D2.2

Scenario definitions and modelling requirements

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☐ 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. Another possibility under consideration is the combination of multiple basic scenarios into one new more complex use case.

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.

Note that there may be some variations regarding the succession of these events, e.g. at which point the ToC succeeds or for the case that the situation is successfully resolved without requiring a ToC (due to TransAID traffic management). 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.

1.3 Structure of this document

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, vehicle numbers and traffic compositions used 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.

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
TM	Traffic Management
ToC	Transition of Control
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

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 Scenario 1.1: Provide path around road works via bus lane

2.1.1 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.
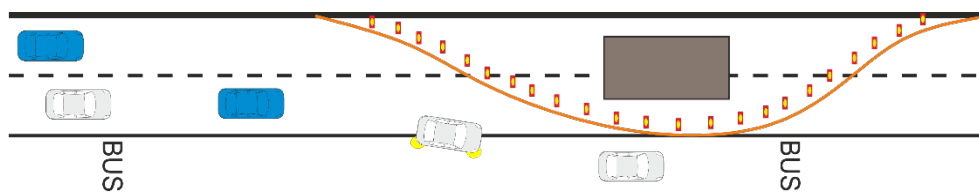

Figure 1: schematic overview of Scenario 1.1

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.

2.1.2 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 yes → 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 a MRM. This might be supported by Service 4 (e.g. Scenario 4.2 below) to minimize the impact of the MRM.

2.1.3 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.
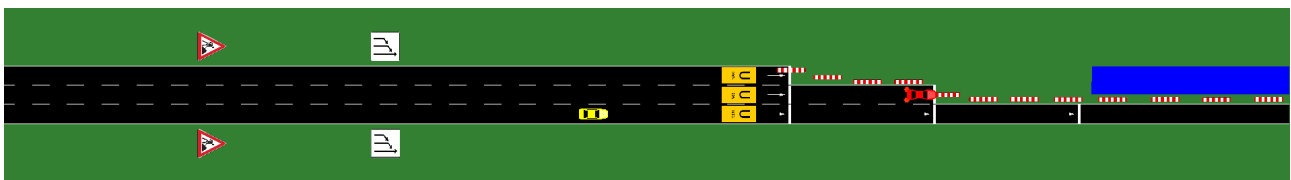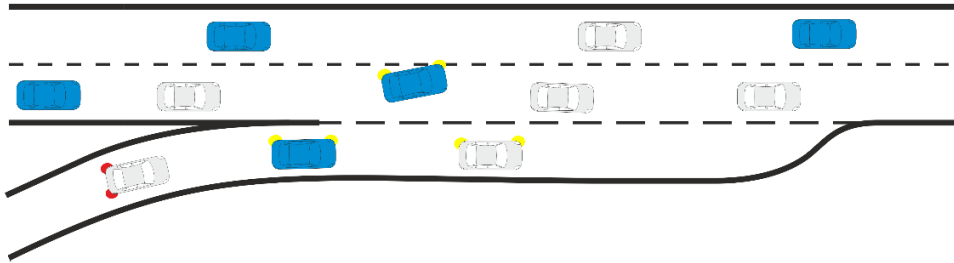

Figure 2: SUMO network for Scenario 1.1

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

2.2.1 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.

2.2.2 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.

2.2.3 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

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

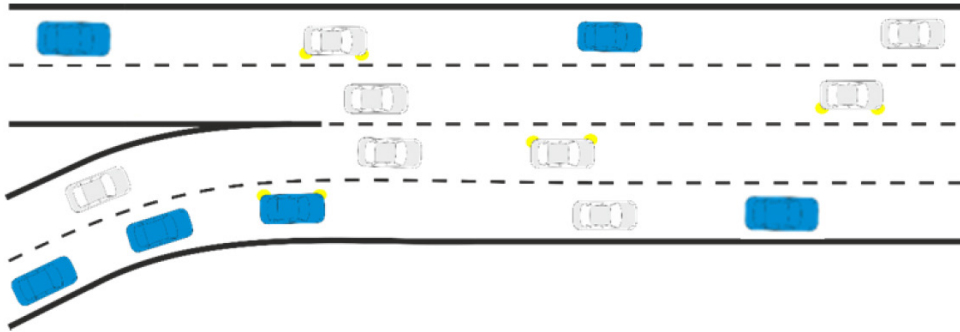### 2.3.1 General description

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.

