INFRAMIX

Grant Agreement Number: 723016

Project acronym: **INFRAMIX**

Project full title: INFRAMIX - Road INFRAstructure ready for MIXed vehicle traffic flows

D.2.1

REQUIREMENTS CATALOGUE FROM THE STATUS QUO ANALYSIS

Due delivery date: 30/11/2017
Actual delivery date: 12/02/2018
Revised version: 28.06.2019
Organization name of lead participant for this deliverable: **ICCS**

Project co-funded by the European Commission within Horizon 2020		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants	
RE	Restricted to a group specified by the consortium	
CO	Confidential, only for members of the consortium	

Project funded by the European Union's Horizon 2020 Research and Innovation Programme (2014 – 2020)

Document Control Sheet

Deliverable number:	2.1
Deliverable responsible:	ICCS
Work package:	2
Editor:	Evdokia Papanikolaou

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Document Revision History			
Version	Date	Modifications Introduced	
0.1	29.06.2017	Subdocument for Chapter 3, Status quo analysis, template– "List of equipment"	ICCS
0.2	29.06.2017	Subdocument for Chapter 4, use case description and requirements – "Scenarios template"	ICCS after feedback from all the WP2 involved partners
0.3	13.07.2017	Subdocument for Chapter 4, use case description and requirements – "Scenarios template"	ICCS after feedback from all the WP2 involved partners
0.4	24.07.2017	Subdocument for Chapter 4, use case description and requirements – "Scenarios template"	ICCS after feedback from all the WP2 involved partners
0.5	15.08.2017	Subdocument for Chapter 4, use case description and requirements – "Scenarios template"	ICCS after feedback from all the WP2 involved partners
0.6	14.09.2017	Subdocument for Chapter 4, use case description and	ICCS after feedback from all the WP2 involved partners

		requirements – “Scenarios template”	
0.7	10.10.2017	Subdocument for Chapter 4, use case description and requirements – “Scenarios template”	ICCS after feedback from all the WP2 involved partners
0.8	12.10.2017	Subdocument for Chapter 3, Status quo analysis, template– “List of equipment”	ICCS after feedback from FOK, AAE, VIF, ASF.
0.9	17.10.2017	Subdocument for Chapter 4, use case description and requirements – “Scenarios template”	ICCS after feedback from all the WP2 involved partners
1.0	02.11.2017	D2.1 Requirements catalogue from status quo analysis	ICCS after merging the subdocuments
2.0	10.11.2017	D2.1 Requirements catalogue from status quo analysis	ICCS after feedback from all the WP2 involved partners
3.0	24.11.2017	D2.1 Requirements catalogue from status quo analysis	ICCS after feedback from all the WP2 involved partners
3.1	25.11.2017	D2.1 Requirements catalogue from status quo analysis	ICCS after feedback from all the WP2 involved partners
4.0	04.12.2017	D2.1 Requirements catalogue from status quo analysis	ICCS after feedback from F2F plenary meeting
5.0	09.01.2018	D2.1 Requirements catalogue from status quo analysis	ICCS after internal review from TUC, VIF, and feedback from AAE, ASF. ATE, BMW, FOK, SIE.
6.0	02.02.2018	D2.1 Requirements catalogue from status quo analysis	ICCS after internal review from all the WP2 involved partners
7.0	23.04.2019	D2.1 Requirements catalogue from status quo analysis	ICCS after P.O request for revision
7.1	03.05.2019	D2.1 Requirements catalogue from status quo analysis	ICCS after internal review from TUC, VIF of v7.0

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
ACC	Adaptive Cruise Control
AV	Automated Vehicle
AWC	Adverse Weather Conditions
BTN	Bottleneck
CAM	Cooperative Awareness Message
CCV	Connected Conventional Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CV	Conventional Vehicle
DEMN	Decentralized Environmental Notification Message
DLA	Dynamic Lane Assignment
DPR	Dynamic Penetration Rate of automated vehicles
EC	European Commission
EU	European Union
GA	Grant Agreement
GNSS	Global Navigation Satellite System
IP	IP Connectivity
ITS	Intelligent Transport Systems
IVIM	Infrastructure to Vehicle Information Message
KPI	Key Performance Indicator
LCA	Lane change advice
LCAFC	Lane Change Advice Flow Control
MTFC	Mainstream Traffic Flow Control
NLD	New Lane Design
OBU	OnBoard Unit
PO	Project Officer
RSU	RoadSide Unit
RWZ	Roadworks Zone
SLC	Single Lane Closure
TMC	Traffic Management Center
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-X (X represents any entity capable of receiving C-ITS communications)
WP	Work Package

Table of Contents

List of Figures

List of Tables

Executive Summary

The EU project, INFRAMIX, aims to prepare the road infrastructure to support the coexistence of conventional and automated vehicles, targeting to the transition period when the number of automated vehicles will gradually increase. A “hybrid” road infrastructure concept will be the project outcome after defining the necessary upgrades and adaptations of the current road infrastructure as well as designing and testing novel physical and digital elements. In order to ensure an uninterrupted, predictable, safe and efficient traffic, novel technologies are designed, diverse components are incorporated, and different technologies are combined, making the definition of the requirements for such a system, a complicated rather crucial step to the concept design and to the project workflow. An indispensable part of this process is the status quo analysis that sets the baseline of the technological level.

This deliverable is prepared at the starting phase of INFRAMIX in order to set the scene, where the project will actively contribute. It begins with a detailed status quo analysis for the highways as well as for the traffic simulation environment and goes from target traffic scenarios and their use cases to the definition of functional, feasibility and non-functional requirements. The defined requirements will serve as an input to the following project work such as specification and definition of its architecture, and consequently to the development work.

Chapter 1 presents the project's scope and the purpose of this document. Chapter 2 describes the methodology of the requirements capture. Starting from a detailed status quo analysis (Chapter 3) that includes the highways technological level as well as the current state of the traffic simulation tools, the methodology is based on high importance traffic scenarios, in terms of traffic safety and performance, which are described in detail in Chapter 4. Several use cases are defined for each scenario in order to assist the process of requirements capture. Chapter 4 also includes, the functional, the feasibility as well as the non-functional requirements for each use case. In Chapter 5, the requirements are clustered per INFRAMIX major component in order to convenient the next steps of the project for defining the specifications of the technical parts.

Through the specific high value (in terms of importance with regard to traffic efficiency and safety) traffic scenarios: *dynamic lane assignment*, *roadworks zones* and *bottlenecks* and the related use cases, the required upgrade of the current highways infrastructure in physical and digital equipment is detected. The important aspect of vehicles categorization in a mixed traffic situation is highlighted through this document. The most important criteria, in matters of “hybrid” infrastructure design, for this categorization are the vehicle’s level of automation along with the Vehicle-to-Infrastructure communication. Finally, the required extension of the needed wireless messages between infrastructure and vehicles, the need for new visual signs regarding automated driving as well as several safety critical issues for the transition period consist important results of the analysis presented in this document.

1. Introduction

1.1 Aim of the project

Over the last years, significant resources have been devoted to developing new automation technologies for vehicles, whereas investment and resources for road infrastructure, in general, have steadily dwindled. INFRAMIX is preparing the road infrastructure to support the transition period and the coexistence of conventional and automated vehicles. Its main target is to design, upgrade, adapt and test both physical and digital elements of the road infrastructure, ensuring an uninterrupted, predictable, safe and efficient traffic. Towards this objective different technologies are deployed; mature simulation tools adapted to the peculiarities of automated vehicles, new methods for traffic flow modelling, to study the traffic-level influence of different levels of automated vehicles in different penetration rates, traffic estimation and traffic control algorithms. Moreover, ways of informing all types of vehicles about the control commands issued by the road operator are developed and new kind of visual and electronic signals are proposed for the needs of mixed scenarios. The project outcomes will be assessed via simulation and in real stretches of advanced highways.

Designing such a diversified and novel concept makes the capture of the infrastructure as well as the various component requirements challenging and at the same time crucial for the project outcome. INFRAMIX selects a bottom-up approach. Instead of working with generic solutions with questionable impact, it builds on the specific high value (in terms of importance with regard to traffic efficiency and safety) traffic scenarios: *dynamic lane assignment*, *roadworks zones* and *bottlenecks*. INFRAMIX addresses mainly highways, as they are expected to be the initial hosts of mixed traffic, but the key results can also be transferred to urban roads.

1.2 Purpose of Document

The purpose of this document is to provide a concise requirements catalogue as an outcome of a status quo analysis, resulting in a high-level conceptual view of the INFRAMIX real- world infrastructure as well as of the simulation environment. The document contains a status quo analysis using as a baseline the status of state-of-the-art test sites in Europe. Specifically, the ASFINAG's Living Laboratory, located in Vienna, Austria and the A9 highway between Munich and Nurnberg, in Germany were considered. The status quo analysis includes also a description of the technological status of the two modern highways in Austria and in Spain that will be used for tests in real world in the frame of INFRAMIX and specifies the current status of the traffic simulation tools. The three traffic scenarios: *dynamic lane assignment*, *roadworks zones* and *bottlenecks* which are further diverged into use cases, lead the process of the requirements capture. Requirements related to data and measurements from the infrastructure side, the diversion of the traffic in vehicle types and their level of automation, as well as the required visual signs and electronic signals, are resulted from this analysis. The use cases will serve as a guideline to the next steps of the project and the defined requirements will be an input to the following work in architecture and system specifications.

1.3 Choice of Scenarios

The three scenarios were chosen based on the fact that mixed vehicles share the same road infrastructure and must co-exist in the same traffic. As a result, no matter how intelligent and automated they are, or they will become, this mixed co-existence may lead to degraded traffic flow efficiency and, even worse, to new safety problems, if not managed appropriately. One of the reasons, that safety is at risk in the new mixed environment is the fact that investments and resources for road infrastructure have been decreasing in the recent years.

Since INFRAMIX's main target is to design, implement and test both physical and digital elements of the road infrastructure as well as to ensure an uninterrupted, predictable, safe and efficient traffic through the transition period from conventional vehicles (CV) to autonomous vehicles (AV), the chosen scenarios should ideally cover the needs for increased traffic flow efficiency and enhanced safety performance.

These scenarios through their implementation, should provide valuable insight to make a decisions concerning challenges and, help answer question such as the following:

- What is the penetration level of AVs on a highway, at which a dedicated lane can increase traffic efficiency?
- What are the safety parameters that need to be addressed for the integration of automated vehicles?
- How will the special roadway conditions affect the coexistence of conventional and automated vehicles?
- What is the influence on safety and traffic flow with regard to different percentage of automated vehicles?
- What are the distinct benefits of V2V and V2I communications?

All the scenarios are identified for the transition period between pure human driving and automated driving (mixed traffic).

In general, the three key traffic scenarios were chosen through criteria set by project experts, and based on their expected impact on traffic flows. Also these scenarios will aid in analysis of the impacts on traffic safety, the management of potential risks as well as to find out unknown problems with negative influence in the introduction of automated vehicles in road networks. Based on the results, the general application of the results in many (different from the chosen), scenarios in real life should also be possible.

2. Methodology

INFRAMIX main target is to design, upgrade, adapt and test (in simulation and in real-world) both physical and digital elements of the road infrastructure, to enable the coexistence of automated and conventional vehicles, ensuring an uninterrupted, predictable, safe and efficient traffic.

The key outcome will be a "hybrid" road infrastructure able to handle the transition period and become the basis for future automated transport systems. The design of such a "hybrid" road infrastructure, which is a combination of different technological components, is driven by specific traffic scenarios. This approach was decided from the very beginning of the project in order to avoid generic solutions and instead have a clear impact on the expected mixed traffic conditions.

