Internal or external factors can disrupt the Level 1 & 2 ADAS operation of LV-As, and thus incur a ToC (driver has to perform all driving tasks). However, the duration and effects of ToCs in these cases are expected to be marginal since LV-As' drivers are responsible for the primary driving tasks and can instantly take-over vehicle control when requested. LV-As are not capable of executing MRMs.
SUMO Driving Models	- Longitudinal Motion: ACC Car-following Model - Lateral Motion: 2015 Sub-Lane Lane Change Model

Table 2: properties of Legacy Vehicle – ADAS Equipped

Vehicle Type/Name	Cooperative Vehicle – Type 1 (CV-1)
AD Capabilities	CV-1s are equipped with Level 1 & 2 ADAS (Adaptive Cruise Control, Lane Keep Assist, Forward Collision Warning, etc.) that assist drivers with the longitudinal and lateral vehicle control. However, drivers are responsible for the primary driving tasks and thus, they are continuously required to remain in the driving loop.
Communication Capabilities	CV-1s can communicate both with the infrastructure (V2I) and other vehicles (V2V). They can transmit and receive warnings, as well as other messages from the infrastructure (e.g. MAP, SPaT, IVI messages)
ToC/MRM Capabilities	Internal or external factors can disrupt the Level 1 & 2 ADAS operation of CV-1s, and thus incur a ToC (driver has to perform all driving tasks). However, the duration and effects of ToCs in these cases are expected to be marginal since CV-1s drivers are responsible for the primary driving tasks and can instantly take-over vehicle control when requested. CV-1s are not capable of executing MRMs.
SUMO Driving Models	- Longitudinal Motion: ACC Car-following Model - Lateral Motion: 2015 Sub-Lane Lane Change Model

Table 3: properties of Cooperative Vehicle – Type 1

Vehicle Type/Name	Cooperative Vehicle – Type 2 (CV-2)
AD Capabilities	CV-2s are equipped with Level 1 & 2 ADAS (Adaptive Cruise Control, Lane Keep Assist, Forward Collision Warning, etc.) that assist drivers with the longitudinal and lateral vehicle control. However, drivers are responsible for the primary driving tasks and thus, they are continuously required to remain

	in the driving loop.
Communication Capabilities	CV-2s have the same communication capabilities with CV-1s, but additionally they can also receive and transmit collective perception messages (CPM) and support the operation of Cooperative Adaptive Cruise Control (CACC).
ToC/MRM Capabilities	Internal or external factors can disrupt the Level 1 & 2 ADAS operation of CV-2s, and thus incur a ToC (driver has to undertake all driving tasks). However, the duration and effects of ToCs in these cases are expected to be marginal since CV-2s drivers are responsible for the primary driving tasks and can instantly take-over vehicle control when requested. CV-2s are not capable of executing MRMs.
SUMO Driving Models	- Longitudinal Motion: ACC/CACC Car-following Model - Lateral Motion: 2015 Sub-Lane Lane Change Model

Table 4: properties of Cooperative Vehicle – Type 2

Vehicle Type/Name	Automated Vehicle – Level 3 (AV-L3)
AD Capabilities	AV-L3 automated systems can fully handle the longitudinal and lateral vehicle control under specific environmental, traffic and road conditions. However, drivers are responsible for the primary driving tasks and thus, they are continuously required to remain in the driving loop.
Communication Capabilities	AV-L3s have no communication capabilities with the infrastructure (V2I) or other vehicles (V2V).
ToC/MRM Capabilities	Internal or external factors can disrupt the automated operation of AV-L3s, and thus incur a ToC (driver has to undertake all driving tasks). The duration and effects of ToCs in these cases are normally expected to be marginal since AV-L3 drivers are responsible for the primary driving tasks and can instantly take-over vehicle control when requested. However, a minor effect on driving performance after a take-over may be present. If the driver is irresponsive to the ToC request the vehicle has the capability to execute an MRM and provide standstill in the ego lane.
SUMO Driving Models	- Longitudinal Motion: ACC/CACC Car-following Model, Krauss Car-following Model with imperfection (Task Capability Interface (TCI) Model) - Lateral Motion: Parametrised 2015 Sub-Lane Lane Change Model - ToC/MRM Model

Table 5: properties of Automated Vehicle – Level 3

Vehicle Type/Name	Automated Vehicle – Level 4 (AV-L4)
AD Capabilities	AV-L4 automated systems can fully handle the longitudinal and lateral vehicle control under specific environmental, traffic and road conditions (they can accommodate more complex situations compared to AV-L3 AD systems). Drivers are not responsible for the primary driving tasks and thus, they are not continuously required to remain in the driving loop.

Communication Capabilities	AV-L4s have no communication capabilities with the infrastructure (V2I) or other vehicles (V2V).
ToC/MRM Capabilities	Internal or external factors can disrupt the automated operation of AV-L4s, and thus incur a ToC (driver has to undertake all driving tasks). The duration and effects of ToCs in these cases can be significant since AV-L4 drivers are not responsible for the primary driving tasks and they might not be able to instantly take-over vehicle control when requested. However, AV-L4s can warn the driver in advance of an imminent ToC (prolonged ToC duration), and if the driver is irresponsive to the ToC request the vehicle has the capability to execute an MRM and provide standstill either in the ego lane or in the right-most lane.
SUMO Driving Models	- Longitudinal Motion: ACC/CACC Car-following Model, Krauss Car-following Model with imperfection (TCI Model) - Lateral Motion: Parametrised 2015 Sub-Lane Lane Change Model - Extended ToC/MRM Model (Lane change during MRM is possible)

Table 6: properties of Automated Vehicle – Level 4

Vehicle Type/Name	Cooperative Automated Vehicle – Level 3 (CAV-L3)
AD Capabilities	CAV-L3 automated systems can fully handle the longitudinal and lateral vehicle control under specific environmental, traffic and road conditions. However, drivers are responsible for the primary driving tasks and thus, they are continuously required to remain in the driving loop.
Communication Capabilities	CAV-L3s can communicate both with the infrastructure (V2I) and other vehicles (V2V). They have the same communication capabilities with CV-2s, but they can also share intentions and coordinate their actions (longitudinally and laterally) with other CAVs (cooperative manoeuvring).
ToC/MRM Capabilities	Internal or external factors can disrupt the automated operation of AV-L3s, and thus incur a ToC (driver has to undertake all driving tasks). The duration and effects of ToCs in these cases are normally expected to be marginal since AV-L3 drivers are responsible for the primary driving tasks and can instantly take-over vehicle control when requested. However, a minor effect on driving performance after a take-over may be present. If the driver is irresponsive to the ToC request the vehicle has the capability to execute an MRM and provide standstill in the ego lane.
SUMO Driving Models	- Longitudinal Motion: ACC/CACC Car-following Model, Krauss Car-following Model with imperfection (TCI Model) - Lateral Motion: Parametrised 2015 Sub-Lane Lane Change Model - ToC/MRM Model

Table 7: properties of Cooperative Automated Vehicle – Level 3

Vehicle Type/Name	Cooperative Automated Vehicle – Level 4 (CAV-L4)
AD Capabilities	CAV-L4 automated systems can fully handle the longitudinal and lateral vehicle control under specific environmental, traffic and road conditions (they can accommodate more complex situations compared to AV-L3 AD

	systems). Drivers are not responsible for the primary driving tasks and thus, they are not continuously required to remain in the driving loop.
Communication Capabilities	CAV-L4s can communicate both with the infrastructure (V2I) and other vehicles (V2V). They have the same communication capabilities with CV-2s, but they can also share intentions and coordinate their actions (longitudinally and laterally) with other CAVs (cooperative manoeuvring).
ToC/MRM Capabilities	Internal or external factors can disrupt the automated operation of AV-L4s, and thus incur a ToC (driver has to undertake all driving tasks). The duration and effects of ToCs in these cases can be significant since AV-L4 drivers are not responsible for the primary driving tasks and they might not be able to instantly take-over vehicle control when requested. However, AV-L4s can warn the driver in advance of an imminent ToC (prolonged ToC duration), and if the driver is irresponsive to the ToC request the vehicle has the capability to execute an MRM and provide standstill either in the ego lane or in the right-most lane.
SUMO Driving Models	- Longitudinal Motion: ACC/CACC Car-following Model, Krauss Car-following Model with imperfection (TCI Model) - Lateral Motion: Parametrised 2015 Sub-Lane Lane Change Model - Extended ToC/MRM Model (Lane change during MRM is possible)

Table 8: properties of Cooperative Automated Vehicle – Level 4

3.1.2 AV Modelling Requirements

A description of the AV modelling requirements for the simulation of the baseline scenario (without traffic management measures) and the test scenario (with traffic management measures) is given below. The difference in results between the two will tell the effectiveness of the developed measures.

3.1.2.1 Baseline Scenarios

The baseline scenarios of use cases 1.1, 2.1, 3.1, 4.2 and 5.1 encompass the operation of CAVs and AVs in automated driving mode. As human driving behaviour differs currently significantly from the operation of CAVs/AVs automated functionalities for longitudinal and lateral vehicle motion control, models capable of differentiating between CAV's/AV's behaviour in AD mode and human driving in manual mode have to be integrated into the microscopic traffic simulation software SUMO. To this end, an Adaptive Cruise Control controller (Milanés & Shladover, 2014, 2016; Xiao, Wang, & van Arem, 2017) is going to be simulated in SUMO to reflect CAVs/AVs longitudinal driving behaviour. Moreover, the SUMO 2015 Sub-lane Lane Change Model will be parametrised based on a comprehensive sensitivity analysis to reflect the lateral motion of CAVs/AVs during the simulation of the baseline scenarios.

To simulate the variable performance of human driving during the manual mode, SUMO's standard car-following model (Krauß, 1998) will be extended by a mechanism controlling error rates on the driver's perception and actuation. This mechanism will loosely rely on the task-capability interface (Fuller, 2005; Saifuzzaman, Zheng, Mazharul Haque, & Washington, 2015). Baseline scenarios assume no infrastructure-assisted traffic management measures for CAVs/AVs. Moreover, according to the description of use cases 1.1, 2.1, 3.1, 4.2 and 5.1 CAVs/AVs encounter situations, which are challenging for AD operations. Thus, it is expected that CAVs/AVs are going to initiate ToCs, which in some instances might result in MRMs if the driver is not able to fulfil the ToC request in time.