2.3.2 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).

2.3.3 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.
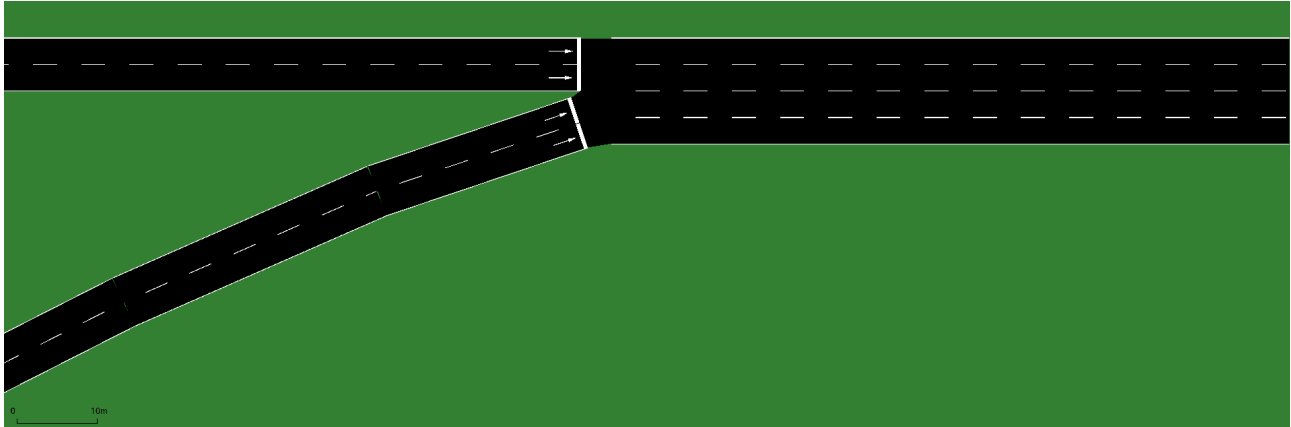

Figure 5: SUMO network for Scenario 3.1

2.4 Scenario 4.2: Safe spot in lane of blockage
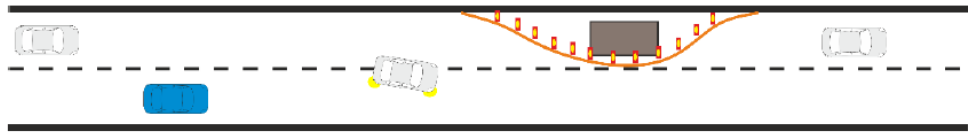
2.4.1 General description

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.

2.4.2 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.

2.4.3 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.
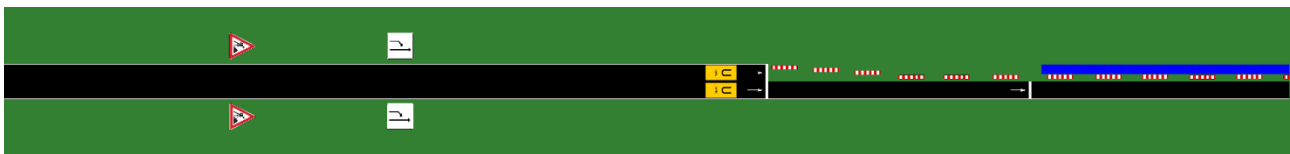

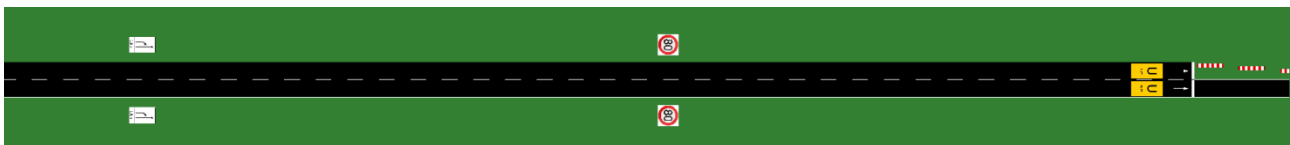**Figure 7: SUMO network for Scenario 4.2 in urban conditions**