These scenarios are identified for the transition period, to be tackled within the project duration, based on four criteria: a) the expected impact on traffic flow, b) the expected impact on traffic safety, c) the importance of the challenges faced, in the sense that if not handled in a proper and timely way, they will negatively influence the introduction of automated vehicles on the roads, and d) the ability to generalize on the results (applicable in other scenarios and environments). As illustrated in Figure 1, considering these four criteria, three key traffic scenarios are distinguished: (1) Dynamic lane assignment (incl. speed recommendations) (2) Construction sites / Roadworks zones and (3) Bottlenecks (on-ramps, off-ramps, lane drops, tunnels, sags). These scenarios and the expected impact of the project outcome through them are thoroughly analysed at Chapter 4.

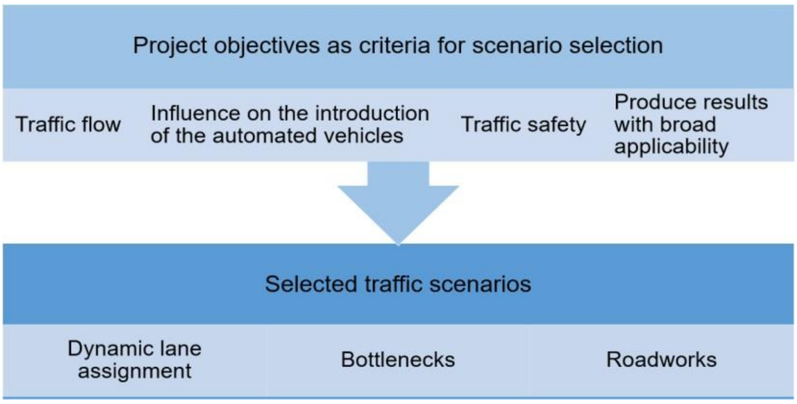


Figure 1 – Traffic scenarios definition from INFRAMIX objectives

For each of the scenarios, the project focuses on several representative traffic situations, use cases, which demonstrate the influence of the project outcome to the most critical in matters of safety and performance traffic conditions. These use cases are extracted based on the current technological level of the road infrastructure and the expected issues of the transition period while targeting to demonstrate and assess the innovation impact and the related novel solutions provided by INFRAMIX. Through the simulation and the tests in real stretches of the use cases, the INFRAMIX components will be evaluated.

These use cases increase clarity and assist the requirements capture. Firstly, for each use case the realisation prerequisites, the required physical and digital equipment, are considered. Through that process, a comparison of the current technological level with the INFRAMIX upgrades is inevitable. Consequently, the innovation impact is clearly depicted from the feasibility requirements for each use case.

Moreover, considering the story (the sequence of actions) for each one of the use cases a concise list of the functional requirements is completed. The way that the INFRAMIX components should perform and interact with each other in order to provide the specific functionalities could then be defined. Taking also into account the feasibility requirements, the design of the INFRAMIX concept is formulated. The outcome is a catalogue of non- functional requirements for the “hybrid” road infrastructure as a system, in the real world as well as in simulation (co-simulated environment). In this document, the term non-functional requirements, is used to describe the requirements that ensure the correct operation of the INFRAMIX components in the system e.g. performance, operation conditions, scalability requirements, persistence requirements, etc.

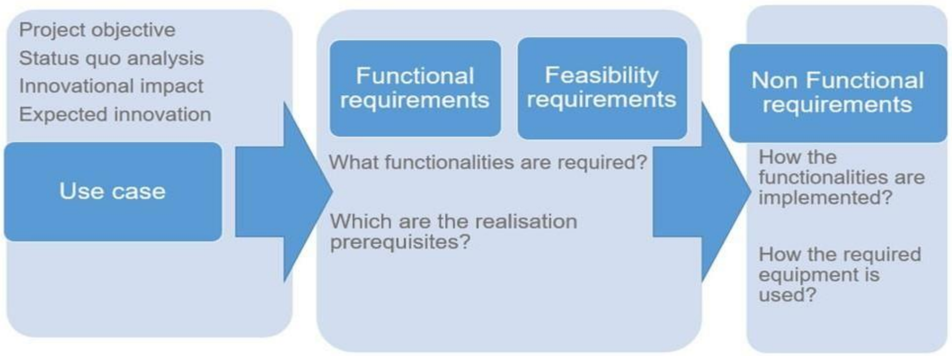


Figure 2 – Capture of the “hybrid” infrastructure requirements at each traffic situation.

Reassuring that the use case based catalogue of requirements is concise, a mapping is performed with the INFRAMIX components of a high-level architecture. The requirements are clustered per component at Chapter 5, formulating a requirements catalogue, based on the information provided at this status of the project. For each of the INFRAMIX components, technical specifications will be defined and documented in the later stage of the project. The deliverables concerning the design of specific components such as D2.2, D2.3, D2.4, D2.5, D3.1, D3.2 and D3.3, will further analyse the requirements in component level. Figure 3 summarises the methodology followed for the requirements capture in this project.

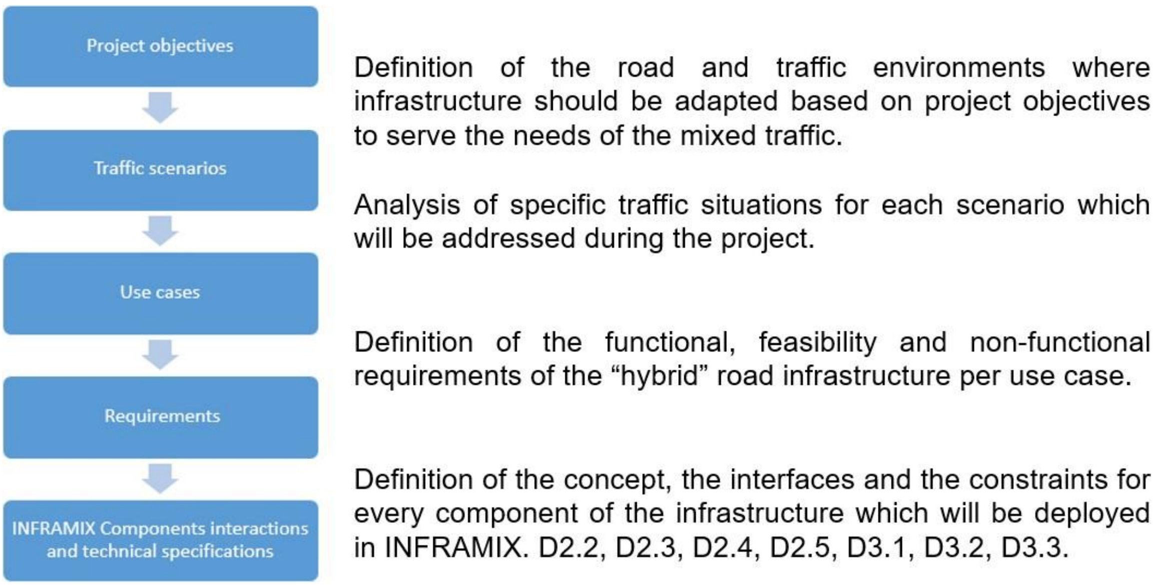


Figure 3 – Requirements capture process

3. Status quo analysis (infrastructure status/ simulation status)

A status quo analysis of the road infrastructure is necessary for detecting the inadequacies of the infrastructure [1], [2], in matters of mixed traffic conditions in order to address them as project objectives. Since the proposal phase of the project, a review of the current status of road infrastructure functionalities related to automated driving was made and INFRAMIX innovation potential was clearly defined. In such study, state-of-the-art test sites in Europe were considered. Specifically, the ASFINAG's Living Laboratory, located in Vienna, Austria and the A9 highway between Munich and Nurnberg, in Germany were taken into account. An overview of that study is described in this document, the detailed one shared only among the consortium as it contains confidential information.

In order to compare the technological level of the state-of-the-art on highways with the technological level of the INFRAMIX test sites which are located in Austria (Graz) and in Spain, the available infrastructure equipment and services were listed. In the following paragraphs, there is a brief description of the two test sites. At this point, it should be stressed that apart from the two test sites above, INFRAMIX has also an additional reference site in Germany, in the A9 motorway, that will be used by BMW during the implementation phase. In this document, only an outline of the test sites equipment and the latest projects related to infrastructure is given. The detail list of equipment and services for the Austrian, Spanish and also the German test site is shared only among the consortium.

Austrian Test Site

The Austrian Test Site includes 20km of A2 motorway between Laßnitzhöhe and City of Graz. The test site is equipped with gantries, mobile VMS, road works warning equipment, ITS-G5 RSUs, video cameras (traffic management, single vehicle detection), single-vehicle counters, environmental sensors and radar detection. It enables testing of new developed visual information, ITS-G5 short range communication, cellular communication and real time communication with the traffic control center. The infrastructure is based on a fibre-optic network that provides IP-based network connectivity to gantries.

The additional intention of the Austrian test site is to provide for each test run the complete precise trajectories of the tested vehicle as well as all vehicles in the surrounding traffic for the testing party to analyse. The data can be played back via a 3-D simulation tool.

Spanish test site

The Spanish test site is located within the Mediterranean Corridor between Barcelona and the French border. The specific highway segment is over 20km of four-lane carriageway. Each lane is 3,5m wide. The internal hard shoulder is 1m and the external hard shoulder is 2,5m. The highway median is 5m wide (in average). The test site includes four intersections and a 180m tunnel. The Average Daily Traffic (ADT) in this section was around 30.000 vehicles per day in 2016, and the speed limit is 120km/h.
Regarding the available maps, Abertis Autopistas has an Aerophotogrammetric restitution of all the highway and a video inventory (Mobile Mapping) including the layout, ITS equipment, signaling, etc.

The currently available equipment covers a modern Traffic Management Centre (TMC), various types of VMSs for signaling, A proprietary Fibre Optic ring network with 10 Gb Bandwidth along the test site and connected to the TMC, video cameras, 95 geolocalized fleet vehicles, 1 Bluetooth antenna for measuring occupancy, 1 Emergency Response Unit (ERU) and 1 Weather station. Furthermore, in the context of the C-Roads Spain project, around 50 magnetic loop sensors and at least 10 ITS-G5 RSUs will be installed and C-ITS Day Services will be deployed based on ITS-G5 in the test site before mid-2018.

The above-mentioned equipment of the test sites, will allow ASFINAG and Abertis Autopistas to provide real time information regarding the number and type of vehicles, speed, time gap, and heading in each segment of the test site between intersections as well as regarding any traffic incident.

In this point, it should be mentioned that along with the status quo analysis in the highways, the current technological level of the traffic simulation tools is defined through detailed information about simulation models that already exists or need to be developed in the frame of INFRAMIX. This information shared only among the consortium.

After the description of the use cases and the definition of the realisation prerequisites for each one of them, the required upgrade on the road infrastructure equipment and the deployment of the simulation tools can be clearly detected. The following chapters describe this need for upgrade through the eight use cases.

4. Use case based requirements capture for traffic scenarios

As described in Chapter 2, INFRAMIX builds on specific high-value traffic scenarios, in terms of importance with regard to traffic efficiency and safety: (1) Dynamic lane assignment (incl. speed recommendations), (2) Construction sites / Roadworks zones, and (3) Bottlenecks. A number of use cases per scenario were discussed and a selection of them was made, based on the consortium expertise and scientific interest. An important criterion for the use cases selection was to address the Day 1 C-ITS service lists [12]. Table 1 lists the traffic scenarios and the related use cases with the expected associated benefit.

This chapter describes each scenario and its expected impact. Each chapter section contains the detailed description of the use cases for each scenario, including the requirements per use case. Firstly, the functional requirements (required functions in order to realise the use case) describe the features, behaviour, and general functionality that the proposed infrastructure's system must support. The feasibility requirements consist of the infrastructure, physical and digital, elements, equipment etc. Feasibility requirements answer the question: In what means are the use case functionalities achieved? At last, non- functional requirements ensure a correct use case operation, e.g. systems performance, operation conditions, scalability requirements, persistence requirements, etc. Non-functional requirements answer the question: How, in technological terms, functional requirements are achieved?