The corresponding modelling of ToCs and MRMs will be realised by implementing a corresponding *vehicle device* ("Developer/How To/Device - Sumo," n.d.), which provides an interface for the scheduling of ToCs and for the control of the drivers' response distributions. Further, the device may initiate MRMs if the maximal time until the ToC request should be fulfilled is exceeded. A deceleration profile will be assumed for MRM modelling and simulation. The user should be able to specify time and location of ToCs/MRMs, as well as the post-ToC impairment of driving performance explicitly and deterministically. Further, a probabilistic determination of response times and post-ToC performance should be possible.

3.1.2.2 TransAID measures

Car-following models developed within the context of the baseline scenarios will be used for the test scenarios (with traffic management measures) as well. Thus, CAVs/AVs behaviour in AD can be replicated in SUMO along with ToC/MRM manoeuvre execution. Test scenarios examine the impacts of infrastructure-assisted traffic management for mixed traffic in AD challenging zones (Transition Areas). The proposed services described in the use cases prevent, manage or distribute ToC to mitigate negative impacts from potential difficulties in the ToC process. Therefore, designated lane changes, ToCs and MRMs will be instructed to CAVs/CVs during the simulation time-line. Moreover, cooperative actions could be conveyed to CAVs from the infrastructure or in a decentralised way to facilitate the execution of the designated manoeuvres.

A brief description of the execution of the proposed traffic management measures in terms of simulation tasks is provided subsequently. Designated lane changes (use cases 1.1, 2.1 and 3.1) will be explicitly dictated to vehicles in space and time during the simulation. The underlying SUMO models (car-following, lane changing, and gap acceptance models) will then handle the operational execution of the lane change manoeuvres. This means, that it is possible that the gap acceptance logic may hinder the execution of a particular lane change manoeuvre right after the lane change advice due to prevailing traffic conditions, but the manoeuvre will take place during subsequent time steps. ToCs/MRMs for CAVs will be deterministically or stochastically scheduled in space and time during the simulation (use cases 4.2 and 5.1). Finally, cooperative manoeuvring will be considered based on a set of predefined conditions relating to prevailing traffic conditions (e.g., What are the ego CAV's neighbour vehicles?). Then, vehicles actions will be specified either by providing speed/headway and/or lane advice, or by planning specific vehicle trajectories.

3.1.2.3 Traffic demand

The numbers in the table below are the vehicles per hour per lane. For the Level of Service (LOS) (HCM, 2010) levels A, B and C the numbers are provided for urban, rural and motorway road types. For other levels (i.e. I/C ration > 0.8), numbers are not provided because of several reasons:

- insufficient capacity remains to efficiently manage traffic,
- there is hardly any impact of a ToC or MRM on the traffic flow, and
- results (i.e. KPIs) can vary a lot where it is often difficult to map those to a specific cause.

Therefore, LOS levels D and lower are not feasible and out of scope. Note that these are preliminary numbers and can be changed based on new insights during future work.

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

Intensity / Capacity (IC) ratio	0,35	0,55	0,77

Table 9: Vehicles/hour/lane for Level Of Service A, B and C in urban, rural and motorway conditions

3.1.2.4 Fleet composition

In most countries the percentage of cargo vehicles is between 10% and 20% on typical roads. Based on those numbers 15% of traffic is seen as cargo traffic. Of that 15%, 5% are considered light goods vehicles.

Vehicle type	Share
Passenger vehicle	85%
LGV	5%
HGV	10%

Table 10: distribution of passenger vehicles, light and heavy goods vehicles

3.1.2.5 Composition of actors

ADAS were gradually introduced into new passenger cars during the past decade. Currently, passenger cars of higher automation level (L3 automated systems) are market ready due to the rapid advancements in the fields of vehicle automation and communications. Projections pertinent to the development path of vehicle autmation indicate that highly automated systems (e.g. Highway Pilot) will enter the car market during the upcoming decade (Figure 22), while a solid time horizon for the accomplishment of the far-reaching goal of full automation is not yet feasible (ERTRAC Working Group, 2017).

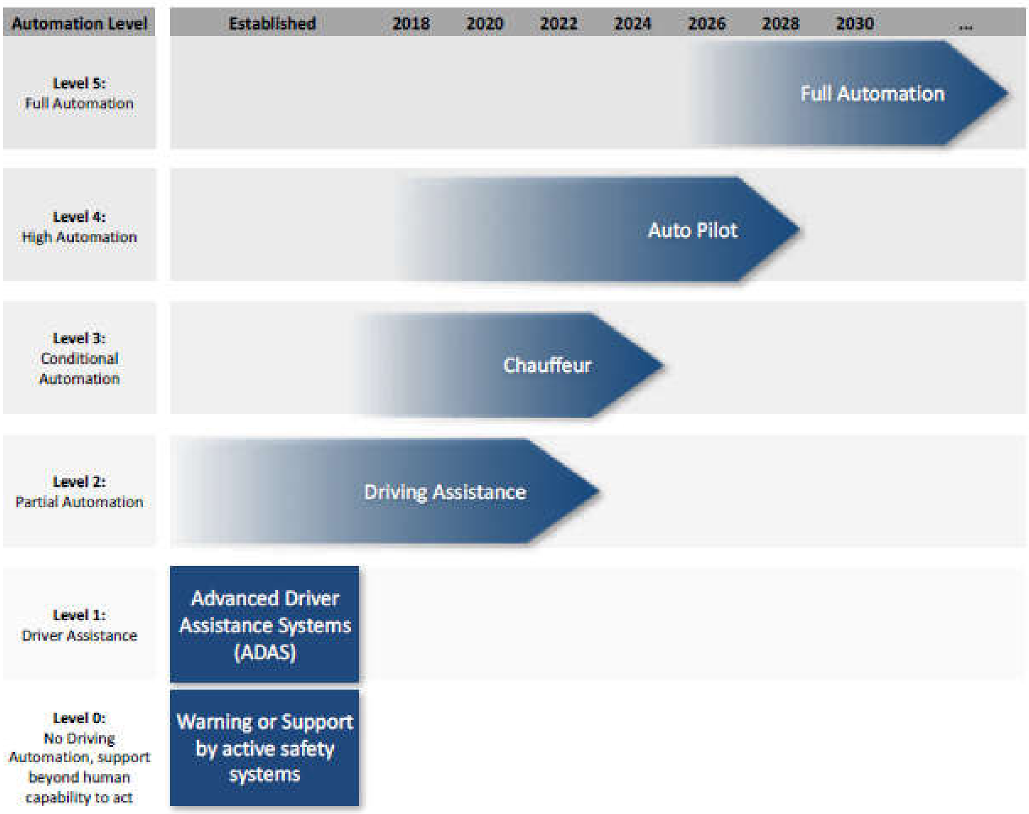


Figure 22: **projection of establishment for vehicle automation levels (ERTRAC Working Group, 2017)**

Communication capabilities of automated vehicles will play a pivotal role in the safe and efficient traffic management (centralised or decentralised) of mixed traffic during the upcoming decades.

The installation of Cooperative-ITS equipment both on the vehicle and the infrastructure side is expected to grow exponentially between 2020 and 2030 (Figure 23). (C-ITS Platform, 2016) estimates (pessimistic scenario) that over 75 thousand intersections (motorway and urban) and over 250 million vehicles will be equipped with C-ITS technology by the end of the next decade. The optimistic scenario estimate doubles the numbers on the infrastructure side.

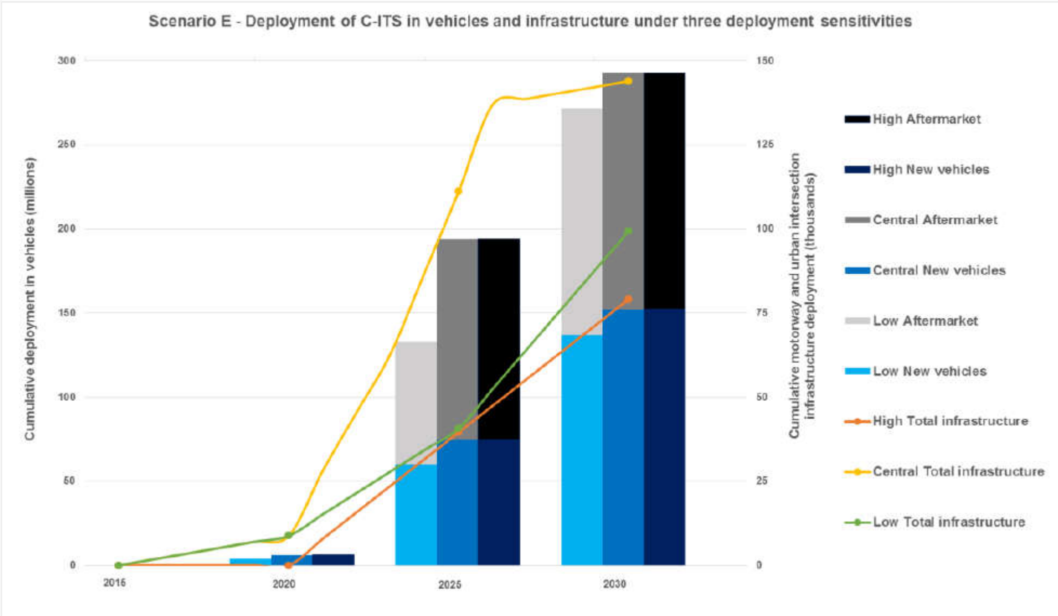


Figure 23: **future deployment (vehicle and infrastructure) of C-ITS technologies (C-ITS Platform, 2016)**

(PTOLEMUS Consulting Group, 2017) placed focus on the estimation of future market penetration of automaed vehicles according to their automation level. Based on the projections of their report, highly automated vehicles are expected to enter the market around 2025, but their share among new passenger car sales will remain low until 2030 (Figure 24). L2 vehicles will comprise the largest portion of new passenger cars until 2020, but this trend is expected to be reversed during the next decade (2020 – 2030) in favor of L3 vehicles.