Figure 8: SUMO network for Scenario 4.2 in motorway conditions

2.5 Scenario 5.1: Schedule ToCs before no AD zone

2.5.1 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).
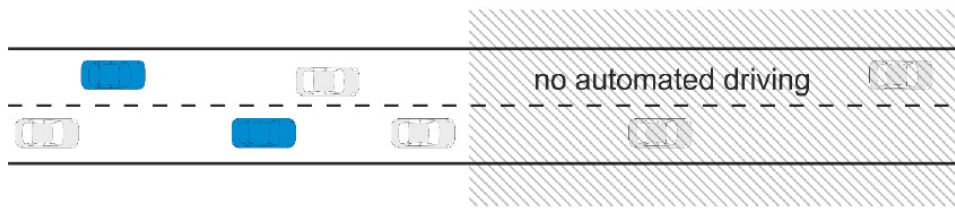

Figure 9: schematic overview of Scenario 5.1

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.

2.5.2 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.

2.5.3 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

3 Modelling requirements

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 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

3.2 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.

3.2.1 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.

3.2.2 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.

3.2.3 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

3.2.4 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

3.2.5 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 11), while a solid time horizon for the accomplishment of the far-reaching goal of full automation is not yet feasible (ERTRAC Working Group, 2017).
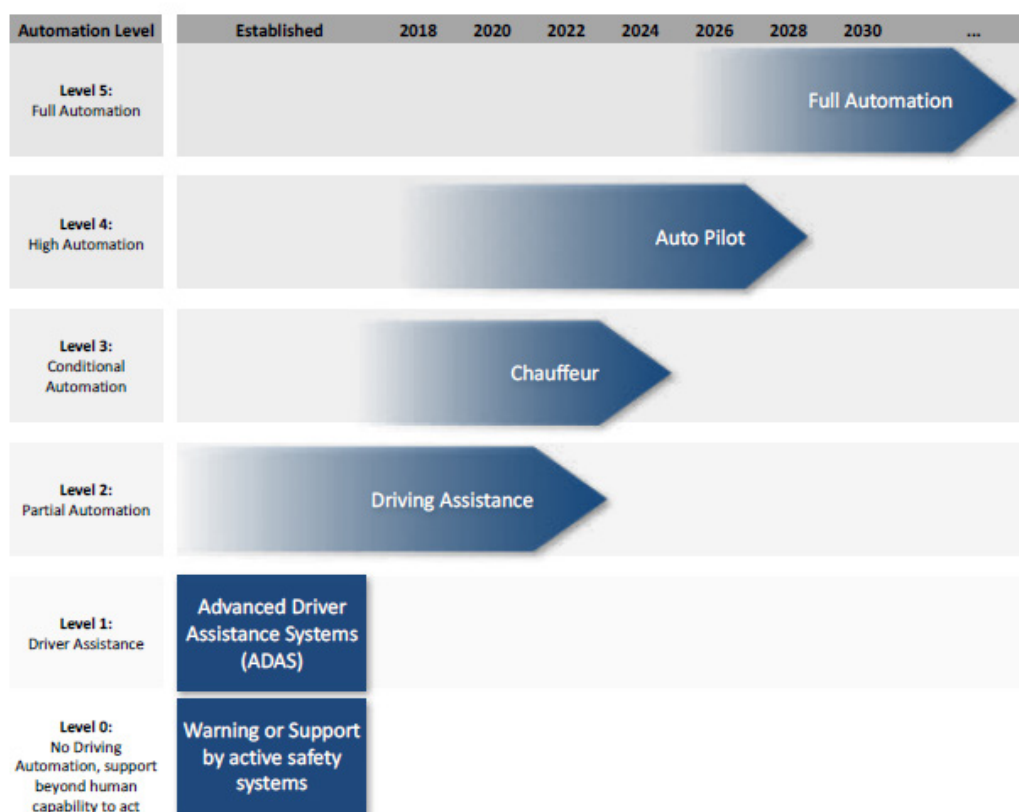

Figure 11: **projection of establishment for vehicle automation levels (ERTRAC Working Group, 2017)**