Table 1 – List of use cases per scenario

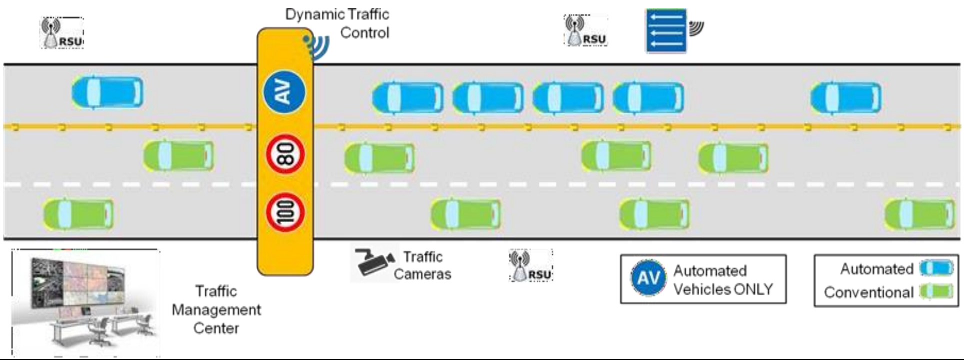
Scenarios	Use cases	Associated benefit
Dynamic lane assignment (incl. speed recommenda tions)	Real-time lane assignment under Dynamic Penetration Rate of Automated Vehicles (AVs[1])	Evaluation of the effect of the exclusive dedication of a lane to AVs. It allows the investigation of the traffic throughput based on their penetration rate, considering also the capacity of the road for conventional vehicles (CVs)[2].
	Exceptional traffic situations-adverse weather conditions as an example	Taken adverse weather conditions as an example, the effect of situations that disturb the smooth operation of infrastructure services and traffic management is investigated. The maintenance of smooth traffic flow under adverse weather conditions consist an objective.
	A conventional vehicle drives on a dedicated lane for AVs	Investigation of the consequences to traffic efficiency and safety, when a CV drives on or enters a lane dedicated to AVs.
Roadworks zones	Single Lane Closure (e.g. short term constructions)	Investigation of the necessary V2X communication, visual signs as well as physical elements when roadworks take place in a road segment. Moreover, evaluation of the efficiency of V2X communication in the aspect of safety and user's appreciation during roadworks will take place. The key aspect is to ensure that all kinds of vehicles are timely and sufficiently informed about the roadworks zone to act accordingly.
	New Lane Design (e.g. long term constructions)	Investigation of V2X communication, visual signs as well as physical elements in order to reassure a smooth and efficient traffic flow when roadwork zone covers more than one lane in a road segment. It is focused on the required visual signs that depict the new lane marking, the possible electronic horizon applications that help an AV to accurately follow the new lane markings and the establishment of the required interface.
Bottlenecks	Automated vehicles (AV) Driving Behaviour Adaptation in Real Time at Sags	Investigation of a traffic management concept to exploit AV capabilities towards increased traffic flow efficiency by changing the automated vehicles longitudinal driving behaviour according to the traffic management requirements. More specifically, the control strategy receives real-time measurements (or estimates) of the current traffic conditions and suggests to the AVs (or to the connected conventional ones which are equipped with ACC (level 2)) an appropriate value for the time-gap parameter and possibly also for the vehicle acceleration.
	Lane-Change Advice to connected vehicles at Bottlenecks	Investigation of a traffic management concept to decide on the necessary lane-changing activities in order to achieve a pre-specified (possibly traffic-dependent) lane distribution of vehicles while approaching a bottleneck, aiming at increasing the bottleneck capacity. A control strategy is fed with real-time lane-specific information about the prevailing traffic conditions in order to provide the lane–changing recommendations.
	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles	Investigation of improving the traffic flow at bottlenecks by controlling the upstream flow. Several innovative flow control strategies are investigated with different approaches (Mainstream Traffic Flow Control (MTFC), individual control).

[1] See Chapter 6 "Terms and Definitions" for the term Automated Vehicle (AV).
[2] See Chapter 6 "Terms and Definitions" for the term Conventional Vehicle (CV).

4.1 Scenario 1: Dynamic Lane Assignment (incl. speed recommendations)

The target of this scenario is to cater for mixed traffic on normal multilane highway segments (without tunnels, lane drops and entry or exit ramps) by assigning dynamically a lane to automated traffic. The assignment of a dedicated lane to automated traffic is expected to reduce the safety concerns around the interference of the automated vehicles with conventional traffic [13]. Moreover, one of the targets of this scenario is to understand how to balance mixed traffic in order to maintain the traffic throughput at least at the same level, as in case of today's traffic consisted of only conventional vehicles.

Table 2 – Description of scenario 1, Dynamic Lane Assignment (incl. speed recommendations)

Name	Dynamic Lane Assignment (incl. speed recommendations)
Short name	DLA
ID	S1-DLA
Overview	Assign dynamically a lane or several lanes to automated traffic (either isolated automated vehicles or forming platoons), based on the currently prevailing traffic conditions, on the percentage of trucks / heavy vehicles and on the penetration rate of automated vehicles using or not specific segregation elements; dynamically adapt the speed limits per lane or road segment considering also potential adverse weather conditions.
Schematic	
Derived Use Cases	1) Real-time lane assignment under Dynamic Penetration Rate of Automated Vehicles 2) Exceptional traffic situations-Adverse Weather Conditions as an example 3) A conventional vehicle drives on a dedicated lane for AVs
Objective	Examine mixed traffic on normal multilane highway segments (without tunnels, lane drops, entry or exit ramps) by assigning dynamically a lane to automated traffic. Questions such as "At which penetration level of automated vehicles a dedicated lane for them will be beneficial in terms of traffic efficiency and safety?" and "What kind of physical elements will be used, according to the existing (or emerging) traffic regulations, to make the dedicated lane obvious to all traffic participants?" will be studied.
Expected impact	The study of this scenario, in simulation and in real conditions, will provide insights on how to manage in an efficient manner mixed traffic flows on normal highway segments. It will provide proper indicators for activation and deactivation of lanes assigned to automated vehicles, speed and lane recommendations for all vehicles on this segment based on prevailing traffic conditions and also visual and electronic ways for informing all vehicles and drivers involved.

4.1.1 Real-time lane assignment under dynamic penetration rate of automated vehicles

The dynamic assignment of a lane to AVs, under different penetration rates and in mixed traffic, is investigated in this use case. Aiming to maintain traffic throughput at least at the same level as in case of today's traffic consisted of only CVs, the following key aspects are investigated:

- Lane assignment to AVs, when their percentage is above a certain limit, taking also into account the capacity of the road portion that is left for conventional traffic.
- The location of the dedicated lane is examined (e.g. right or left lane), considering traffic management goals as well as safety parameters.
- Adequate physical infrastructure adaptations are considered as well as the type and kind of V2X communication, in order to achieve availability and consistency of information for all types of vehicles. The driving behaviour and user's appreciation regarding these adaptations are investigated.

Figure 4 depicts the idea of a highway having a lane dedicated to AVs in mixed traffic.

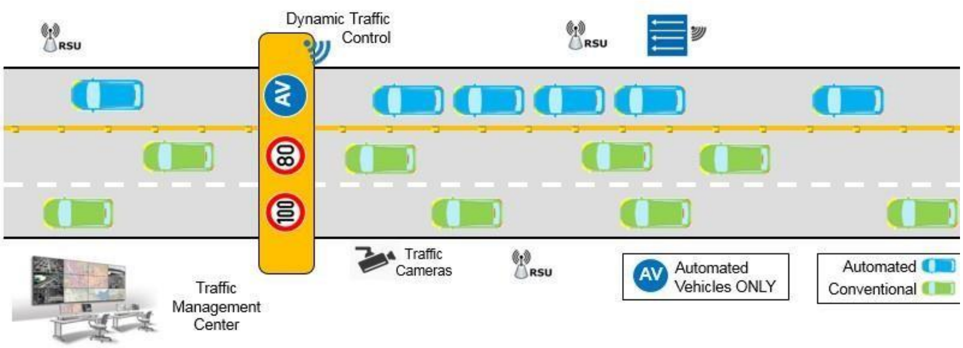


Figure 4 – Real-time lane assignment to automated driving

In the frame of this use case, the possibility of dedicating permanently a lane to automated traffic will be also investigated. In the near future, it is expected that the permanent assignment of a lane to AVs may be the normal case for mixed traffic due to safety considerations [13]. In this situation, the dynamic control of the traffic flow is attempted by giving the permission to different groups of automated vehicles to use the dedicated lane, during specific time intervals. As different groups of automated vehicles, the automated trucks and the automated passenger vehicles are considered. Under the frame of this subcase, the following key aspects will be investigated:

- Different time intervals that specific group of vehicles will be allowed to use the lane. The time zones when the trucks are currently not permitted to use a highway will be considered.
- Adequate means and ways of V2I communication to inform the automated vehicles about the time intervals and the vehicle groups which are permitted to use the lane.
- The possibility of several entrances and exits of the permanently dedicated lane will be analysed.
- Various speed limits applied at the dedicated lane depending on the type of the

automated vehicles using the lane (e.g. automated trucks forming a platoon, automated passenger vehicles, mixed passenger and truck automated vehicles).

- Various speed limits applied at the dedicated lane depending on the lane segment (taking into account the influence of the entrances and exits in the road traffic, i.e. adapting the speed of the lane to the rest of the traffic).

Figure 5 depicts the idea of a highway having a lane permanently dedicated to automated vehicles which is assigned to different automated vehicle groups based on the time interval.

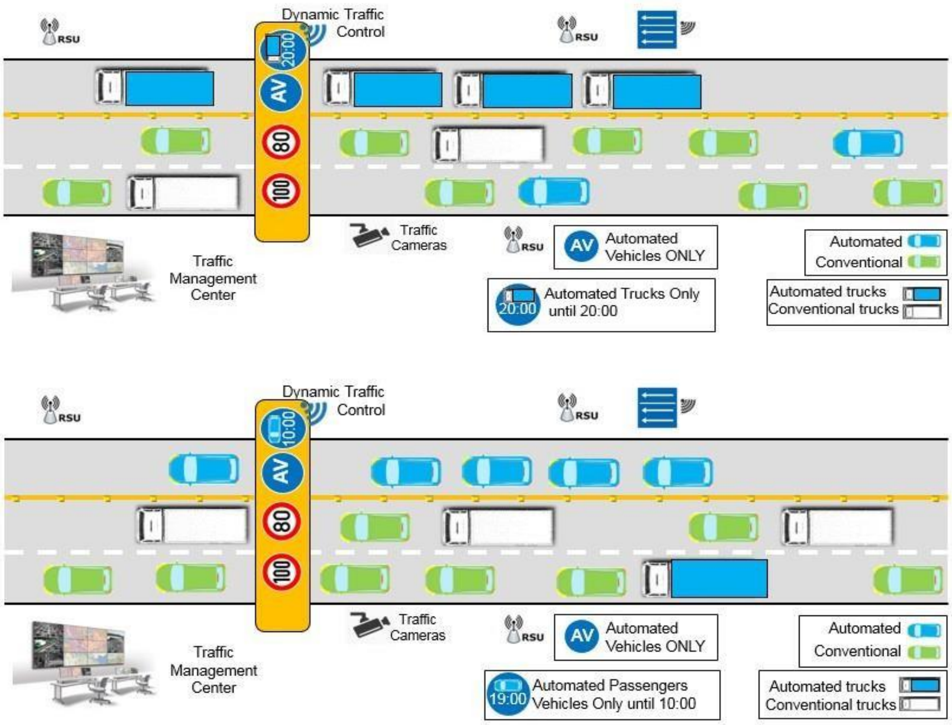


Figure 5 – Permanent lane for automated driving with real time assignment to different automated vehicle groups

Table 3 – Use case description: Real-time lane assignment under Dynamic Penetration Rate of automated vehicles (S1-DLA-UC1-DPR).