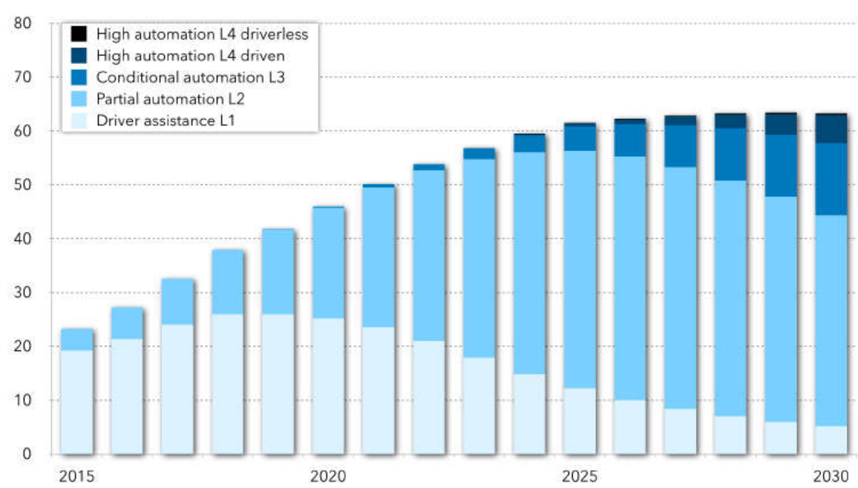


Figure 24: projected sales of new passenger cars (in millions) (PTOLEMUS Consulting Group, 2017)

Although automated vehicle sales will be increasing during the upcoming years, it is still expected that a significant portion of vehicles on the streets will be driven manually, since the fleet turnover process spans to at least three decades. (Litman, 2017) predicted that by 2020 (optimistic estimate) automated vehicles will account for 22% of vehicle sales, 19% of vehicle travel, and 16% of vehicles. These numbers are expected to substantially increase by 2040 when automated vehicles will comprise 50% of vehicle sales, 40% of all vehicle travel, and 30% of all vehicles according to the latter study (Figure 25). However, technological barriers, legal issues, cyber-security concerns and user preferences might result in lower adoption rate of automated driving and impact automated vehicle sales (pessimistic scenario).

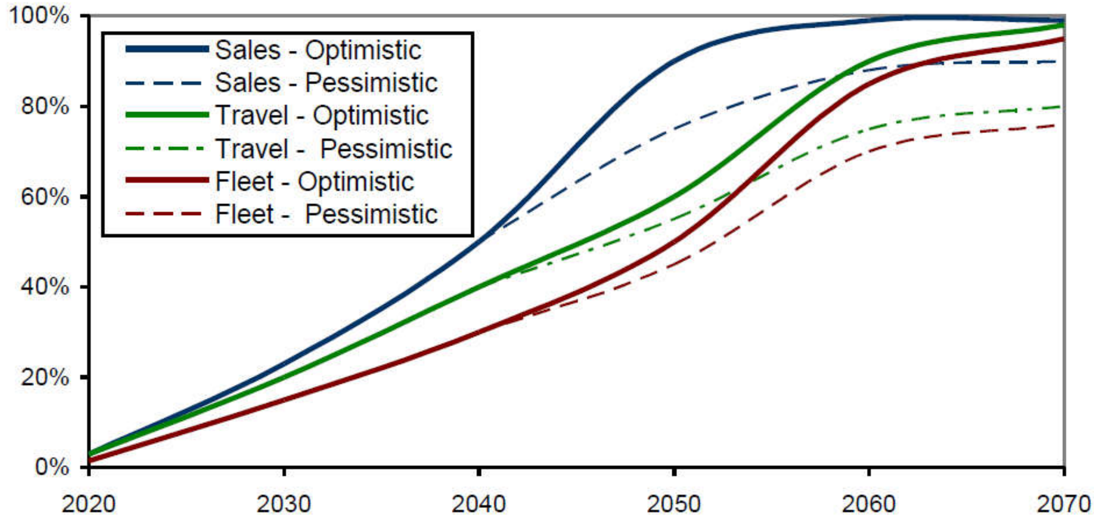


Figure 25: sales, travel and fleet projections of Automated Vehicles (Litman, 2017)

The share of cooperative automated, automated, and cooperative vehicles in the future mix of traffic will affect the traffic management practices for mixed traffic. TransAID is developing traffic management schemes that assume automated vehicles have communication capabilities. To identify the benefits of the proposed traffic management schemes simulations will be run with different penetration rates of the different vehicle types (i.e. vehicle mix).

First, Table 11 has been constructed by TransAID, based on the fleet penetration rate of different vehicle types (see 3.1.1 Definition of actors) in the vehicular fleet according to the projections and estimates of the aforementioned studies. For convenience, the percentages have been aggregated to reflect the actors used in the service/use case descriptions of D2.1.

Mix#	Year	LV	LV-A	CV-1	CV-2	AV-L3	AV-L4	CAV-L3	CAV-L4	AD*
1	**2025**	90%	6%	4%	-	-	-	-	-	10%
2	**2030**	85%	6%	4%	2%	2%	-	1%	-	15%
3	**2035**	80%	6%	4%	3%	3%	1%	2%	1%	20%
4	**2040**	70%	6%	4%	4%	5%	4%	4%	3%	30%
5	**2045**	60%	5%	3%	4%	9%	6%	8%	5%	40%
6	**2050**	50%	5%	3%	4%	12%	8%	12%	6%	50%
7	**2055**	40%	5%	3%	4%	15%	12%	15%	9%	60%
8	**2060**	15%	5%	3%	4%	22%	11%	22%	10%	70%

Table 11: estimated 'realistic' vehicle composition mapped to TransAID actors

Mix#	Year	LV	CV	AV	CAV	AD*
1	**2025**	90%	4%	6%	-	10%
2	**2030**	85%	6%	8%	1%	15%
3	**2035**	80%	7%	10%	3%	20%
4	**2040**	70%	8%	15%	7%	30%
5	**2045**	60%	7%	20%	13%	40%
6	**2050**	50%	7%	25%	18%	50%
7	**2055**	40%	7%	32%	24%	60%
8	**2060**	15%	7%	38%	32%	70%

Table 12: aggregated vehicles shares per vehicle type as used in D2.1

As can be seen, the share of automated vehicles with communication (CAV) is expected to increase to significant levels only after a few decades. Also, the difference between other percentages is sometimes quite small, which is expected to have a very small impact in simulations. The same is true for vehicle types with very low percentages.

For the purposes of TransAID and to effectively evaluate the developed measures, a more artificial / theoretical mix of vehicles is used.

Mix #	LV	LV-A	CV-1	CV-2	AV-L3	AV-L4	CAV-L3	CAV-L4
1	90%			5%			5%	
2	80%			10%			10%	
3	70%			15%			15%	
4	50%			25%			25%	
5	10%			40%			50%	
6	10%			5%			85%	
7	70%			15%				15%
8	70%		15%				15%	
9	55%			15%	15%		15%	
10	55%			15%		15%	15%	

Table 13: initial vehicle penetration rates for simulations

These mixes are a simplification (e.g. exclusion of LV-A) of the combination of possible actors on the one hand and offers more extreme values on the other (e.g. 85% CAV-L3). Also, some artificial combinations are included to very specifically evaluate what happens when certain functionality is included/excluded (e.g. mix 8, excluding CPM / CACC).

In addition to the mixes of Table 13, mix numbers 3 and 7 from Table 11 are used to evaluate more realistic vehicle compositions. Number 3 represents the ‘near’ future (i.e. approx. 17 years) while number 7 represents a more distant future (i.e. 37 years), but has higher penetration rates for automated vehicles, thereby possibly showing more impact of the applied TransAID measures.

It needs to be noted that arguments can be made for many other mixes as well, but within TransAID there are many other variables that need to be studied as well. Increasing the number of values for any variable, exponentially increases the number of simulations runs needed. During construction of the first scenario’s preliminary measures and after the first (informal) results, these numbers will be evaluated and probably adapted to optimally evaluate TransAID measures.

3.2 Second iteration

We gained several insights during the first iteration based on the performed simulations. In addition to ideas to improve existing vehicle models, like the lane change model or the ToC/MRM model, we want to add new behaviours to the simulations like CACC and cooperative manoeuvring. Other changes for the second iteration include different levels of services (LOSs, level B, C and D instead of A, B and C; HCM, 2010) and changing the fleet composition (i.e. add light goods vehicles and heavy goods vehicles). The planned improvements and changes to the simulations can be found in the sections below.

3.2.1 Definition of Actors

A comprehensive classification of vehicle types was presented in the 1st version of this deliverable in section 3.1.1. Vehicles were allocated in different categories according to their automated driving (AD), communication, and ToC/MRM capabilities. Moreover, the respective SUMO models that would emulate the motion of the different vehicle types (based on their aforementioned capabilities) were also determined. The latter classification was revised and consolidated in the 1st version of Deliverable D3.1 (Table 6) (Mintsis et al., 2018). The dimension of system activation was additionally considered in this latter classification, since automated driving systems are not expected to be continuously deployed, but system engagement will rely on driver's discretion in real word conditions.

Connectivity capabilities were assumed explicitly for a subset of each vehicle class proposed in the 1st version of Deliverable D3.1 (Table 6). For the second iteration, in addition to the communication aspects described for each scenario (see sections 0 to 2.2.8), the vehicle connectivity capabilities will be revisited and evaluated in the context of the new scenarios (Section 2.2) in upcoming WP5 activities.