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 12). (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.
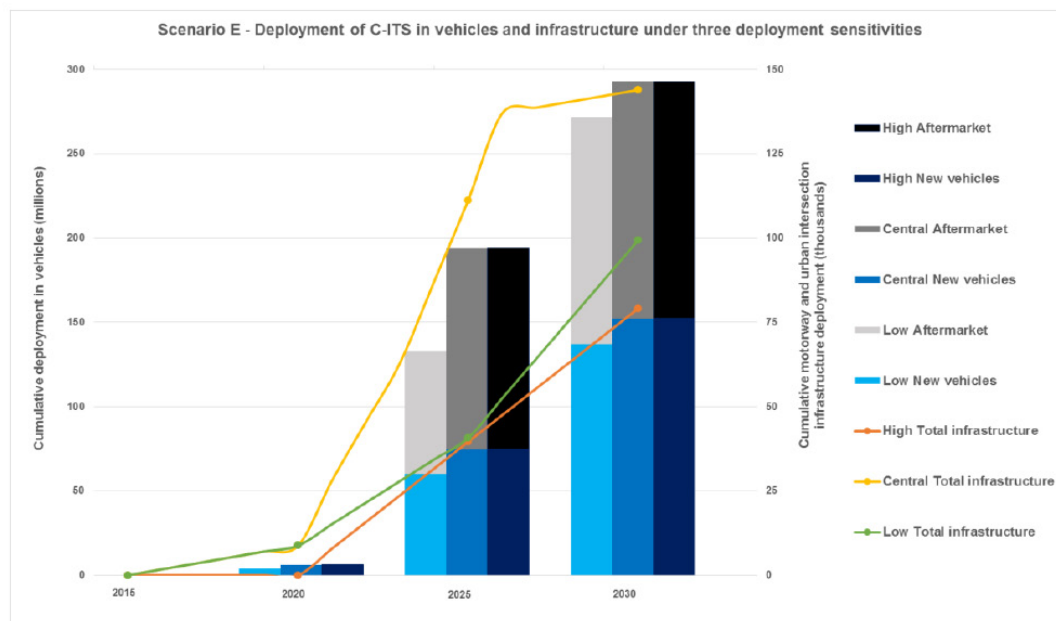

Figure 12: **future deployment (vehicle and infrastructure) of C-ITS technologies (C-ITS Platform, 2016)**

(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 13). 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.
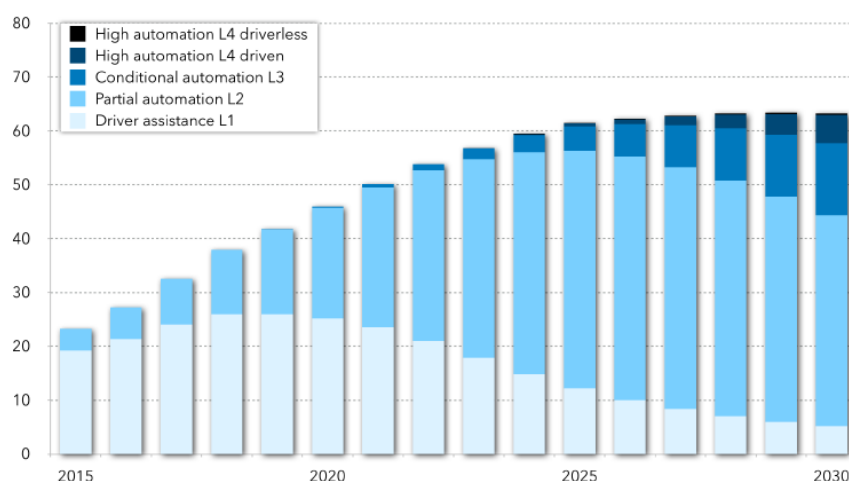

Figure 13: projected sales of new passenger cars (in millions) (PTOLEMUS Consulting Group, 2017)