Name	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles
Short name	DPR
ID	S1-DLA-UC1-DPR
Overview	A lane is assigned dynamically to automated vehicles in mixed traffic, when their percentage is above a certain limit, taking also into account the capacity of the road portion left for conventional traffic. As an example, a representative sequence of actions follows: ➢ In a multilane roadway of mixed traffic, a lane has been assigned to automated vehicles with level of automation equal or higher than 3; ➢ Speed limits are set in real-time to all lanes. The limits are based on traffic conditions and safety considerations related to the lane dedication; ➢ The amount of conventional vehicles approaches the capacity of the rest lanes; ➢ The traffic management strategy recommends the deactivation of the dedicated lane; ➢ Speed limits per lane are adjusted for a short period of time when activating or de-activating a dedicated lane, to increase safety (e.g. apply lower speed limits); ➢ The dedicated lane operation is de-activated. TMC communicates that event to all road users; ➢ Lane change and speed recommendations are given by the TMC to the connected vehicles to facilitate smooth traffic flow; ➢ The traffic management strategy recommends the activation of the lane dedicated to the automated vehicles when this event would improve the traffic flow in all of the lanes; the penetration rate of the automated vehicles is above a minimum limit considering also the overall ratio of AVs compared to conventional traffic. ➢ The dedicated lane operation is activated. TMC communicates that event to all road users; Speed limits per lane are adjusted for a short period of time according to safety considerations (e.g. apply lower speed limits); ➢ Lane change recommendations are given by the TMC to the connected vehicles to support the separation of the traffic into conventional and automated; ➢ Speed limits are set for all of the lanes. The limits are based on traffic conditions and on safety considerations related to the lane dedication. A lane is permanently dedicated to automated driving. The dynamic traffic management is attempted by assigning the lane exclusively to automated trucks or to automated passenger vehicles depending on the time zone of the day. As an example, a representative sequence of actions follows: ➢ A multilane highway with a permanently dedicated lane to automated driving, only automated truck vehicles are permitted for the specific time zone; ➢ Speed limits are set for all of the lanes. The limits are based on traffic conditions as well as safety considerations related to the lane dedication and the lane segment (taking into account the influence of the entrances and exits in the road traffic, i.e. adapting the speed of the lane to the rest of the traffic)

		➢ The amount of the conventional and the automated passenger vehicles approaches the capacity of the rest lanes; there is not a safety reason that implies the remaining of the automated trucks in the lane. ➢ The traffic management strategy recommends the assignment of the permanently dedicated lane to automated passenger vehicles; ➢ Lower speed limits are applied to all vehicles for a short period of time when there is a change in the vehicle group that is permitted to use the lane for safety reasons; ➢ The dedicated lane is assigned to automated passenger vehicles. TMC communicates that event to all road users; ➢ Lane change and speed recommendations are given by the TMC to the connected vehicles to convenient the traffic flow; ➢ Speed limits are set in real-time for all of the lanes. The limits are based on traffic conditions, on safety considerations related to the lane dedication and to vehicle group using the lane, as well as to the lane segment.
Real world tested through this use case		• The signalling could be evaluated by a group of users, especially the comprehensibility of the visual signs. • User's appreciation on the way that information are provided during the activation and deactivation of the dedicated lane.
Key assumptions		• A multilane motorway segment without any apparent bottlenecks, therefore there is no risk for a traffic breakdown, and any applied control measures do not need to address such a risk. • Conventional vehicles comply with the traffic signs and they don't drive on the lane dedicated to automated driving. • There are enough vehicles with High Definition maps
Realisation Prerequisites	**A. Physical infrastructure**	• Roadway with minimum 3 lanes. • Traffic Management Center (TMC) extended with INFRAMIX Management Center (IMC)[3] (refer to Figure 15). • RSUs for network connectivity coverage[4]. • Sensors for real-time traffic information. • Gantries or/and mobile VMS to provide information to conventional non-connected vehicles. • Infrastructure traffic signs: pictogram and pictogram code need to be defined for the dynamic lane assignment signage. • Vehicles equipped with OBU (ITS-G5) or cellular communication device[5].

	B. Digital infrastructure	• Communication technologies:
		  ○ Cellular network (communication to centralized backend servers)
		  ○ ITS-G5 (5.9 GHz Geobroadcast communication)
		  ○ IP Connectivity
		• Wireless messages:
		  ○ IVIM[6] (including new DLA sign codes, Speed limits per lane after lane assignment to automated traffic, dedicated lane activation / deactivation)
		  ○ CAM[7] (Continuous broadcast of Vehicle, Speed, heading, Position in real time, awareness message about existence of other vehicles (optional), level of automation (has to be added to the data element

[3] In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX Management Center (IMC).
[4] Connected to TMC and to OBUs.
[5] For real test demonstration, at least one automated vehicle and/or one conventional vehicle shall be equipped with a communication for validation of the use case under real conditions
[6] Infrastructure to Vehicle Information Message (IVIM) [21].
[7] Cooperative Awareness Message (CAM) [23].

		"vehicle role" ETSI standards)) o DENM[8] (Basic Hazardous location warnings, Basic safety warnings e.g. braking (optional))
	C. Data availability	• Traffic data from real traffic conditions (to use in simulation) o Lane change behaviour o Traffic flow, occupancy and speed per lane o Type of vehicles (trucks or passenger vehicles) per hour • Real-time traffic data (measurements or estimates): o Traffic flow, occupancy and speed per lane measurements o Level of automation of vehicles per lane (automated or conventional) o Type of vehicles (truck or passenger vehicles)
	D. Simulators capability	• Realistic driving behaviour of automated vehicles (acceleration, deceleration, lane changes). • Automated driving functions with cruise control and lane keeping. • Naturalistic human driving style for the conventional vehicles (acceleration, deceleration, lane changes). • Influence of infrastructure on driving strategy. • Communication links for messages between vehicles and RSUs via ITS-G5. • Communication links for messages between vehicles and a Cellular Central Server via Cellular. • Traffic Control Interface for coupling of traffic control algorithms (including speed advisories, lane recommendations) and traffic flow estimation. • Usage of HD-Map information in simulation environment including RSU, VMS, and sensor positions. • Sensor-models for the measurements capabilities of road-sensors. • VMS models that indicate the variable speed limits and the lane assignments.
Challenges	**Technical**	• Modelling of realistic driving behaviour of conventional and automated vehicles. • The real-time logic for activating and de-activating the dedicated lane is based on the prevailing traffic conditions, which are reflected in appropriate traffic data (measurements or estimates) to be specified.
	Others e.g. operations, safety regulations	Safety challenges expected to arise due to the inevitable increase in the number of lane changes at the activation/de-activation periods. For the subcase of a permanent lane: o New protocol for setting the segregated lane and managing the exclusive access of AVs. o Safety regulations related to the segregation and signalling elements for these types of lanes.
Target/Evaluation metrics		Evaluation of the changes in traffic efficiency when a lane is dedicated to AVs under different penetration rates. Evaluation of the infrastructure physical adaptations in the aspect of road user's appreciation. Investigation of the stakeholders' benefits (e.g. freight companies) related to functionality of different groups of AVs using a permanently dedicated lane at different time intervals. Research questions to be replied o How the throughput of conventional vehicles is affected when there is a lane assigned to AVs? o At which % of automated vehicles a dedicated lane is more appropriate in terms of traffic efficiency?

[8] Decentralized Environmental Notification Message (DENM) [22].

	○ How does the way of providing information about a lane assignment affect the driver/passenger attitude? ○ Which is the adequate number of gantries per kilometric distance that should be installed to inform the non-connected vehicles about the dynamical lane assignment? ○ How much does the location of the dedicated lane (left or right) affect the traffic throughput? KPIs/ metrics: Measure the throughput under different penetration rates of AVs and compare it to the baseline (conventional traffic).

Use case requirements

Requirement ID	Functional requirements	Comments
S1_DLA_UC1_DPR_F_01	TMC should inform the road users about the infrastructure capability to dynamically assign a lane to AVs before entering the highway and while using the roadway.	
S1_DLA_UC1_DPR_F_02	TMC should inform the road users about the possibility of changing the current speed limit applied to the lane that they use before entering the highway and while using the roadway.	
S1_DLA_UC1_DPR_F_03	Control strategies should decide dynamically about the activation and deactivation of the dedicated lane based on real-time traffic flow information.	
S1_DLA_UC1_DPR_F_04	TMC should inform the road users about the activation and deactivation of the dedicated lane, while using the roadway.	This requirement includes the exact time period that the dedicated lane will be activated or deactivated.
S1_DLA_UC1_DPR_F_05	TMC should inform the automated vehicles about the criteria (level of automation, type of vehicles (e.g. passenger vehicles or trucks)) to use the dedicated lane.	
S1_DLA_UC1_DPR_F_06	TMC should inform the road users about the duration of the transition period which is defined between the time that they receive the information to the time that the lane will be actually activated or deactivated.	
S1_DLA_UC1_DPR_F_07	TMC should be able to communicate with the AVs and connected conventional vehicles through ITS-G5 messages.	
S1_DLA_UC1_DPR_F_08	TMC should be able to communicate with the AVs and connected conventional vehicles via Cellular network (communication to centralized backend servers).	
S1_DLA_UC1_DPR_F_09	TMC should be able to inform the conventional vehicles dynamically about the speed limits applied to the lane that they use.	
S1_DLA_UC1_DPR_F_10	V2I communication should support the AVs to provide information to TMC through ITS-G5 or Cellular, regarding their speed, location, surrounding environment and their level of automation while they use the roadway.	
S1_DLA_UC1_DPR_F_11	Control strategies should be able to decide about the lane dedication to automated passenger vehicles or to automated trucks based on traffic flow criteria.	The criteria will be defined in the next project steps Task 2.6
S1_DLA_UC1_DPR_F_12	TMC should be able to recommend the automated vehicles the speed depending on the lane they use.	

Requirement ID	Feasibility requirements	Comments
S1_DLA_UC1_DPR_FE_01	Infrastructure should be equipped with gantries or/and mobile VMS that provide signage of pictogram code for the dynamic lane assignment that ensure the functional requirements: S1_DLA_UC1_DPR_F_01, S1_DLA_UC1_DPR_F_02, S1_DLA_UC1_DPR_F_04, S1_DLA_UC1_DPR_F_06, S1_DLA_UC1_DPR_F_09	The pictogram and pictogram code for the dynamic lane assignment need to be defined, the service is novel.
S1_DLA_UC1_DPR_FE_02	The number of gantries or/and mobile VMS should be adequate for ensuring the functional requirements: S1_DLA_UC1_DPR_F_01, S1_DLA_UC1_DPR_F_02, S1_DLA_UC1_DPR_F_04, S1_DLA_UC1_DPR_F_06	The specific kilometric distance of the gantries will be determined during the next phases of the project.
S1_DLA_UC1_DPR_FE_03	Infrastructure should be equipped with sensors that provide real-time traffic information to ensure the functional requirements: S1_DLA_UC1_DPR_F_03, S1_DLA_UC1_DPR_F_11	
S1_DLA_UC1_DPR_FE_04	The number of sensors for real-time traffic information should be adequate for ensuring the requirements: S1_DLA_UC1_DPR_F_03, S1_DLA_UC1_DPR_F_11, S1_DLA_UC1_DPR_NF_01, S1_DLA_UC1_DPR_NF_02, S1_DLA_UC1_DPR_NF_03	
S1_DLA_UC1_DPR_FE_05	Wireless messages (CAM and DEMN) from connected vehicles to TMC containing information of vehicle's speed, heading, position in real time, surrounding environment and their level of automation, ensuring the functional requirements: S1_DLA_UC1_DPR_F_03, S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_11	Specification of standard V2X communication is included in WP3 (Task 3.2). CAM: level of automation (has to be added to the data element "vehicle role" ETSI standards) Optionally: CAM, awareness messages about existence of other vehicles DEMN, basic safety warnings e.g. braking
S1_DLA_UC1_DPR_FE_06	Wireless messages (IVIM and DEMN) from TMC to connected vehicles containing information for lane assignment service, speed regulation and basic hazardous location warnings ensuring the functional requirements: S1_DLA_UC1_DPR_F_05 S1_DLA_UC1_DPR_F_06 S1_DLA_UC1_DPR_F_07 S1_DLA_UC1_DPR_F_08	Specification of standard V2X communication is included in WP3 (Task 3.2).