Class Name	Class Type	Vehicle Capabilities
Class 1	Manual Driving	– Legacy Vehicles – (C)AVs/CVs (any level of driving automation) – Driving Automation: Off
Class 2	Partial Automation	– AVs/CVs equipped with Level 1/2 driving automation systems – Driving Automation: On – Instant ToC (driver responsible for monitoring road environment) – Emergency braking in case of distracted driving
Class 3	Conditional Automation	– (C)AVs equipped with Level 3 driving automation systems – Driving Automation: On – Basic ToC (normal duration)/MRM capability (ego lane)
Class 4	High Automation	– (C)AVs equipped with Level 4 driving automation systems – Driving Automation: On – Proactive ToC (prolonged duration)/MRM capability (right-most lane)

Table 14: Classification of vehicles based on automated driving, communications, and ToC/MRM capabilities

3.2.2 Traffic Composition

Artificial and realistic traffic mixes for simulation purposes were previously proposed in the 1st versions of Deliverable D2.2 (Tables 11 – 13) and Deliverable D3.1 (Tables 7 – 9). The proposed mixes were selected based on projections regarding future penetration of automated driving and communication technologies that were reported in past studies (C-ITS Platform, 2016; ERTRAC Working Group, 2017; Litman, 2017; PTOLEMUS Consulting Group, 2017). Moreover, traffic mixes for the 2nd iteration simulations were also suggested in the 1st version of Deliverable D3.1 (Tables 8/9). During the 1st project iteration we decided to explicitly simulate automated vehicles with communication capabilities apart from manual driven vehicles, since non-connected automated vehicles would disturb the performance of the TransAID measures and complicate the evaluation of the simulation results due to the increased variability in vehicle behaviour as an outcome of the presence of multiple vehicle classes in the simulations. Thus, we suggested that we would consider the effects of these non-connected AVs on the performance of the TransAID measures by introducing them into the traffic mix during the 2nd project iteration simulation activities. However, simulation findings during the 1st project iteration (Deliverables D3.1 and D4.2) indicated that vehicle interactions are already complex in the presence of three different classes. In addition, for scenario 1.1, 25% of the connected automated vehicles was assumed to not respond to measures due to either not understanding the received messages or missing them. In practice, the behaviour of that percentage of vehicles is the same as the non-connected automated vehicles. Hence, those non-connected automated vehicles are included implicitly as part of the connected automated vehicles. For the second iteration, we will assume a non-compliance rate (the percentage will be determined at a later stage) for all scenarios, thereby including the behaviour of AVs implicitly as well as non-compliant CAVs. These non-compliant CAVs do not comply either due to not understanding the message or not receiving it (the latter will be explicitly modelled in WP6 when communications are added).

The varying behaviour of these four different vehicle classes result in quite complex interactions during simulation and consequently the evaluation of the simulation results. Also, the proposed percentages of realistic vehicle mixes as shown Table 9 of Deliverable D3.1 are quite close to the percentages presented in Table 15. Therefore, we decided to focus on the three mixes as presented, without adding any other mixes.

Vehicle Mix	Class 1	Class 1 (Conn.)	Class 2	Class 2 (Conn.)	Class 3	Class 3 (Conn.)	Class 4	Class 4 (Conn.)
1	60%	10%	-	15%	-	10%	-	5%
2	40%	10%	-	25%	-	15%	-	10%
3	10%	10%	-	40%	-	25%	-	15%

Table 15: Artificial vehicle mixes for baseline simulations during 2nd project iteration

Aside from vehicle capabilities regarding automation and communication, the type of vehicle also can impact the overall traffic behaviour. During the first iteration, a distribution of passenger cars, light goods vehicles (LGV) and heavy goods vehicles (HGV) was proposed in this deliverable, but eventually not included in the simulations. The reason is, that we wanted to study the effects of the developed measures without them being impacted too much by other complicating factors (e.g. a safe spot cannot be reached just because incidentally a long heavy truck is blocking access). We wanted to focus on testing test the principle of the measures and deal with complicating aspects due to more realistic factors in the second iteration. Thus, for the second iteration, the LGVs and HGVs will be included. The updated table below shows the distributions of passenger cars, LGVs and HGVs for both urban roads and motorways. The percentages were determined by studying reports from the Belgian road authorities and the TREMOVE project (Kilometers afgelegd op het Belgische wegennet in 2015, 2017; Kilometers afgelegd door Belgische voertuigen in 2017, 2018; TREMOVE, 2010).

Vehicle type	Share on urban roads	Share on motorways
Passenger vehicle	83%	77%
LGV	10%	10%
HGV	2%	13%

Table 16: distribution of passenger vehicles, light and heavy goods vehicles on urban roads and motorways

3.2.3 Traffic Demand

During the 1st project iteration three different traffic demand levels were considered for simulation purposes. These traffic demand levels corresponded to Levels of Service (LOS) A, B, and C. Consideration was also given to road type (urban, rural, and motorway) for the selection of the corresponding hourly volume per LOS. Higher demand levels were not considered initially due to the following reasons:

- insufficient capacity remains to efficiently manage traffic,
- marginal impact of ToC/MRM is expected on the traffic flow, and
- high variability of results (difficult to map KPIs to a specific cause).

However, simulation results presented in Deliverables D3.1 and D4.2 showed that further examination of LOS A is of limited interest. For all the examined scenarios (i.e. 1.1, 2.1, 3.1, 4.2, and 5.1) free-flow traffic conditions prevailed irrespective of the traffic mix and the parametrization of the vehicle/driver models. Thus, the benefits generated by the implementation of the TransAID measures were of minor significance. On the contrary, it was observed that for some scenarios (1.1, 4.2 – Urban), the examination of LOS D would be meaningful, since traffic conditions did not substantially deteriorate for LOS C. Hence, if demand is increased and traffic flow performance is reduced in the baseline simulations, it can be expected that the implementation of the TransAID measures will yield benefits that are more substantial. Therefore, we exclude LOS A and include LOS D with respect to the simulation of the scenarios selected for the 2nd project iteration. The hourly volumes per lane corresponding to the proposed LOS and the respective intensity/capacity ratios are depicted in Table 17.

Facility Type	**Capacity (veh/h/l)**	**Level of Service (LOS)**		
		B	**C**	**D**
Urban (50km/h)	1500 veh/h/l	825	1155	1386
Rural (80 km/h)	1900 veh/h/l	1045	1463	1756
Motorway (120 km/h)	2100 veh/h/l	1155	1617	1940
Intensity / Capacity (IC) ratio		0,55	0,77	0.92

Table 17: Vehicles/hour/lane for LOS B, C and D in urban, rural, and motorway facilities

3.2.4 Vehicle/Driver Models

Vehicle/driver models were introduced in the 1st project iteration to mimic AV longitudinal/lateral motion, and driver behaviour during ToC in SUMO. An Adaptive Cruise Control (ACC) algorithm was used to replicate the longitudinal motion of AVs, while the default SUMO lane change model (LC2013) was parametrized based on AV experimental lane change data to reflect actual AV lane change behaviour. Finally, a novel ToC/MRM model was developed to replicate driver response to take-over request (TOR), driver post-TOC performance, and MRM in case of unsuccessful ToC.

In the 2nd project iteration a Cooperative Adaptive Cruise Control (CACC) algorithm is introduced to emulate CAV car-following behaviour in the presence of V2V communications. Moreover, the parametrization of the LC2013 lane change model is revisited, since simulation findings reported in the 1st versions of Deliverable D3.1 and D4.2 indicated that the lane change behaviour of AVs was modelled rather conservative. Thus, updated values for the calibration parameters of the LC2013 lane change model will be selected based on lane change related KPIs that will be plotted for the simulation scenarios tested during the 1st project iteration. Finally, extensions are made to the ToC/MRM model presented in the 1st version of Deliverable D3.1 and to the cooperative manoeuvring logic introduced in the 1st version of Deliverable D3.2. Detailed information regarding the latter model extensions can be found in the following sections.

3.2.4.1 Dynamical triggering of TORs

In certain situations, the necessity and available lead time of downward transitions cannot be planned strictly statically. Primarily this concerns situations, where an automated vehicle is not able to follow its route due to a failing intent to change lanes. To depict these situations in the simulations it will be necessary to issue take-over requests with situation-specific lead times. The dynamic trigger condition will depend on the vehicles current speed and the available distance until the lane change must be completed. A dynamic selection of the available lead time will, in turn, imply that the driver’s response times cannot be provided through static configuration files since the time a driver needs or takes for resuming control is correlated with the given lead time (Gold et al., 2013).

3.2.4.2 ToC Preparation Phase

For the ToC preparation phase, it seems reasonable to assume that an automated vehicle may simplify the situation for the driver by increasing the headway prior to the takeover. In particular, this is obviously necessary if the automated vehicle is driving at very short headways within a group of CACC vehicles or a platoon. In this case, any following CACC vehicle will also need to adapt its headway prior to the takeover of its leader, since we assume that CACC control can only be activated when a CACC is directly following another CACC.

To this end, we will refine the model behaviour in the preparation phase to include a mechanism that can smoothly establish increased headways between subsequent vehicles. The configurability of this mechanism should allow the user to specify the desired target headways (in space and time measures), the maximal braking rate applied to comply with the new headway, and the rate by which the headway parameter changes from the original to the new value.

Moreover, such a mechanism may prove useful to smooth out vehicle type transitions in general, and re-establish desired headways after a cut-in with diminished headways as occurring for models with increased lane change agility (parameter values larger than one for the SUMO parameter $lcAssertive$). Handling such situations smoothly will require a continuous relaxation of the headways of the merging vehicle as well as the follower on the target lane.

3.2.4.3 Improving post-ToC error characteristics

The realism of simulations and in particular the estimation of safety indicators would greatly benefit if more accurate representations of the characteristics of manual driving are introduced. In particular, we plan to extend the ToC model by including configurable post-ToC lane change abstinence.

Furthermore, we will test the effects of an increased reaction time within the recovery phase, which may be included directly by means of an increased action point frequency, or indirectly by coupling elevated perception thresholds to the awareness level for the driver state module assigned for the manual control regime of vehicle models, c.f. (Mintsis et al., 2018).

Another characteristic observed experimentally is the occasional occurrence of overly sensitive braking, i.e. unnecessarily high deceleration rates in the immediate post-ToC phase. We will evaluate possible ways to evoke these phenomena for the employed models. One possibility is to model them as short episodes of initiated MRMs following the preparation phase, that is merely assigning response times slightly above the given lead time, another possibility is that they already arise as a side effect of elevated reaction times.

Finally, the inaccuracy caused by the error process of the driver state model is symmetric with respect to the desired value, given the same probability to deviations into safer and less safe effective parameters. That is, when driving at the desired headway, the probability of erroneously undercutting it in the course of the simulation is the same as for exceeding it. In reality, a driver is more likely inclined to accept errors towards the safer side than in the opposite direction, which could be incorporated by asynchronous coefficients for the underlying Ornstein-Uhlenbeck process (Mintsis et al., 2018).