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 14). 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).
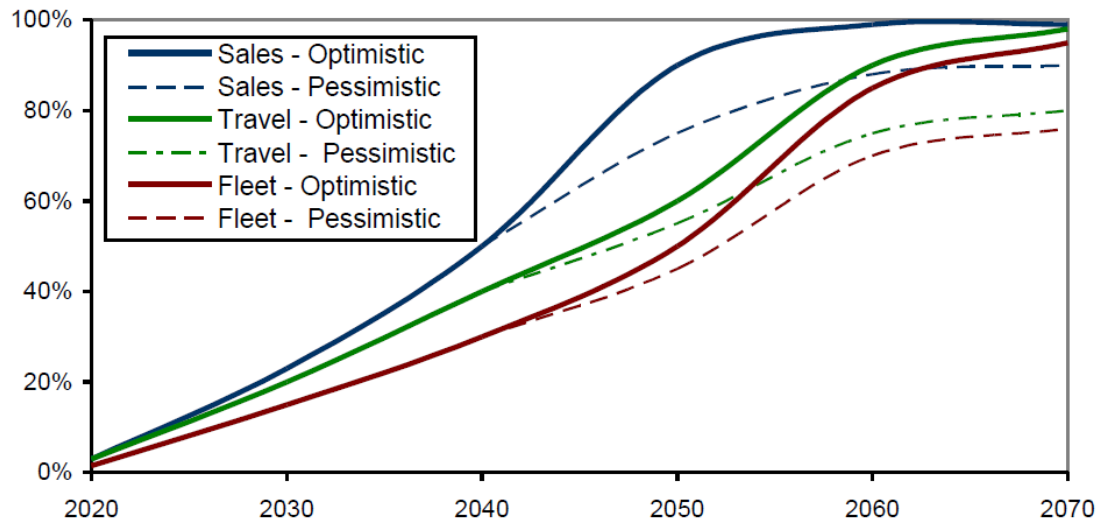

Figure 14: sales, travel and fleet projections of Automated Vehicles (Litman, 2017)

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 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.

4 Conclusion and outlook

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 WP 5[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.

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

References

C-ITS Platform. (2016). Phase I Final Report. Retrieved from https://ec.europa.eu/transport/sites/transport/files/themes/its/doc/c-its-platform-final-report-january-2016.pdf.

C2C-CC, "Vehicle manufacturers: C-ITS deployment plans and role in vehicle automation", presentation at the CODECS City Pool Workshop #4, Dublin, March 2018, available at http://www.codecs-project.eu/fileadmin/user_upload/pdfs/City_Pool_Workshop_4/C2C-CC_Deployment_Plan_and_Roadmaps_Rondinone.pdf

Developer/How To/Device - Sumo. (n.d.). Retrieved April 23, 2018, from http://sumo.dlr.de/wiki/Developer/How_To/Device

ERTRAC Working Group, "Connectivity and Automated Driving." (2017). Automated Driving Roadmap (No. Version 7.0). ERTRAC.

Fuller, R. (2005). Towards a general theory of driver behaviour. Accident Analysis & Prevention, 37(3), 461–472. https://doi.org/10.1016/j.aap.2004.11.003

HCM 2010 : Highway Capacity Manual. Washington, D.C. :Transportation Research Board, 2010.

Krauß, S. (1998). Microscopic Modeling of Traffic Flow: Investigation of Collision Free Vehicle Dynamics (Doctoral Thesis). DLR-Forschungsbericht. Retrieved from http://elib.dlr.de/8380/

Litman, T. (2017). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning (pp. 1–23). Victoria Transport Policy Institute. Retrieved from http://leempo.com/wp-content/uploads/2017/03/M09.pdf

Milanés, V., & Shladover, S. E. (2014). Modeling cooperative and autonomous adaptive cruise control dynamic responses using experimental data. Transportation Research Part C: Emerging Technologies, 48, 285–300. https://doi.org/10.1016/j.trc.2014.09.001

Milanés, V., & Shladover, S. E. (2016). Handling Cut-In Vehicles in Strings of Cooperative Adaptive Cruise Control Vehicles. Journal of Intelligent Transportation Systems, 20(2), 178–191. https://doi.org/10.1080/15472450.2015.1016023

PTOLEMUS Consulting Group. (2017). Autonomous Vehicle Global Study - Free Abstract. Retrieved from www.ptolemus.com

Saifuzzaman, M., Zheng, Z., Mazharul Haque, M., & Washington, S. (2015). Revisiting the Task–Capability Interface model for incorporating human factors into car-following models. Transportation Research Part B: Methodological, 82, 1–19. https://doi.org/10.1016/j.trb.2015.09.011