S1_DLA_UC1_DPR_FE_07	The number of RSUs should be adequate for ensuring network connectivity coverage.	The specific kilometric distance of RSUs will be determined in the next phases of the project.
S1_DLA_UC1_DPR_FE_08	Infrastructure should be consisted of a roadway with at least three lanes.	
S1_DLA_UC1_DPR_FE_09	Infrastructure should include Traffic Management Center (TMC) to supervise traffic and cooperate with traffic control and estimation strategies (INFRAMIX Management Center)	
S1_DLA_UC1_DPR_FE_10	High definition maps should provide information for traffic simulation.	Requirement apply also for the Microscopic traffic simulation model (e.g. in OpenDrive format) and Static environment model.
S1_DLA_UC1_DPR_FE_11	Infrastructure should provide 5.9 GHz Geobroadcast communication (ITS-G5), ensuring the functional requirements: S1_DLA_UC1_DPR_F_05, S1_DLA_UC1_DPR_F_06, S1_DLA_UC1_DPR_F_07, S1_DLA_UC1_DPR_F_10	Apart from ITS-G5, Cellular network (communication to centralized backend servers) and IP Connectivity are required.

Requirement ID	Non-functional requirements	Comments
S1_DLA_UC1_DPR_NF_01	Real-time measurements of flow, speed and occupancy should be delivered per lane per specific kilometric distance every 60 seconds.	The specific kilometric distance will be determined in the next phases of the project. The acceptable frequency of real-time provided data is set to every 60 seconds, as a first draft estimation for enabling an efficient traffic management. This requirement applies also for the Microscopic traffic simulation model.
S1_DLA_UC1_DPR_NF_02	Real-time count of AVs should be delivered per lane per specific kilometric distance every 60 seconds.	The specific kilometric distance will be determined in the next phases of the project. The acceptable frequency of real-time provided data is set to every 60 seconds, as a first draft estimation for enabling an efficient traffic management. This requirement applies also for the Microscopic traffic simulation model.

S1_DLA_UC1_DPR_NF_03	The real data information from road measurements and the estimated data regarding traffic flow should be consistent and their combination should be accurate enough to permit the decision making from the traffic control strategies (ensuring the functional requirements: S1_DLA_UC1_DPR_F_03, S1_DLA_UC1_DPR_F_11).	
S1_DLA_UC1_DPR_NF_04	ITS-G5 communication (air interface) should have a latency which is less than 10 seconds.	
S1_DLA_UC1_DPR_NF_05	TMC should provide dynamic information to the road users with a delay which is less than 60 seconds.	
S1_DLA_UC1_DPR_NF_06	TMC should be able to recommend specific ordered AV-settings to all AVs within specific sections.	“AV-settings”, refer to velocity and lane-change related settings that will be defined based on the control strategy in the next phases of the project
S1_DLA_UC1_DPR_NF_07	The % of decrease of speed limits applied during the transition periods should not cause emergency braking to AVs.	
S1_DLA_UC1_DPR_NF_08	By increasing the penetration rate of AVs the throughput should always be at least at the same level as in the case of today’s traffic consisted of only CVs.	
S1_DLA_UC1_DPR_NF_09	TMC should generate and communicate IVIM messages to connected vehicles in order to satisfy the functional requirements: S1_DLA_UC1_DPR_F_04, S1_DLA_UC1_DPR_F_05, S1_DLA_UC1_DPR_F_06, S1_DLA_UC1_DPR_F_07.	
S1_DLA_UC1_DPR_NF_10	RSUs should be able to send out the IVIM and DEMN messages to all vehicles that are connected via ITS-G5 in real-time.	
S1_DLA_UC1_DPR_NF_11	TMC should generate and communicate IVIM message content to centralized backend servers (Cellular network) in order to satisfy the functional requirements: S1_DLA_UC1_DPR_F_04, S1_DLA_UC1_DPR_F_05, S1_DLA_UC1_DPR_F_06, S1_DLA_UC1_DPR_F_08.	
S1_DLA_UC1_DPR_NF_12	TMC should communicate dynamically with road signage equipment (gantries, VMS etc.)	
S1_DLA_UC1_DPR_NF_13	V2I communication should support the real- time data exchange between connected vehicles (equipped with ITS-G5 OBU or cellular communication device) to TMC.	

4.1.2 Exceptional traffic situations-Adverse Weather Conditions as an example

The purpose of this use case is to explore the effect on traffic flow when there is a disturbance in the smooth operation of the "hybrid" infrastructure. Taken adverse weather conditions (AWCs) as an example, the effect of disturbances in the operation of infrastructure services and traffic management is investigated. Disturbances like low visibility of the traffic signs, are analysed from the perspective of the mixed traffic (automated and conventional driving). Additionally, the operation of "hybrid" infrastructure services like dynamic lane assignment (S1-DLA-UC1-DPR) is assessed under environmental conditions that hassle the automated driving.

A brief description of the way that automated vehicles react nowadays when driving under adverse weather conditions, is necessary in order to develop an infrastructure that supports the mixed traffic. There are many situations where AWCs are influencing the automated driving. Due to AWCs the lane marks may not be detected, traffic signs may not be visible, awareness of other traffic vehicles may be affected, etc. Specifically, it is possible that crossing specified level of visibility the level of automation is degraded[9].

The decision to degrade the automated driving mode can be done in the backend for specific road segments. The degradation concept, e.g. for BMW, is based on the principle of road clearance which is determined online for each link based on several information like for example:

- Slippery Road
- Strong side wind
- Heavy rain
- Snow
- Reduced visibility

These information can come from infrastructure weather stations and/or from connected cars which can detect this information with their own sensors. Additionally, each automated vehicle can also decide to go in a (private) degradation mode. So even if information towards adverse weather conditions is not provided from central services, the car itself can on basis of its own sensors (including camera) decide to degrade or to completely switch off the autonomous driving mode.

For sake of safety, the critical thresholds where a degradation mode is engaged are initially chosen conservatively low. It is expected that with the support of infrastructure sensor technology these thresholds can be chosen higher. Taking into consideration the way that AVs change level of automation, the lane assignment under adverse weather conditions is analysed as a representative subcase.

[9] A first level of degradation is the mode, eyes ON, hands OFF, which means that the driver has to supervise the autonomous driving. If the manual driver finds it necessary he should intervene and continue the driving manually. In a further degradation mode, eyes ON and hands ON, the human driver not only has to supervise the autonomous driving but he should be ready to take over the driving himself anytime. In the last degradation mode, the automated driving is switched off and the human driver has to fully take over the driving. In all three degradation modes the human driver becomes responsible for the driving behaviour.

Table 4 – Use case description: Exceptional traffic situations-Adverse Weather Conditions as an example (S1-DLA-UC2-AWC).

	Exceptional traffic situations-Adverse Weather Conditions as an example
Short name	AWC
ID	S1_DLA_UC2_AWC
Overview	The scope is to investigate how infrastructure services will influence in a beneficial way the maintenance of safe and smooth traffic flow in exceptional situations such as the adverse weather conditions. Sequence of actions for the case of lane assignment under adverse weather conditions, using as example the occurrence of fog: ➢ In a multilane roadway of mixed traffic, a lane has been assigned to AVs; ➢ Some miles ahead dense fog with very limited visibility is detected (e.g. from the sensors of the infrastructure, information provided by third party services); ➢ The infrastructure services transmit via ITS-G5 (e.g. DENM, IVIM) and/or over web services, the traffic information displayed on the VMS as well as the position and the extent of fog in driving direction; ➢ The traffic management strategy processes safety criteria related to the low visibility as well as criteria based on the amount of the AVs that have degraded their level of automation; ➢ The traffic management strategy, based on the above-mentioned criteria, assigns a lane to a specific level of automation of AV's. For example, in case of dense fog, it will be for automation level 3 (assumption). ➢ The AVs will drive on the dedicated lane or leave to the other lanes for CVs based on their automated driving capabilities. ➢ Based on the V2X communication channel additional advisory driving behaviour will be transmitted to the vehicles (e.g. minimum driving distance gap between vehicles).
Parts of the use case that will be tested in real world	This use case will be tested mainly through simulation. Possible real tests might contain the calibration and the test of the ambient sensors of the infrastructure (optional).
Key assumptions	• A multilane motorway segment without any apparent bottlenecks, therefore there is no risk for a traffic breakdown, and any applied control measures do not need to address such a risk. • The lane delimitation on the roadway, is constant and well-marked in matters of visibility. • Vehicles comply with the TMC change lane instructions.

Realisation Prerequisites	**A. Physical infrastructure**	• Roadway with minimum 3 lanes. • Traffic Management Center (TMC) extended with INFRAMIX Management Center (IMC)[10] (refer to Figure 15) • RSUs for network connectivity coverage. • Sensors for real-time traffic information. • Sensors for ambient detection values (e.g. fog, rain, snow, wind etc.). • Gantries or/and mobile VMS to provide information to traffic regarding weather conditions. • Infrastructure traffic signs: pictogram and pictogram code need to be defined for the dynamic lane assignment signage related to weather conditions.
	B. Digital infrastructure	• Communication technologies: ○ Cellular network (communication to centralized backend servers) ○ ITS-G5 (5.9 GHz Geobroadcast communication) ○ IP Connectivity • Wireless messages: ○ IVIM (including new DLA sign codes, Speed limits per lane after lane assignment to automated traffic, dedicated lane activation / deactivation) ○ CAM (Continuous broadcast of Vehicle, Speed, heading, Position in real time, awareness message about existence of other vehicles, level of automation (has to be added to the data element “vehicle role” ETSI standards)) ○ DENM (Basic Hazardous location warnings (e.g. rain), Basic safety warnings e.g. braking (optional))
	C. Data availability	• Traffic data from real traffic conditions (to use in simulation) ○ Lane change behaviour ○ Traffic flow, occupancy and speed per lane ○ Type of vehicles (trucks or passenger vehicles) per hour ○ Information about local weather conditions in high quality. • Real-time traffic data (measurements or estimates): ○ Traffic flow, occupancy and speed per lane measurements ○ Level of automation of vehicles per lane (automated or conventional) ○ Aggregated traffic information from connected vehicles and/ or from cellular backend servers of vehicle services (real-time eXtended Floating Car Data (XFCD)) ○ Information about local weather conditions in high quality.
	D. Simulators capability	• Capability of enhancing the simulation with local weather conditions.
Challenges	**Technical**	• The real-time logic for activating and de-activating the dedicated lane is based on traffic conditions, which are reflected in appropriate traffic data and on ambient sensor data (measurements or estimates).
	Others e.g. operations, safety regulations	• Trade-off between traffic efficiency and safety (lane changes) due to DLA or release of dedicated lane to AV's e.g. due to adverse weather conditions.

[10] In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX Management Center (IMC).