3.2.4.4 Cooperative manoeuvring

In the 1st project iteration cooperative manoeuvring was introduced in the form of cooperation between the ego CAV and the target follower CAV. This cooperation entails the creation of a gap from the side of the target follower CAV to facilitate merging of the ego CAV into the desired lane. A prerequisite regarding this type of cooperation is that the ego CAV is explicitly surrounded by other CAVs (current leader, current follower, target leader, target follower) for cooperative manoeuvring to finally take place. Moreover, cooperative manoeuvring is not planned so that global optimum conditions are ensured for the traffic stream, but its logic is confined in explicitly considering local traffic conditions for the manoeuvring planning and execution.

However, during the 2nd project iteration we plan to enhance the latter cooperative manoeuvring logic by considering more types of cooperation between the ego CAV and its surrounding CAVs. Thus, we will also investigate cooperative manoeuvring in the form of: a) speed advice provision to the ego CAV to facilitate its lane changing, b) gap creation advice provision concurrently to the target follower and target leader CAVs, and c) lane change advice provision to the target follower CAV to allow merging of the ego CAV on the desired lane. Finally, we will explore the option of implementing a cooperative manoeuvring framework that plans cooperative manoeuvres in a global optimum way which does not deteriorates neighbouring traffic in favour of the cooperating CAVs.

4 Conclusion and outlook

4.1 First iteration

Based on the use cases and scenarios provided as examples within the five services described in D2.1, five scenarios were chosen and worked out in more detail. For those scenarios, timelines have been created which describe the different steps (or scenes) of the scenarios. To be able to simulate those scenarios, for each scenario one or more simulation (SUMO) networks were created. 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. The detailed descriptions (fact sheets) of these networks can be found in Appendix A.

From the detailed scenario descriptions (timelines) requirements can be derived for WPs 3-6. Especially for WP 3 (vehicle modelling) requirements can be determined following the descriptions in chapter 3. Based on the descriptions of the timelines and vehicle requirements, many requirements for communication are implied which are to be (further) identified in WP5[1].

Completing this deliverable 2.2 fulfils 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 MS6 due in project month 18, a revised version of this deliverable will be created by updating it with insights gathered during the first TransAID iteration and needed information for the second one.

As a next step, WP4 will further design the traffic measures proposed in the timelines of the scenarios. The work done there might imply additional vehicle modelling requirements and/or communication requirements. WPs 3-5 will therefore work closely together towards an integrated solution (integration to be done in WP6), by combining the vehicle models, traffic measures and communication protocols, so that the TransAID measures can be evaluated.

4.2 Second iteration

The first iteration provided many insights, which have been used to select new scenarios and create the corresponding SUMO networks (deltails in Appendix B) to study. These scenarios partly focus on new situations and others combine multiple measures (services) into one scenario. It is expected the hierarchical approach of applying multiple services (i.e. speed and lane advice, safe spot reservation and ToC requests) in parallel or sequential will result in improved mitigation of the negative impact of transition areas.

In addition, ideas to improve on vehicle modelling (i.e. lane change behaviour and ToC/MRM behaviour) are introduced and will worked out in WP3. Moreover, enhanced cooperative manoeuvring (merging) will be also investigated.

[1] WPs 3-6 already started their work based on D2.1 and the concept versions of this deliverable D2.2 (1st iteration).

To focus on more realistic scenarios, each scenario has been extended with opposite traffic to create realistic communication traffic and support the evaluation of possible congestion of the communication channels. Also, other types of vehicles will be used to create a more realistic traffic mix (i.e. adding light good vehicles and heavy good vehicles), aside from the already proposed mixes of vehicles encompassing different communication and automation capabilities.

As in the first iteration, WP4 will further design the traffic measures proposed in the timelines of the scenarios. The work done there might imply additional vehicle modelling requirements and/or communication requirements. WPs 3-5 will therefore work closely together towards an integrated solution (integration to be done in WP6), by combining the vehicle models, traffic measures and communication protocols, so that the TransAID measures can be evaluated.

Finally, the setup and questions of a survey to be held among stakeholders has been included in Appendix C. This will provide feedback on the choices made in the TransAID project and guide future decisions in the upcoming work.

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Appendix A

Scenario 1.1	Settings	Notes
Road section length	1.85 km	
Road priority	3	
Allowed road speed	13.89 m/s	• 50 km/h
Number of nodes	11	• n0 – n10
Number of edges	10	
Number of O-D relations	1	• from n0 to n8
Number of lanes	3	• 2 normal lanes; 1 bus lane (the rightmost lane)
Work zone location	from n5 to n6	• 250 m
Closed edges[1, 2] (defined in the file closeLanes.add.xml)	workzone	• 2 normal lanes
	safetyzone1_1	• the leftmost lane
	safetyzone1_2	• 2 normal lanes
	safetyzone2_1	• 2 normal lanes
	safetyzone2_2	• the leftmost lane
Disallowed vehicle classes	• normal lanes: pedestrians, tram, rail_urban, rail, rail_electric, ship	• from n0 to n10
	• bus lane: all expect buses, coaches and emergency vehicles	• from n0 to n2 • from n9 to n10
	• bus lane: same as the normal lanes with custom_1	• from n2 to n9 • custom_1: AVs without providing information
Filenames	• network: UC1_1.net.xml • lane closure: closeLanes.add.xml • traffic signs: shapes.add.xml	

Intended control of lane usage

Around the construction site, the bus lane's vClass permissions are altered to allow all classes but the class 'custom1' which is assigned to automated vehicles, which were not informed about the possible circumvention along the bus lane. As soon as they are informed, their vClass should be switched to the default class ("passenger"), which in turn allows them to use the bus lane in the specified region.

Network layout

Road segments

n0→n1: Insertion and backlog area (300 m)
n0→n2: Bus only on bus lane (650 m)
n2→n9: all vClasses but uninformed automated allowed (class "custom1") on bus lane (800 m)
n3→n4: the leftmost lane closed (safety zone 1_1) (25 m)
n4→n5: the second leftmost lane closed as well (safety zone 1_2 (25 m))
n5→n6: the second leftmost lane closed as well (work site (250 m))
n6→n7: the second leftmost lane closed as well (safety zone 2_1 (25 m))
n7→n8: the leftmost lane closed (safety zone 2_2 (25 m))
n9→n10: Bus only on bus lane (400 m)

[1] Required minimum safety distance according to the German Technical Rules for Workplaces ASR A5.2: 10m with allowed maximum speed 30 km/h; 50 m with allowed maximum speed 50 km/h; 100 m with allowed maximum speed 100 km/h. Each safety area is divided into two parts: one is with one-lane closure and the other one is with two-lane closure for smoother transition.;

[2] The placement of the traffic signs is based on the German Guidelines for road job security (RSA).

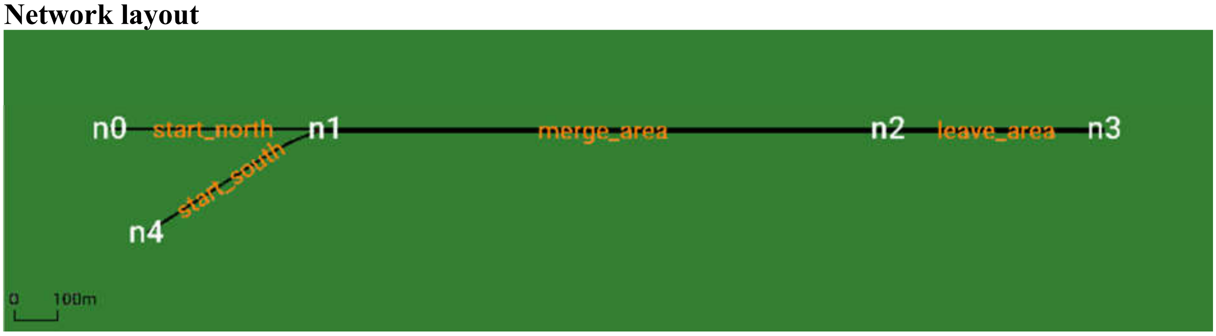
Scenario 2.1	Settings	Notes
Road section length	• Motorway: 1.5 km • On-ramp: 0.5 km	
Road priority	3	
Allowed road speed	• Motorway: 27.78 m/s • On-ramp: 13.89 m/s	• Motorway: 100 km/h • On-ramp: 50 km/h
Number of nodes	7	• n1- n7 priority nodes
Number of edges	6	
Number of O-D relations	2	• from n1 to n7 • from n3 to n7
Number of lanes	1-2-3	• 1 lane on-ramp • 2 normal lanes on motorway • 3 lanes at merging zone/ acceleration lane
Disallowed vehicle classes	• normal lanes: pedestrians, tram, rail_urban, rail, rail_electric, ship	• from n1 to n7
Filenames	• network: UC2_1.net.xml	
Network layout 		
Road segments n1→ n2: Insertion and backlog area (100 m, 2 lanes) n2→ n4: mainstream motorway (500 m, 2 lanes) n3→ n4: on-ramp (500 m, 1 lane) n4→ n5: mainstream motorway with acceleration lane (150 m, 3 lanes) n5→ n6: mainstream motorway (650 m, 2 lanes) n6→ n7: exit (100 m, 2 lanes)		

Scenario 3.1	Settings	Notes
Road section length	2.3 km	• for each motorway
Road priority	9	
Allowed road speed	36.11 m/s	130 km/h
Number of nodes	5	• n0 – n5
Number of edges	4	
Number of start nodes	2	• n0, n4
Number of end nodes	1	• n3
Number of O-D relations	2	• From n0 to n3 • From n4 to n3
Number of lanes upstream of the merging area	2	
Number of lanes upstream of the merging area	4	• from n1 to n2
Merging area length	1.3 km	
Filename	• network: UC3_1.net.xml	

Intended control of lane usage

There is no control on lane usage. In the sub-scenario 1, 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. 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.