Xiao, L., Wang, M., & van Arem, B. (2017). Realistic Car-Following Models for Microscopic Simulation of Adaptive and Cooperative Adaptive Cruise Control Vehicles. Transportation Research Record: Journal of the Transportation Research Board, 2623, 1–9. https://doi.org/10.3141/2623-01
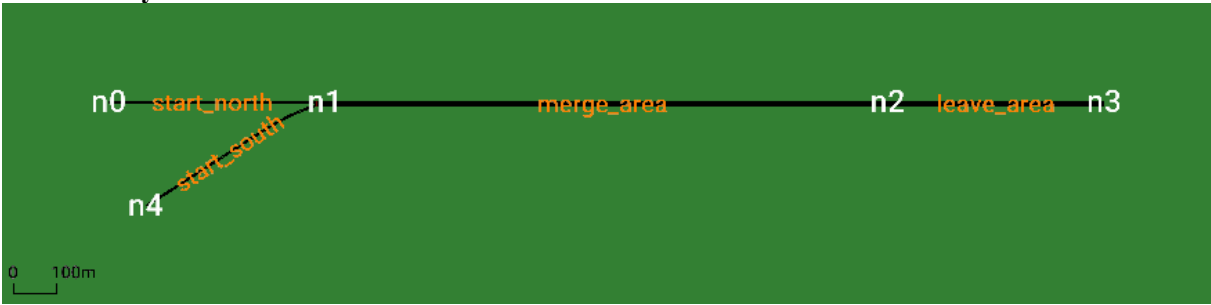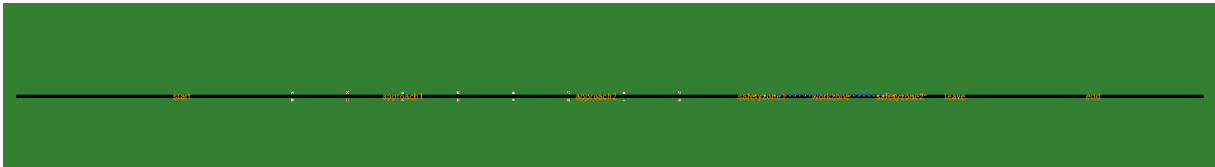
Appendix A

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)

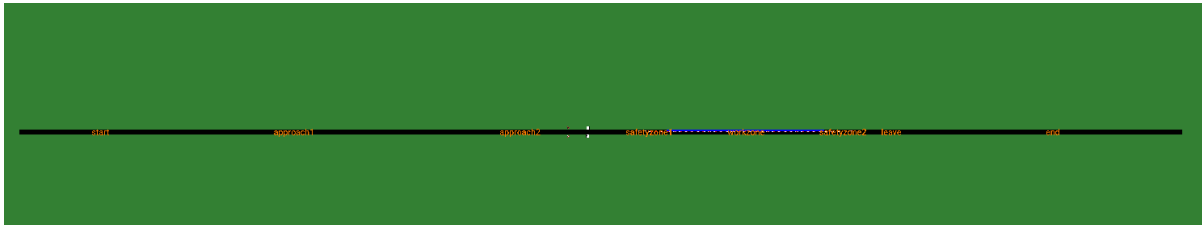[3] The placement of the traffic signs is based on the German Guidelines for road job security (RSA).

[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.
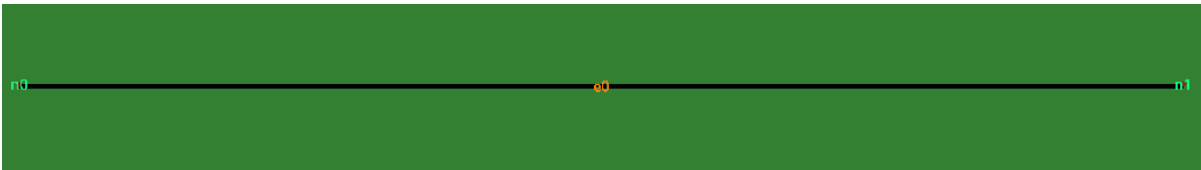
Network layout

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)