Target/Evaluation metrics	Evaluation of the adaptations related to infrastructure signs in the aspect of road user's appreciation. Comparison of the amount of changes of the AV level degradation with and without the updates of the infrastructure. *Research questions:* ○ How can we safely manage the mixed traffic under AWC? What kind of control strategies could be employed? ○ Lane markings cannot be detected by the AVs due to AWC. (How can this situation be handled without degradation of the level of automation)? Which are the proper actions that IMC should perform in that case in order to reassure safety? ○ How overtaking is allowed under exceptional circumstances (considering mixed traffic)? KPIs/metrics: Traffic throughput.(Evaluate the decrease at the traffic throughput due to adverse weather conditions when there is a lane assigned to automated vehicles (explore the throughput change under the lane dedication to different level of automation based on weather conditions))

Use case requirements

Requirement ID	Functional requirements	Comments
S1_DLA_UC2_AWC_F_00	Requirements: S1_DLA_UC1_DPR_F_01, S1_DLA_UC1_DPR_F_02, S1_DLA_UC1_DPR_F_03, S1_DLA_UC1_DPR_F_04, S1_DLA_UC1_DPR_F_06, S1_DLA_UC1_DPR_F_07, S1_DLA_UC1_DPR_F_08, S1_DLA_UC1_DPR_F_09 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_12 are also applied in this use case.	
S1_DLA_UC2_AWC_F_01	TMC should process all the related data for defining the traffic management strategies, taking into account the interpretation of weather conditions into the possible degradation of automated driving.	Specific assumptions and process of data from different sources (Vehicle services (cellular backend), sensors, AVs wireless messages (CAM)) should be performed.
S1_DLA_UC2_AWC_F_02	A reduced visibility due to rain, snow, smoke, insolation, darkness or others should be recorded, positioned and quantified by the “hybrid” road infrastructure.	
S1_DLA_UC2_AWC_F_03	A reduced friction value of the road due to rain, snow, ice, oil, or others should be recorded, positioned on a map and quantified by the “hybrid” road infrastructure.	
S1_DLA_UC2_AWC_F_04	Side winds should be recorded, positioned on a map and quantified by the “hybrid” road infrastructure.	
S1_DLA_UC2_AWC_F_05	Precipitation should be recorded, positioned on a map and quantified by the “hybrid” road infrastructure.	
S1_DLA_UC2_AWC_F_06	Road temperatures must be recorded, positioned on a map and quantified by the “hybrid” road infrastructure.	
S1_DLA_UC2_AWC _F_07	TMC should be able to provide specific “vehicle- settings” recommendations to centralized backend servers for individualized traffic control strategy parametrizations to vehicles with cellular OBU (based on the Traffic control strategies of the TMC).	“vehicle-settings”, refer to the choice of level of automation (if it is applicable), velocity and lane-change related settings that will be defined based on the control strategy in the next phases of the project.
S1_DLA_UC2_AWC_F_08	Traffic Services should transmit aggregated traffic information from Cellular-side to TMC.	

Requirement ID	Feasibility requirements	Comments
S1_DLA_UC2_AWC_FE_00	Requirements: S1_DLA_UC1_DPR_FE_01, S1_DLA_UC1_DPR_FE_02, S1_DLA_UC1_DPR_FE_03, S1_DLA_UC1_DPR_FE_04, S1_DLA_UC1_DPR_FE_05, S1_DLA_UC1_DPR_FE_06, S1_DLA_UC1_DPR_FE_07, S1_DLA_UC1_DPR_FE_08 S1_DLA_UC1_DPR_FE_09, S1_DLA_UC1_DPR_FE_10 S1_DLA_UC1_DPR_FE_11 are also applied in this use case.	
S1_DLA_UC2_AWC_FE_01	TMC should include Incident traffic management database.	
S1_DLA_UC2_AWC_FE_02	Infrastructure should be equipped with sensors that provide real-time rain information (precipitation in l/m^2).	In the next phases of the project, it will be defined if it is possible to aggregate the required real-time weather information from other sources than sensors.
S1_DLA_UC2_AWC_FE_03	Infrastructure should be equipped with sensors that provide real-time wind information (wind velocity in m/s and wind direction relate to driving direction).	In the next phases of the project, it will be defined if it is possible to aggregate the required real-time weather information from other sources than sensors.
S1_DLA_UC2_AWC_FE_04	DEMN message from connected vehicles to TMC containing information related to the functional requirements: S1_DLA_UC2_AWC_F_03, S1_DLA_UC2_AWC_F_04, S1_DLA_UC2_AWC_F_05.	
S1_DLA_UC2_AWC_FE_05	Wireless messages (IVIM and DEMN) from TMC to connected vehicles containing information related to the functional requirements: S1_DLA_UC2_AWC_F_03, S1_DLA_UC2_AWC_F_04, S1_DLA_UC2_AWC_F_05.	

Requirement ID	Non-functional requirements	Comments
S1_DLA_UC2_AWC_NF_00	Requirements: S1_DLA_UC1_DPR_NF_01, S1_DLA_UC1_DPR_NF_02, S1_DLA_UC1_DPR_NF_03, S1_DLA_UC1_DPR_NF_04, S1_DLA_UC1_DPR_NF_05, S1_DLA_UC1_DPR_NF_06, S1_DLA_UC1_DPR_NF_07, S1_DLA_UC1_DPR_NF_09, S1_DLA_UC1_DPR_NF_10 S1_DLA_UC1_DPR_NF_11 S1_DLA_UC1_DPR_NF_12 S1_DLA_UC1_DPR_NF_13 are also applied in this use case.	
S1_DLA_UC2_AWC_NF_01	The TMC should contain aggregated weather conditions data that permit the recommendation of degradation or not of the level of automation to vehicles in real-time.	
S1_DLA_UC2_AWC_NF_02	The TMC should have specific criteria on the recommendation of degradation or not of the level of automation to vehicles taking into account the individual vehicles thresholds of: o precipitation (in l/m²) o wind velocity in m/s o wind direction related to driving direction o road friction o visibility	The criteria will be defined in the next phases of the project.
S1_DLA_UC2_AWC_NF_03	TMC should generate and communicate IVIM and DEMN messages via ITS-G5 to connected vehicles related to the functional requirements: S1_DLA_UC2_AWC_F_03, S1_DLA_UC2_AWC_F_04, S1_DLA_UC2_AWC_F_05.	
S1_DLA_UC2_AWC_NF_04	TMC should generate and communicate IVIM and DEMN message content to centralized backend servers (Cellular network) related to the functional requirements: S1_DLA_UC2_AWC_F_03, S1_DLA_UC2_AWC_F_04, S1_DLA_UC2_AWC_F_05.	

4.1.3 A conventional vehicle drives on a dedicated lane for automated vehicles

In this use case, the consequences of a CV driving on or entering a lane dedicated to AV on traffic management are investigated, regarding traffic efficiency and safety. Considering also the fact that an automated vehicle may degrade its level of automation any time, an automated vehicle which does not communicate its level of automation regularly to TMC is not a proper user of the dedicated lane. Therefore, the term non-proper user is used in this document to describe a vehicle that it intends to enter or drives on a lane dedicated to automated driving and its level of automation is lower than the one that the lane is dedicated to or it has not communicate its level of automation to TMC for the last 10 seconds[11].

This use case focuses on the following key aspects:

- Identification of AVs and non-proper users;
- Proper signs and TMC messages to prevent a non-proper user from driving on or entering the AV-lane;
- Proper information of AVs about the non-proper user on or entering the AV-lane via infrastructure communication;
- Proper infrastructure support/warning provided to non-proper user to exit the AV-lane
- Minimizing the possibility of an incident or degradation of traffic flow efficiency by suited measures of AVs (e.g. dissolution of platoon);
- The interactions between vehicles as well as vehicle and TMC. In the frame of this use case, two subcases will be investigated:

First, a non-proper user is on the lane which is dedicated to automated vehicles (AV-lane), Figure 6. This subcase, mainly focuses on the consequences in traffic efficiency.

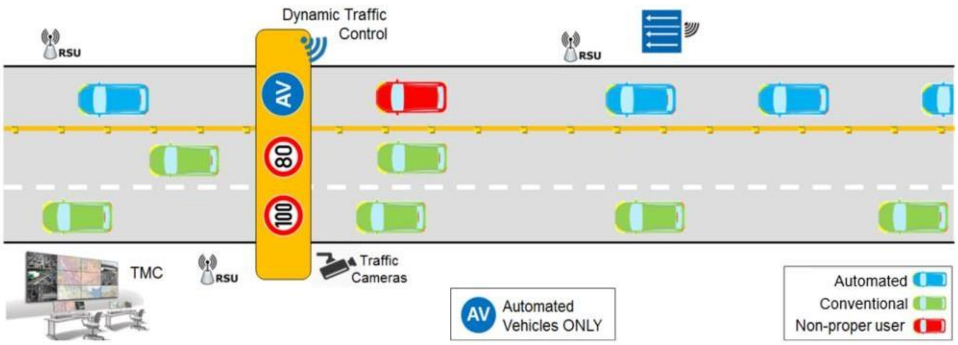


Figure 6 – Non-proper user on a lane dedicated to automated driving

Second, a non-proper user is entering the dedicated lane, Figure 7. Several reasons for entering a dedicated lane exist: Either the non-proper user is not informed about or ignores the dedicated lane, or the non-proper user has to stop because of a breakdown.

[11] See Chapter 6 “Terms and Definitions” for the term Automated Vehicle (AV)

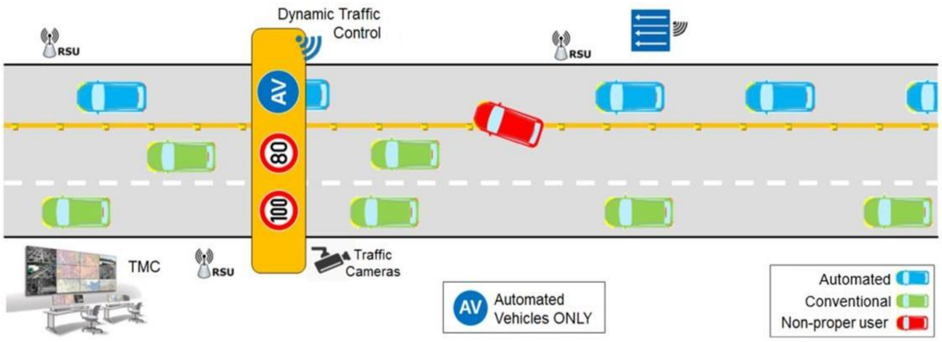


Figure 7 – Non-proper user enters a lane which is dedicated to automated driving

Table 5 – Use case description: A conventional vehicle drives on a dedicated lane for automated vehicles (S1-DLA-UC3-CVDL).