Network layout



Road segments

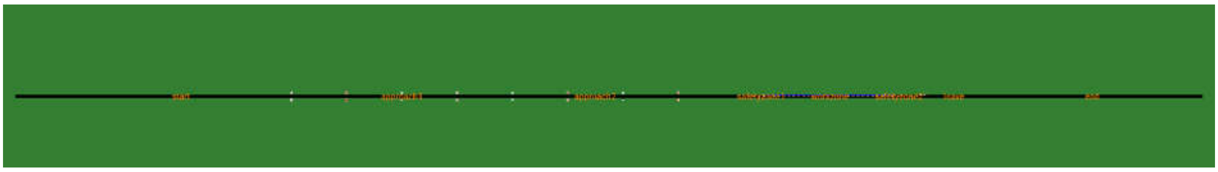
n0→n1: Insertion and backlog area (500 m)
n4→n1: Insertion and backlog area (500 m)
n1→n2: Merging area (1300 m)
n2→n3: Leaving area (500 m)

Scenario 4.2 (motorway)	Settings	Notes
Road section length	2.15 km	
Road priority	3	
Allowed road speed	• 36.11 m/s • 27.78 m/s (700 m in front of the safety zone before entering the work zone area) • 22.22 m/s around the work zone	• 130 km/h • 100 km/h • 80 km/h
Number of nodes	9	• n0 – n8
Number of edges	8	
Number of O-D relations	1	• from n0 to n8
Number of lanes	2	
Construction location	from n4 to n5	• 150 m
Closed edge[3, 4] (defined in the file: closeLanes.add.xml)	workzone	• the leftmost lane (150 m)
	safetyzone1	• the leftmost lane (100 m)
	safetyzone2	• the leftmost lane (100 m)
Filenames	• network: UC4_2_urban.net.xml • lane closure: closeLanes.add.xml • traffic signs: shapes.add.xml	

Intended control of lane usage

There is no control on lane usage. This situation is the same as the situation in an urban area, but on motorways. Speeds are higher, and more space and time are needed to execute the measures of this service.

Network layout



Road segments

n0→n1: Insertion and backlog area (600 m)
n1→n3: Approaching area (700 m)
n3→n4: Safety area (100 m)
n4→n5: Work zone (150 m)
n5→n6: Safety area (100 m)
n6→n8: Leaving area (500 m)

[3] The placement of the traffic signs is based on the German Guidelines for road job security (RSA).

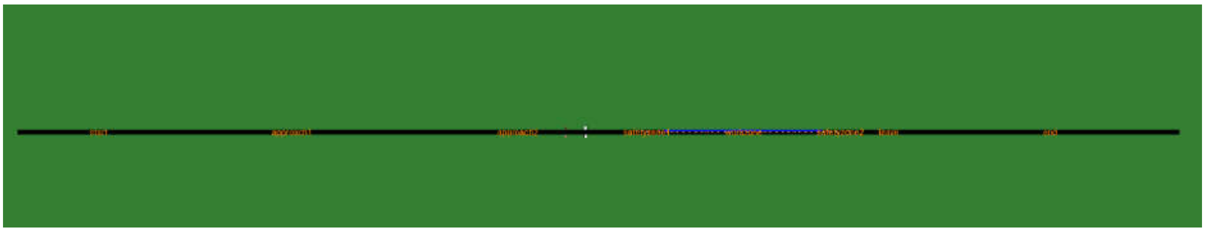
[4] Required minimum safety distance according to the German Technical Rules for Workplaces ASR A5.2: 10m with allowed maximum speed 30 km/h; 50 m with allowed maximum speed 50 km/h; 100 m with allowed maximum speed 100 km/h.

Scenario 4.2 (urban)	Settings	Notes
Road section length	1.85 km	
Road priority	3	
Allowed road speed	13.89 m/s	• 50 km/h
Number of nodes	9	• n0 – n8
Number of edges	8	
Number of O-D relations	1	• from n0 to n8
Number of lanes	2	
Work zone location	from n4 to n5	• 250 m
Closed edge[5, 6] (defined in the file: closeLanes.add.xml)	workzone	• the leftmost lane (250 m)
	safetyzone1	• the leftmost lane (50 m)
	Safetyzone2	• the leftmost lane (50 m)
Filenames	• network: UC4_2_urban.net.xml • lane closure: closeLanes.add.xml • traffic signs: shapes.add.xml	

Intended control of lane usage

There is no control on lane usage. 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.

Network layout



Road segments

n0→n1: Insertion and backlog area (300 m)
n1→n3: Approaching area (700 m)
n3→n4: Safety area (50 m)
n4→n5: Work zone (250 m)
n5→n6: Safety area (50 m)
n6→n8: Leaving area (500 m)

[5] The placement of the traffic signs is based on the German Guidelines for road job security (RSA).

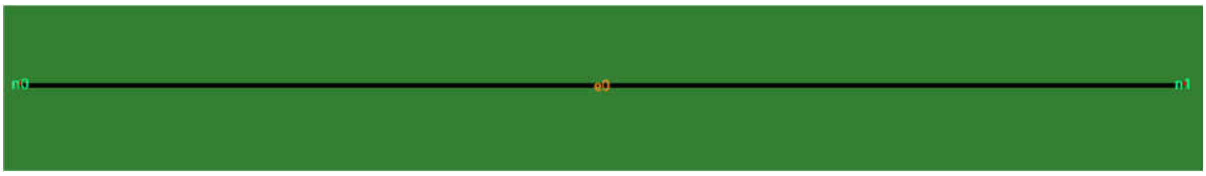
[6] Required minimum safety distance according to the German Technical Rules for Workplaces ASR A5.2: 10m with allowed maximum speed 30 km/h; 50 m with allowed maximum speed 50 km/h; 100 m with allowed maximum speed 100 km/h.

Scenario 5.1	Settings	Notes
Road section length	5.0 km	
Road priority	3	
Allowed road speed	27.78 m/s	• 100 km/h
Number of nodes	2	• n0 – n1
Number of edges	1	
Number of O-D relations	1	• n0 to n1
Number of lanes	2	• 2 normal lanes
Work zone location	-	
Closed edges	-	
Disallowed vehicle classes	• normal lanes: pedestrians, tram, rail_urban, rail, rail_electric, ship	• from n0 to n1
Filenames	• network: TransAID_UC5-1.net.xml	

Intended control of lane usage

CAVs and other traffic are approaching a no AD zone with 2 lanes. Starting about 3.0 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.

Network layout



Road segments

n0→n1: (5.000 m)

Appendix B

Scenario 1.3	Settings	Notes
Road section length	• Motorway: 1.50 km • Exit lane: 0.20 km • Off-ramp: 0.25 km	• Section of the motorway with an additional lane for decelerating traffic • Connection between exit lane and express road network
Road priority	3	
Allowed road speed	• Motorway: 33.33 m/s • Off-ramp: decreasing from 25.00 m/s to 13.89 m/s • Express road: 13.89 m/s	• Motorway: 120 km/h • Off-ramp: decreasing from 90 km/h to 50 km/h • Express road: 50 km/h
Number of nodes	26	• The motorway section upstream of the exit ramp is divided in sections of 50m (1 edge per section). This will allow us to dynamically adapt the section where the emergency lane is opened for queuing • There is one special node: a traffic light (required to induce a queue on the off-ramp)
Number of edges	24	Cf 'Number of nodes' above
Number of O-D relations	3	• 1: motorway traffic • 2-3: traffic from the motorway to the N or to the S direction on the express road
Number of lanes	1-3	• 1 lane off-ramp/ 2x1 lane on express road • 3 lanes at exit zone • 2 normal lanes + emergency lane on all other motorway sections
Disallowed vehicle classes	• normal lanes: pedestrians, tram, rail_urban, rail, rail_electric, ship • emergency lanes: all vehicles are disallowed	• from n1 to n9 • this can be changed dynamically during the simulation
Filenames	• network: UC1_3.net.xml	

Network layout

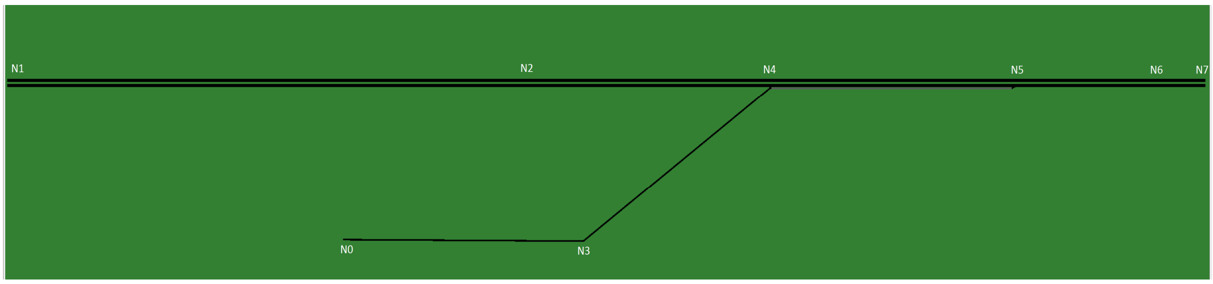
Road segments

n1→ n17: mainstream motorway (800 m, 2 lanes + emergency lane)
n17→ n18: exit zone (200m, 3 lane motorway + exit lane)
n18→ n19: mainstream motorway (500 m, 3 lanes)
n18→ n20→ n21: off-ramp (180 m, 1 lane)
n21→ n22: off-ramp (70 m, 1 lane, ends at traffic light)
n23→ n22→ n24 and vice versa: express road (50 m, 2x1 lanes)
n25→ n26: motorway in opposite direction (1500 m, 2 lanes + emergency lane)

Scenario 2.1	Settings	Notes
Road section length	• Motorway: 2.5 km • On-ramp: 1.5 km	
Road priority	3	
Allowed road speed	• Motorway: 27.78 m/s • On-ramp: 27.78 m/s	• Motorway: 100 km/h • On-ramp: 100 km/h
Number of nodes	8	• n0- n7 priority nodes
Number of edges	8	
Number of O-D relations	3	• from n1 to n7 • from n0 to n7 • from n7 to n1
Number of lanes	1-2-3	• 1 lane on-ramp • 2 normal lanes on motorway • 3 lanes at merging zone/ acceleration lane
Disallowed vehicle classes	• normal lanes: pedestrians, tram, rail_urban, rail, rail_electric, ship	• from n0 to n7
Filenames	• network: UC2_1.net.xml	

Intended control of lane usage
CAVs coming from the on-ramp might have difficulty merging onto the motorway when vehicles on the right lane of the mainline are blocking it. CAVs would then have to perform a ToC and possibly an MRM on the acceleration lane. Speed, lane and headway advices are given to both vehicles on the on-ramp and the motorway to harmonise merging (i.e. create gaps and assign gaps to vehicles entering the motorway).