Name	A conventional vehicle drives on a dedicated lane for automated vehicles (AVs)
Short name	CVDL
ID	S1-DLA-UC3-CVDL
Overview	By dedicating a lane to automated driving, a conventional vehicle is not allowed to use it. Moreover, automated vehicles (both passenger cars and trucks) which cannot be identified as automated due to missing real-time V2I-communication are not allowed to use it either. Defining as, non-proper user, a vehicle which is not allowed to use the lane dedicated to automated driving due to the above-mentioned reasons, the following two subcases will be investigated: 1) Non-proper user is already on the dedicated lane ➢ When the TMC decides to assign a lane, usually there will be non-proper users on this lane. ➢ Vehicles are informed about the lane dedication by physical infrastructure and TMC-messages. ➢ Non-proper users are instructed to leave the lane. ➢ Non-proper users have to be clearly identified. In case of a non-proper users staying on the AV-lane, the AVs are informed properly. ➢ AVs decide either to increase the gap to the non-proper user in the front or to overtake and therefore leave the AV-lane. ➢ If the non-proper user is a connected CV, the AV may ask the connected CV to leave the lane (via V2I communication through TMC). ➢ If it is decided to overtake out of a platoon (minimum vehicle distance), first it has to be dissolved. 2) A conventional vehicle enters the dedicated lane ➢ If no AVs are in the closer environment of the non-proper user, see subcase: “1) Non-proper user is already on the dedicated lane”. ➢ In case of a non-proper user entering the AV-lane, the AVs are informed properly. ➢ Non-proper users are informed properly to leave the lane. ➢ AVs communicate their trajectories to TMC (e.g. through CAM messages) and TMC relates that information with the non-proper user (The AV reaction could be an increase the gap to the non-proper user in the front).
Parts of the use case that will be tested in real world	• Detection of CVs and AVs without V2I communication: A real conventional vehicle is driving on a dedicated lane. The traffic environment of the real vehicle is represented via simulation. The TMC decisions are done based on the real vehicle and the virtual traffic, which is a mixture of automated and conventional vehicles. The real conventional vehicle will be detected by infrastructure (e.g. no extended CAM received by ITS-G5 RSU). By physical infrastructure the vehicle (and its driver respectively) is requested to leave the dedicated lane. Automated vehicles that do not communicate with the infrastructure via V2I communication and so aren’t identified as vehicles with required and activated automated driving functions are handled as conventional vehicles and have to leave or not to use the dedicated lane. • User’s appreciation on how to be informed about the dedicated lane and

		the request of leaving it. • Information chain from detecting a conventional vehicle until leaving the dedicated lane.
Key assumptions		• Vehicles can be identified as conventional or automated. • Automated vehicles without V2I communication are handled as conventional vehicles. • AVs will use the dedicated lane because of benefits. • AVs can only enter the AV-lane when automated drive is active. • There are enough vehicles with High Definition maps
Realisation Prerequisites	**A. Physical infrastructure**	• Traffic Management Center (TMC) extended with INFRAMIX Management Center (IMC)[12] (refer to Figure 15) • RSUs for network connectivity coverage[13] • Sensors for real-time traffic information. • Road sensors for detecting vehicles on the dedicating lane. • Gantries or/and mobile VMS to provide information to conventional non-connected vehicles. • Infrastructure traffic signs: pictogram and pictogram code need to be defined for the dynamic lane assignment signage. • Traffic signs to signal the request of leaving the lane to the non-proper user. • Roadway with at least three lanes (incl. hard shoulder). • Vehicles equipped with OBU (ITS-G5) or cellular communication device.
	B. Digital infrastructure	• Communication technologies: o Cellular network (communication to centralized backend servers) o ITS-G5 (5.9 GHz Geobroadcast communication) o IP Connectivity • Wireless messages: o IVIM (including new DLA sign codes, Speed limits per lane after lane assignment to automated traffic, dedicated lane activation / deactivation, “increase distance gap”, “lane change required”). o CAM (Continuous broadcast of Vehicle, Speed, heading, Position in real time, awareness message about existence of other vehicles (optional), level of automation). o DENM (Basic Hazardous location warnings, Basic safety warnings e.g. braking (optional), “Non-proper user in the dedicated lane” (needs to be defined)).
	C. Data availability	• Traffic data from real traffic conditions (to use in simulation): o Position, speed and lane change behaviour of all vehicles in the situation. o Traffic flow, occupancy and speed per lane. o Digital road (HD maps) including all lanes and infrastructure elements. • Real-time traffic data (measurements or estimates): o Traffic flow, occupancy and speed per lane measurements. o Level of automation of vehicles per lane (automated or conventional). o Aggregated traffic information from connected vehicles and/ or from cellular backend servers of vehicle services (real-time eXtended Floating Car Data (XFCD)). o Digital road (HD maps) including all lanes and infrastructure elements.

[12] In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX. Management Center (IMC).
[13] Connected to TMC and to OBUs

	D. Simulators capability	• Realistic, lane-specific traffic flow behaviour. • Naturalistic human driving behaviour for cruising and lane changing. • Automated driving functions dealing with adaptive cruise control, lane- keeping, lane changing, platoon forming, emergency braking. • V2X communication between all entities. • Road sensor models for traffic detection.
Challenges	**Technical**	• Modelling and parametrization of a realistic human lane change behaviour • Identification of AVs and non-AVs • Functionality of building platoons • Implementation of AV driving strategies • Integration of real infrastructure and vehicle into simulation
	Others e.g. operations, safety regulations	• Evaluation of the effect of traffic signs for non-proper user to leave the AV-lane • Strategy if a non-proper vehicle is not leaving the lane • Realistic description of the situation
Target/Evaluation metrics		• AVs on the dedicated lane are informed about a non-proper user in the front and will react in proper time to mitigate negative effects on traffic flow. • In case of an emergency situation the AVs react in proper time to avoid a collision. *Research questions to be replied* • How often an AV should communicate its level of automation to TMC? • How to identify a vehicle driving in the automated lane while it is not permitted to do it (e.g. through its current level of automation)? • What is the effect (safety, traffic flow) of a non-proper user driving on the AV-lane? What are the critical aspects (in matters of safety) when a non-proper user enters the AV-lane? KPIs/ metrics: • Compare the throughput when a non-proper user drives on a dedicated lane with the estimated throughput when all users comply with the TMC lane recommendations. • Communication latency between the moments when the non-proper user enters the lane until the vehicles that use the dedicated lane are informed about it.

Use case requirements

Requirement ID	Functional requirements	Comments
S1_DLA_UC3_CVDL_F_00	Requirements: S1_DLA_UC1_DPR_F_01, S1_DLA_UC1_DPR_F_02, S1_DLA_UC1_DPR_F_03, S1_DLA_UC1_DPR_F_04, S1_DLA_UC1_DPR_F_06, S1_DLA_UC1_DPR_F_07, S1_DLA_UC1_DPR_F_08, S1_DLA_UC1_DPR_F_09 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_12 are also applied in this use case.	
S1_DLA_UC3_CVDL_F_01	TMC should be able to identify the level of automation of the vehicles on the dedicated lane.	
S1_DLA_UC3_CVDL_F_02	TMC should provide advice to leave the dedicated lane to the non-proper user.	
S1_DLA_UC3_CVDL_F_03	TMC should be able to inform automated vehicles about the existence of a non-proper user in the dedicated lane.	
S1_DLA_UC3_CVDL_F_04	V2I communication should support the AVs to provide information through Dedicated Short Range Communication or Cellular, regarding the existence of a non-proper user on their surrounding environment while they use the dedicated lane.	

Requirement ID	Feasibility requirements	Comments
S1_DLA_UC3_CVDL_FE_00	Requirements: S1_DLA_UC1_DPR_FE_01, S1_DLA_UC1_DPR_FE_02, S1_DLA_UC1_DPR_FE_03, S1_DLA_UC1_DPR_FE_04, S1_DLA_UC1_DPR_FE_05, S1_DLA_UC1_DPR_FE_06, S1_DLA_UC1_DPR_FE_07, S1_DLA_UC1_DPR_FE_08 S1_DLA_UC1_DPR_FE_09, S1_DLA_UC1_DPR_FE_10 S1_DLA_UC1_DPR_FE_11 are also applied in this use case.	
S1_DLA_UC3_CVDL_FE_01	Wireless messages from TMC or cellular server to connected vehicles containing information regarding the existence of a non-proper user.	DEMN "Non-proper user in the dedicated lane" Specification of standard V2X-communication in WP3.
S1_DLA_UC3_CVDL_FE_02	Wireless messages from AVs to TMC or cellular server regarding the existence of a vehicle without	Specification of standard V2X-

	V2V communication on their surrounding environment	communication in WP3.
S1_DLA_UC3_CVDL_FE_03	Infrastructure should have traffic signs with proper pictogram to signal the non-proper user to leave the dedicated lane.	

Requirement ID	Non-functional requirements	Comments
S1_DLA_UC3_CVDL_NF_00	Requirements: S1_DLA_UC1_DPR_NF_01, S1_DLA_UC1_DPR_NF_02, S1_DLA_UC1_DPR_NF_03, S1_DLA_UC1_DPR_NF_04, S1_DLA_UC1_DPR_NF_05, S1_DLA_UC1_DPR_NF_06, S1_DLA_UC1_DPR_NF_07, S1_DLA_UC1_DPR_NF_09, S1_DLA_UC1_DPR_NF_10 S1_DLA_UC1_DPR_NF_11 S1_DLA_UC1_DPR_NF_12 S1_DLA_UC1_DPR_NF_13 are also applied in this use case.	
S1_DLA_UC3_CVDL_NF_01	TMC should be able to identify non-proper user on the dedicated lane real-time.	
S1_DLA_UC3_CVDL_NF_02	RSUs should be able to send out the DEMN message to connected vehicles via ITS-G5.	
S1_DLA_UC3_CVDL_NF_03	The V2I communication latency should permit the TMC to advise a conventional vehicle to leave the dedicated lane, before it would be possible to cause any disturbance in the dedicated lane flow.	
S1_DLA_UC3_CVDL_NF_04	TMC should be able to communicate specific ordered AV-settings, including “time-gap” to all AVs within specific sections.	“AV-settings”, refer to velocity and lane- change related settings that will be defined based on the control strategy in the next phases of the project.

4.1.4 Traffic Scenario conclusions and critical aspects

This section includes several conclusions and critical aspects in matters of safety and performance that were pointed out during the process of use cases definition and requirements capture for the dynamic lane assignment scenario.

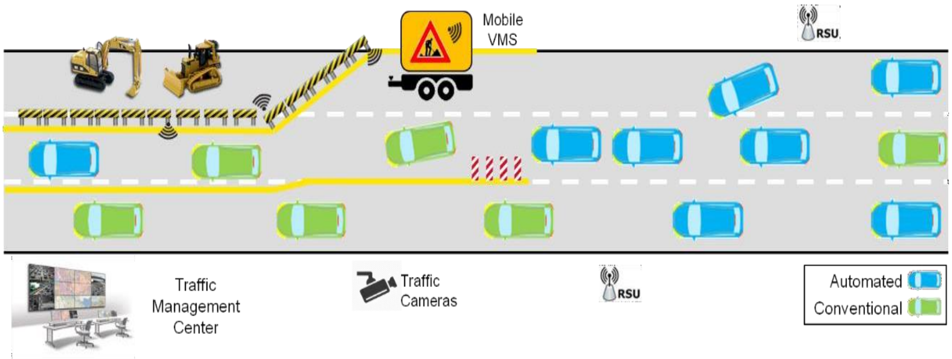
For the first scenario, a major aspect is the frequency of changes. Too often changes in the dynamic assignment of lanes might raise critical issues and increase the probability of an incident, especially when the speed limit is high. Key question: How hazardous is the dynamic lane assignment to mixed traffic condition (set quantitate measures)?

Moreover, the importance of the information about vehicle's level of automation was highlighted in this scenario. The "hybrid" infrastructure services which aim to improve mixed traffic efficiency and safety depend on the information about vehicles level of automation to achieve this aim. TMC should be aware regularly (as an initial assumption the frequency of 10 seconds was set) about the level of automation of the vehicles. This is because vehicles could change their level of automation anytime due to exceptional circumstances like AWC or simply preference. Consequently, the V2I communication is another aspect of vehicle distinction. The vehicles which don't communicate their level of automation to infrastructure are considered conventional (SAE level of automation 0, 1, 2) from the infrastructure perspective.

4.2 Scenario 2: Construction sites / Roadworks zones

Roadworks zones are major safety hotspots with many accidents both for vehicles and for the staff on site [13], [14], [2]. They pose interesting challenges for efficient coordination of mixed traffic flows, where the infrastructure should help the vehicles by providing extended information in real-time like updated maps, additional traffic signs, reference points on the spot for accurate localisation for automated vehicles, new traffic control measures etc. in the particular region. Both the physical and the digital infrastructure should be prepared to accommodate for such situations.
The target of this scenario is to guide in an efficient and safe way mixed traffic through roadworks zones by providing accurate information in these areas both to automated vehicles through electronic signals and up-to-date road information that can be used to update HDmaps on vehicles and to conventional vehicles through guidance to their nomadic devices, visual signs and other physical elements (e.g. cones).