Network layout



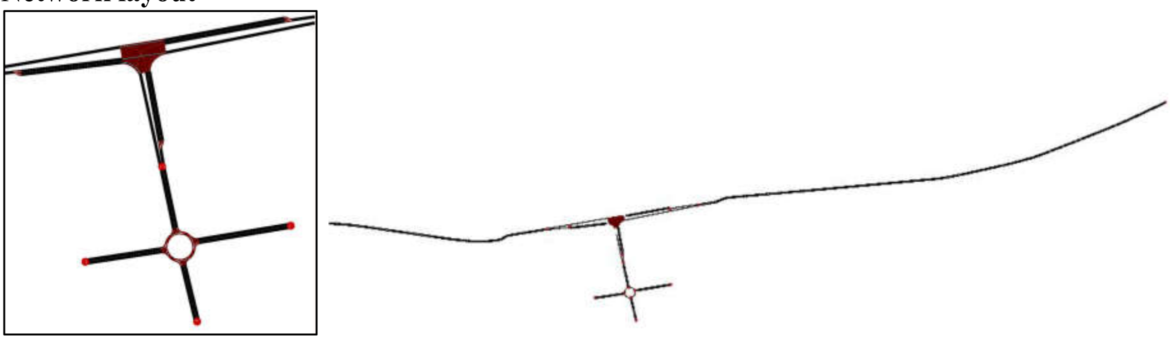
Road segments
n1→ n2: insertion and backlog area (1100 m, 2 lanes)
n2→ n4: mainstream motorway (500 m, 2 lanes)
n4→ n5: mainstream motorway with acceleration lane (150 m, 3 lanes)
n5→ n6: mainstream motorway (650 m, 2 lanes)
n6→ n7: exit (100 m, 2 lanes)
n0→ n3: insertion and backlog area (500 m, 1 lane)
n3→ n4: on-ramp (500 m, 1 lane)
n7→ n1: mainstream motorway in opposite direction (2500 m, 2 lanes)

Scenario 2.3	Settings	Notes
Road section length	1.8 km	
Road priority	3	
Allowed road speed	13.89 m/s	• 50 km/h
Number of nodes	16	• n0 – n15
Number of edges	25	• e0 – e24
Number of O-D relations	14	• from n0 to n13
Number of lanes	1	• 1 normal lane and turning lanes at the junction
Incident zone location	On right turn e4_0	• At stop line
Closed edges (to be defined in the file UC2_3Incident.add.xml)	Incident zone (to be determined which type)	• 1 normal
	safetyzone1_1	• E4_0
Disallowed vehicle classes	normal lanes: pedestrians, tram, rail_urban, rail, rail_electric, ship	• all
Filenames	• network: UC2_3.net.xml • Incident zone: UC2_3Incident.add.xml • traffic signs: UC2_3LTC.add.xml	

Intended control of lane usage

Around the incident location CAVs and CVs are rerouted due to a vehicle that is coming to a stop in the right turn lane. CAVs and CVs are informed about the incident and are rerouted via the left through lane and are facilitated to turn right at the junction due to a temporary adaptation of the RSU in the vicinity.

Network layout



Scenario 4.2_urban	Settings	Notes
Road section length	3.7 km	• both directions
Road priority	3	
Allowed road speed	13.89 m/s	• 50 km/h
Number of nodes	9	• n0 – n8
Number of edges	16	• both directions
Number of O-D relations	2	• from n0 to n8 • from n8 to n0
Number of lanes	4	• both directions
Work zone location	from n4 to n5	• 250 m
Closed edge[1, 2] (defined in the file: closeLanes.add.xml)	workzone	• the leftmost lane (250 m)
	safetyzone1	• the leftmost lane (50 m)
	Safetyzone2	• the leftmost lane (50 m)
Filenames	• network: UC4_2_urban.net.xml • lane closure: closeLanes.add.xml • traffic signs: shapes.add.xml	

Intended control of lane usage

This situation is the same as the situation in motorways, but speeds on urban roads are lower, and thus less space and time are needed to execute the measures of this service.

Network layout

Road segments

n0→n1: Insertion and backlog area (300 m)
n1→n3: Approaching area (700 m)
n3→n4: Safety area (50 m)
n4→n5: Work zone (250 m)
n5→n6: Safety area (50 m)
n6→n8: Leaving area (500 m)
n8→n0: Opposite direction (1850 m)

[1] The placement of the traffic signs is based on the German Guidelines for road job security (RSA).

[2] Required minimum safety distance according to the German Technical Rules for Workplaces ASR A5.2: 10m with allowed maximum speed 30 km/h; 50 m with allowed maximum speed 50 km/h; 100 m with allowed maximum speed 100 km/h.

UC4.2_motorway	Settings	Notes
Road section length	4.3 km	• both directions
Road priority	3	
Allowed road speed	• 36.11 m/s • 27.78 m/s (700 m in front of the safety zone before entering the work zone area) • 22.22 m/s around the work zone	• 130 km/h • 100 km/h • 80 km/h
Number of nodes	9	• n0 – n8
Number of edges	16	• both directions
Number of O-D relations	2	• from n0 to n8 • from n8 to n0
Number of lanes	4	• both directions
Construction location	from n4 to n5	• 150 m
Closed edge[3,4] (defined in the file: closeLanes.add.xml)	workzone	• the leftmost lane (150 m)
	safetyzone1	• the leftmost lane (100 m)
	safetyzone2	• the leftmost lane (100 m)
Filenames	• network: UC4_2_urban.net.xml • lane closure: closeLanes.add.xml • traffic signs: shapes.add.xml	

Intended control of lane usage

A Lane Change Assistant service is providing lane change advice to CAVs upstream of the work zone to facilitate merging in the free right lane. Some CAVs cannot merge on free lane early and are not able to pass the construction site due to the capabilities of their driving automation system. Thus, they perform a ToC. Some of the ToCs are unsuccessful, so the respective CAV must perform an MRM. It uses the safe spot information just in front of the construction site to come to a safe stop.

Network layout

Road segments

n0→n1: Insertion and backlog area (600 m)
n1→n3: Approaching area (700 m)
n3→n4: Safety area (100 m)
n4→n5: Work zone (150 m)
n5→n6: Safety area (100 m)
n6→n8: Leaving area (500 m)
n8→n0: Opposite direction (2150 m)

[3] The placement of the traffic signs is based on the German Guidelines for road job security (RSA).

[4] Required minimum safety distance according to the German Technical Rules for Workplaces ASR A5.2: 10m with allowed maximum speed 30 km/h; 50 m with allowed maximum speed 50 km/h; 100 m with allowed maximum speed 100 km/h.

UC4.1_5	Settings	Notes
Road section length	1.7 km	
Road priority	-	
Allowed road speed	13.89 m/s	• 50 km/h
Number of nodes	6	• n0 – n5
Number of edges	5	•
Number of O-D relations	1	• from n0 to n5
Number of lanes	2	• per direction
NoAD zone location	from n2 to n3	• length: 250 m, disallowed vClasses: custom1/2
Parking facilities	Located along edge “approach”	• five parking areas, equidistantly distributed at 150m. distance
Filenames	• network: UC45.net.xml • visualization: view.xml • parking facilities: UC45.add.xml	

Intended control of lane usage

The section named “noAD” is not allowed to be entered by automated vehicles. The TMC 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 an MRM. It uses the safe spot information provided by the TMC to reach a safe stop.

Network layout

Detail: No-AD zone entry, parking spaces

Road segments

“entry” (n0→n1): Insertion area (300 m)
“approach” (n1→n2): Approaching area with parking places (750 m)
“noAD” (n2→n3): No-AD zone (250 m)
“upward” (n3→n4): Area for upward transitions (500 m)
“exit” (n4→n5): Leaving area (100 m)

Appendix C

To support the results from TransAID's simulations and field trials, it is necessary to get a good grasp on certain issues that require an understanding of how connected and/or automated vehicles operate on the one hand, and what the policy makers allow or require on the other hand. This forms a cornerstone to support TransAID's goal, i.e. achieve a library with applicable and scrutinised measures for transition areas.

To that end, we will pose questions to several stakholders and experts. The goal is to gain insights into legal implications, (expected) driver and/or automated vehicle behaviour and infrastructure specific aspects with respect to automated vehicles. The answers to these questions will provide some feedback on the work done so far, some of which is based on views from experts within the project consortium, and collect insights for future work.

In the following paragraphs, we provide details about the targeted audience, the dissemination strategy for our (survey) questions, a note on privacy aspects, and finally the questions themselves.

Target audience

We intend to pose our questions to the following stakeholders[2] (with the specific questions to be asked dependent on the type of stakeholder):

- *Authorities and infrastructure and service providers*: closely related to road operators, these groups are also considered very important for the deployment process of automated vehicle services. Although this stakeholder group might not be a direct consumer or client of the services, their acceptance and support could help to overcome deployment barriers related to regulation or political support among others.

- *Road operators*: these are key stakeholders as, e.g., their consent is a core ingredient for successful trials and scaling up of the solutions developed in TransAID.

- *OEMs*: the inclusion of this group of stakeholders forms a necessary ingredient in order to have successful field trials within the TransAID project. They also provide the necessary 'real world mirror', to validate our theoretical/simulation and academic results against what can be expected from a practical point of view in a realistic setting.

- *Academia*: these encompass various research and academic organisations, as well as (peer-reviewed) journals and fora.

[2] Information retrieved from Dissemination Strategy and Innovation Process (2017). TransAID Deliverable D9.1.

Dissemination strategy

Given the target audience as defined before, we plan to use a two-fold approach to receive answers to our questions:

- In first instance, our idea is to host a question-answer round at a workshop during the upcoming TransAID symposium. This can take the form of handouts that are distributed beforehand, giving the attendees ample time to reflect on them and provide us with their views. We may also set up a specific session, with a subset of the questions and organise the question-answering process in a more interactive manner.

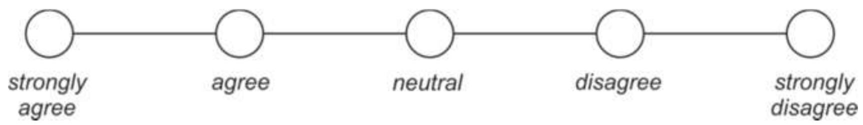
- Secondly, we would like to address the rest of TransAID's professional network members, for which we have their consent via the recurring Newsletter. This will take the form of an online questionnaire that is created within LimeSurvey[3], an open-source online tool. The consortium partner TML hosts its own server to process such surveys.

Protection of personal data

Just as with the website and newsletter, we make the protection of personal data compliant the EU's GDPR regulations. The execution of our surveys will be in line with the ethics aspects as covered in TransAID's Deliverable D10.1[4]. Moreover, the template for the information and consent form in Appendix A of D10.1 will be adapted in line with the setup of the survey.

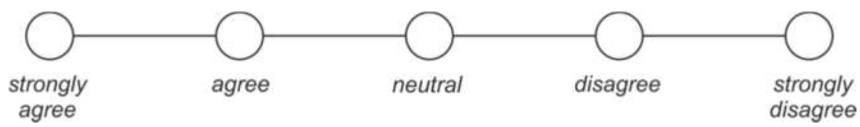
Questions regarding policy making and OEMs

Q1_1_A: Do you foresee areas in the road network where you do not want to allow automated driving?



Q1_1_B: Which?

Q1_2_A: Do you foresee areas in the road network which are for automated driving only (dedicated lanes)?



[3] https://www.limesurvey.org/

[4] H – Requirement No. 1 (2018). TransAID Deliverable D10.1

Q1_6_A: What should be the maximum acceleration rate during ACC/CACC driving?

0-1 m/s^2	1-2 m/s^2	2-3 m/s^2	3-4 m/s^2	>4 m/s^2

Q1_6_B: What should be the maximum deceleration rate during ACC/CACC driving?

0-1 m/s^2	1-2 m/s^2	2-3 m/s^2	3-4 m/s^2	>4 m/s^2

Q1_3_A: What should a vehicle equipped with ACC do if another vehicle cuts in front and triggers the emergency braking system? Do we need ToC?

Q1_7_A: In case the vehicle automation knows that it will need to perform a transition of control (ToC) to the driver, when should it tell this to the driver?

as early as possible	early	moderate	later	as late as possible

Q1_7_B: Why?

Q1_4_A: In case of a Minimum Risk Maneuver, how strong should the vehicle decelerate?

very strong	strong	weak	very weak	no deceleration

Q1_4_B: Why?

Q1_5_A: Does a Minimum Risk Maneuver (MRM) always end with a full stop of the vehicle?

strongly agree	agree	neutral	disagree	strongly disagree

Q1_5_B: Can the driver take-over control during the MRM?

strongly agree	agree	neutral	disagree	strongly disagree
○	○	○	○	○

Q1_8_A: What do you expect a CAV to do in case of a MRM? (multiple answers possible)

- ❑ Brake
- ❑ Drive to the road boundary
- ❑ Drive to an adjacent emergency lane, if any.
- ❑ Drive to the emergency lane, if any, even if this means crossing other lanes
- ❑ Other:

Q1_8_B: In that case, should the vehicle use its emergency flashers?

strongly agree	agree	neutral	disagree	strongly disagree
○	○	○	○	○

Q1_8_C: Should the vehicle have a mandatory additional sign in its back for this (and other) purposes?

strongly agree	agree	neutral	disagree	strongly disagree
○	○	○	○	○

Q1_9_A: How should an automated vehicle respond <u>in the moment of detection</u> in case the planned route cannot be followed?

- ❑ Slow down and ask the driver what to do
- ❑ Slow down and issue a take over request
- ❑ Just continue driving
- ❑ Other:

Q1_9_B: How should an automated vehicle respond <u>in the given area</u> in case the planned route cannot be followed?

- ❑ Follow another route without further information to the driver
- ❑ Follow another route and inform the driver
- ❑ Stop the vehicle and wait
- ❑ Stop the vehicle and/or ask the driver to take over
- ❑ Other:

Q1_10_A: How should an automated vehicle on highways respond in case an emergency vehicle is coming from behind?

- ❑ Try to drive faster than the emergency vehicle
- ❑ Try to stop
- ❑ Try to stop at the road boundary
- ❑ Try to stop on an adjacent emergency lane, if any
- ❑ Try to stop on an emergency lane, if any, even if this means crossing other lanes
- ❑ Ignore and continue driving
- ❑ Ask the driver to take over control
- ❑ Other:

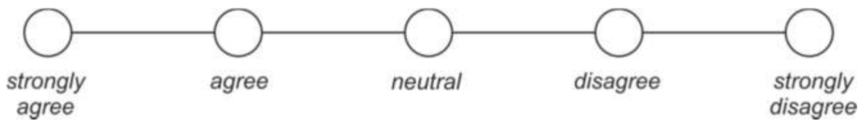
Q1_10_B: How should an automated vehicle on urban roads respond in case an emergency vehicle is coming from behind?

- ❑ Try to drive faster than the emergency vehicle
- ❑ Try to stop
- ❑ Try to stop at the road boundary
- ❑ Try to stop on an adjacent parking space, if any
- ❑ Try to stop on an parking space, if any, even if this means crossing other lanes
- ❑ Ignore and continue driving
- ❑ Ask the driver to take over control
- ❑ Other:

Q1_10_C: How should an automated vehicle on urban roads respond in case an emergency vehicle is crossing its way at the next intersection from the side?

- ❑ Try to cross the intersection earlier than the emergency vehicle
- ❑ Try to stop
- ❑ Ignore and continue driving
- ❑ Ask the driver to take over control
- ❑ Other:

Q1_11_A: Will OEMs identify areas on the network where automated driving is not possible/less reliable?



Q1_11_B: Would these areas be static map information?

strongly agree	agree	neutral	disagree	strongly disagree

Q1_11_C: Would they be updated OTA?

strongly agree	agree	neutral	disagree	strongly disagree

Q1_11_D: Would vehicles ‘call home’ to report on difficult areas?

strongly agree	agree	neutral	disagree	strongly disagree

Q1_11_E: Is automated driving supported by a backend in some way?

strongly agree	agree	neutral	disagree	strongly disagree

Q1_12_A: What kind of information would OEMs be interested in to get from road authorities / TMCs?

Questions regarding legal implications

Q2_1_A: We want to validate results by OEMs, but there (possibly) are different points of view between OEMs (assuming the same characteristics) versus country-specific laws and driving behaviour. How does this influence the modelling/take-up?

Q2_2_A: What legal frameworks are necessary (regarding permissions, licences, …) to drive with AVs?

Q2_3_A: What if there is a glitch in the system, e.g., a recommended speed that is higher than the stated speed limit (which can be dynamic in the case of speed harmonisation through VMSs, cf. 70 km/h)?

Q2_4_A: How to deal with a motorway with two or more lanes in each direction, and queue spillback occurring at an off-ramp: Should AVs and CAVs be allowed to break the law and use the emergency lane for queueing?

○ strongly agree — ○ agree — ○ neutral — ○ disagree — ○ strongly disagree

Q2_4_B: Is the TMC allowed to handle this responsibility?

○ strongly agree — ○ agree — ○ neutral — ○ disagree — ○ strongly disagree

Q2_5_A: In case of dynamic lane assignments with (C)AV obliged to drive on the right: Should the vehicles be allowed to overtake other non-compliant vehicles which are on the left-hand lanes?

○ strongly agree — ○ agree — ○ neutral — ○ disagree — ○ strongly disagree

Q2_5_B: Should the TMC be allowed to give advices in this context?

○ strongly agree — ○ agree — ○ neutral — ○ disagree — ○ strongly disagree

Q2_6_A: What does the law prescribe in the case of road works with yellow lines indicating newly-organised lanes (whereas the white ones are still visible and in essence take priority)?

Q2_7_A: Should automated vehicles be allowed to overtake obstacles (i.e. a vehicle doing road-side maintenance, garbage truck, incident, …) when overtaking is normally not allowed (solid line between the two driving directions)?

strongly agree	agree	neutral	disagree	strongly disagree

Q2_7_B: Should the TMC be allowed to give advices in this context?

strongly agree	agree	neutral	disagree	strongly disagree

Questions regarding (expected) driver behaviour

Q3_1_A: Do you think drivers are acting compliant to VMS information?

strongly agree	agree	neutral	disagree	strongly disagree

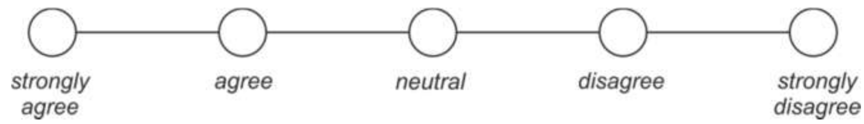
Q3_2_A: In case the vehicle automation issues a take over request, when does the driver react?

at once	early	moderate	later	as late as possible

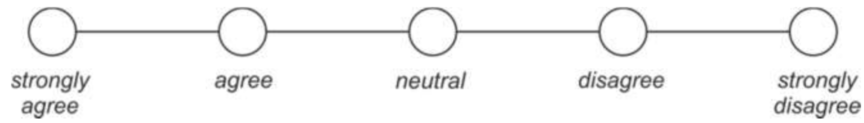
Q3_2_B: Why?

Q3_3_A: What are the expected capabilities of (C)AVs in your view?

Q3_4_A: In some cases, especially in busy traffic, it is needed to be on the ‘right’ lane quite early, because merging at a later stage is not ‘accepted’ by most other cars (vehicles would have to stop and cross several lanes to make a turn…). Do you think (C)AVs will have the ability to drive strategically in this case and change lane early?



Q3_4_B: In some other cases, vehicles are required to merge as late as possible. Do you think (C)AVs will have the ability to drive strategically in this case and change lane late?



Q3_4_C: Do you think vehicles are able to distinguish those situations?