Table 6 – Description of scenario 2, Roadwork zones

Name	Construction site / Roadworks zones
Short name	RWZ
ID	S2-RWZ
Overview	Roadworks zones are major safety hotspots with many accidents both for vehicles and for the staff on site. The infrastructure should help the vehicles by providing extended information in real-time like information that can be used to update HD maps on vehicles (e.g. including the temporary yellow lanes), additional traffic signs, reference points on the spot for accurate localization for automated vehicles, new traffic control measures etc. in the particular region.
Schematic	
Derived Use Cases	1) Roadworks zone in mixed traffic – Single Lane Closure 2) Roadworks zone in mixed traffic – New lanes
Objective	The target of this scenario is to guide in an efficient and safe way mixed traffic through roadworks zones by providing accurate information in these areas both to automated vehicles through electronic signals and up-to- date digital maps and to conventional vehicles through guidance to their nomadic devices, visual signs and other physical elements (e.g. cones). Innovative control strategies will be employed based on the amount of automated vehicles present and the prevailing traffic and weather conditions.
Expected impact	The study of this scenario, in simulation and in real conditions, will give us insights on how to manage in an efficient manner mixed traffic flows while roadworks take place. It will provide proper safety indicators, customised speed and lane recommendations for all vehicles and also visual and electronic ways for informing all vehicles and drivers involved.

4.2.1 Roadworks zone in mixed traffic – Single Lane Closure

This use case investigates the necessary V2X communication, visual signs as well as physical elements when a construction zone is placed in a road segment and evaluates the efficiency of that communication in the aspect of safety and user's appreciation. The key aspect is to ensure that all kinds of vehicles are timely and sufficiently informed about the roadworks zone to act accordingly. The effect of the lane closure on platooning will also be investigated through simulation.
The results of this use case could be easily extended to the exceptional situation when an obstacle e.g. a broken-down vehicle closes one of the lanes of the road segment. The differences in the physical and digital equipment as well as in the V2I communication are analysed.

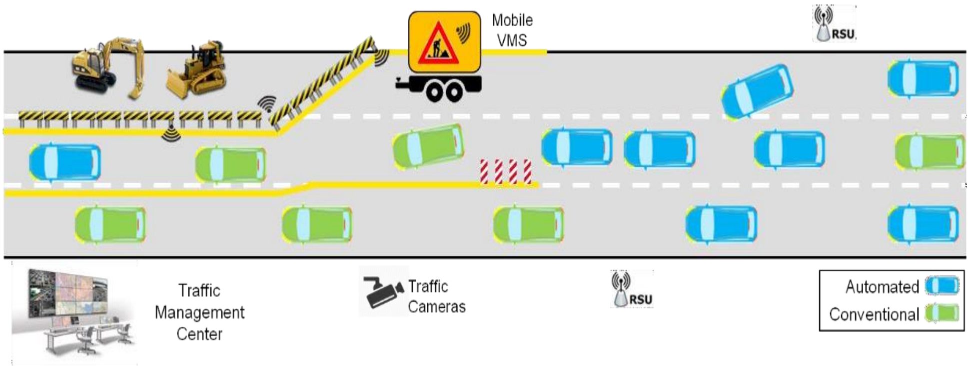


Figure 8 – Roadworks zone in mixed traffic – Single Lane Closure (e.g. short term constructions)

Table 7– Use case description: Roadworks zone in mixed traffic – Single Lane Closure (e.g. short term constructions) (S2-RWZ-UC1-SLC).

Name	Roadworks zone in mixed traffic – Single Lane Closure (e.g. short term constructions)
Short name	SLC
ID	S2-RWZ-UC1- SLC
Overview	In this use case the necessary infrastructure adaptations and upgrades are investigated in order to guide the mixed traffic through a construction zone (or optional around a broken-down vehicle) in a safe and traffic flow efficient way. Sequence of actions: ➢ In the context of a multi-lane roadway with mixed traffic and appropriate lane and speed restrictions o Subcase A) A new roadwork zone is established in a single lane. o Subcase B) a broken down vehicle is identified in a single lane. ➢ Appropriate signalling is setup, including V2X signals for connected vehicles, VMS and physical signals for non-connected vehicles. ➢ New speed and lane restrictions should be evaluated for the new road conditions. ➢ Dissolving AV-platoons.

	➢ Signalling should be sufficient to ensure safe operation and non-degradation of AV levels. ➢ Using aggregated information (e.g from TMC), vehicle services provide a specialized routing function that takes into account possible degradation of level of automation ➢ Signalling should be sufficient to ensure safety of conventional vehicles. ➢ Strategic lane guidance should be provided to connected vehicles to minimize traffic jams when possible.
Real world tested through this use case[14]	*Subcase A)* • The appropriate signalling of a roadworks of a mobile VMS (physical and digital infrastructure) can be tested. • The appropriate ITS-G5 communication along the road (lane and speed restrictions, appropriate messaging for dissolving an AV platoon) can be tested on test-site. • The communication towards cellular services could be validated in the test-site through particular interfaces • The HD-maps are updated by a dynamic overlay of road lane topology using the standardized MAPEM message. *Optional:* *Subcase B)* • The information chain from detecting a broken down/stopped vehicle to sending the information message of an obstacle can optionally be tested. • The appropriate V2X communication along the road (lane and speed restrictions, appropriate messaging for dissolving an AV platoon) can be tested on test-site. • The communication towards cellular services could be validated in the test-site through particular interfaces • The HD-maps are updated by a dynamic overlay of road lane topology using the standardized MAPEM message.
Key assumptions	• The construction zone or the broken-down vehicle zone is not wider than one lane (there is no need for lane width adaptation and new lane markings). • The use case is limited on a road segment without entrance or exit. • An alternative route is possible if non-degradation of AV service level cannot be guaranteed. • AVs can be simulated by appropriately instructing drivers and assuming connected vehicles behave like AVs, therefore enabling this use case to be tested in real highways even if no AV capability is present. • There are enough vehicles with High Definition maps

[14] If roadworks don't take place at the time of real tests, it can be simulated via lane reduction in a part of the test-site.

Realisation Prerequisites	• **Physical infrastructure**	• Traffic Management Center (TMC) extended with INFRAMIX Management Center (IMC)[15] (refer to Figure 15) • RSUs for network connectivity coverage[16]. • Sensors for real-time traffic information. • Gantries or/and mobile VMS to provide information to conventional non-connected vehicles regarding the RWZ. • Vehicles equipped with OBU (ITS-G5) or cellular communication device. • A radar sensor is required for identification of a stopped/broken down vehicle (incident management by a radar sensor. • Infrastructure equipment to fence the construction zone.

	• **Digital infrastructure**	• Communication technologies:
		  ○ Cellular network (communication to centralized backend servers)
		  ○ ITS-G5 (5.9 GHz Geobroadcast communication)
		  ○ IP Connectivity
		• Wireless messages:
		  ○ IVIM (including single lane closure, lane guidance (need to be defined), Speed limits per lane)
		  ○ CAM (Continuous broadcast of Vehicle, Speed, heading, Position in real time, awareness message about existence of other vehicles (optional), level of automation (has to be added to the data element "vehicle role" ETSI standards))
		  ○ DENM (road-works warnings), Basic safety warnings (e.g. braking)
		  ○ MAPEM[17] road lane topology messages used for dynamic overlay of road lane topology to the HD-maps.

	• **Data availability**	Real road data: • Position of the beginning of the roadwork zone/or the broken vehicle • Driving direction and position of closed lane • Width of the roadworks • Position of the VMS
	• **Simulators capability**	Capability of: • Identification of vehicle level of automation and connection to TMC capability • Strategic lane/speed guidance • Strategic time gap recommendations • Strategic distance and time gap recommendations for dissolving a platoon
Challenges	**Technical**	• Identification of connected vehicles with respect to their actual AV-level. • On-time information for connected and non-connected vehicles with respect to safety, efficiency, traffic jam avoidance. • Strategic lane guidance (trucks, automated trucks, for automated vehicles, conventional connected and non- connected vehicles). • Dissolving AV-platoons.
	Others e.g.	New protocol for roadworks at mixed traffic roads should be

[15] In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX Management Center (IMC).

[16] Connected to TMC and to OBUs.

[17] MAP (topology) Extended Message [22]

	operations, safety regulations	established.
Target/Evaluation metrics		• End-user response / compliance rate to guidance instructions • Roadway capacity degradation • AV level degradation

Use case requirements

Requirement ID	Functional requirements	Comments
S2_RWZ_UC1_SLC_F_00	Requirements S1_DLA_UC1_DPR_F_02 S1_DLA_UC1_DPR_F_07 S1_DLA_UC1_DPR_F_08 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_12 are also applied in this use case.	
S2_RWZ_UC1_SLC_F_01	TMC should provide beforehand the information about the lane closure and the road layout to cellular backend server due to roadworks.	The exact time will be defined in the next phases of the project
S2_RWZ_UC1_SLC_F_02	Vehicle services should provide static HD maps to vehicles that contain the information about the lane closure and the road layout.	
S2_RWZ_UC1_SLC_F_03	TMC should provide the information about the lane closure to automated vehicles with ITS-G5 OBU.	
S2_RWZ_UC1_SLC_F_04	Vehicle services should provide HD maps to automated vehicles with cellular communication device which contain the information about the lane closure.	
S2_RWZ_UC1_SLC_F_05	TMC should provide to the automated vehicles the distance and/or time-gap change recommendations in order to dissolve a platoon.	
S2_RWZ_UC1_SLC_F_06	TMC should provide lane guidance via VMS and traffic signs to non-connected vehicles.	
S2_RWZ_UC1_SLC_F_07	TMC/mobile VMS should inform physically the road users about changing the current speed limit.	
S2_RWZ_UC1_SLC_F_08	Control strategies should decide dynamically about lane guidance of connected vehicles based on real– time traffic flow information.	
S2_RWZ_UC1_SLC_F_09	Optional Subcase B: identification of a broken-down vehicle on the motorway via radar technology.	Optional for stopped vehicle detection.
S2_RWZ_UC1_SLC_F_10	Optional Subcase B: identification of a broken-down vehicle on the motorway via V2I communication.	Optional for stopped vehicle detection.

Requirement ID	Feasibility requirements	Comments
S2_RWZ_UC1_SLC_FE_00	Requirements: S1_DLA_UC1_DPR_FE_02 S1_DLA_UC1_DPR_FE_03 S1_DLA_UC1_DPR_FE_04 S1_DLA_UC1_DPR_FE_05 S1_DLA_UC1_DPR_FE_06 S1_DLA_UC1_DPR_FE_07 S1_DLA_UC1_DPR_FE_09 S1_DLA_UC1_DPR_FE_10 S1_DLA_UC1_DPR_FE_11 are also applied in this use case.	
S2_RWZ_UC1_SLC_FE_01	Infrastructure should be equipped with mobile VMS that ensure the functional requirements: S1_DLA_UC1_DPR_F_10 S2_RWZ_UC1_SLC_F_06 S2_RWZ_UC1_SLC_F_07	
S2_RWZ_UC1_SLC_FE_02	Infrastructure should have installed roadworks equipment to fence the construction zone.	
S2_RWZ_UC1_SLC_FE_03	Wireless messages (IVIM) from TMC to connected vehicles including lane closure information, and lane guidance (need to be defined).	IVIM (need to be defined) Specification of standard V2X-communication in WP3.
S2_RWZ_UC1_SLC_FE_04	Wireless messages (DEMN) from TMC to connected vehicles containing road-works warnings.	
S2_RWZ_UC1_SLC_FE_05	Optional: Radar sensors for identification of broken- down vehicles.	Optional: for stopped vehicle detection.

Requirement ID	Non-functional requirements	Comments
S2_RWZ_UC1_SLC_NF_00	Requirements: S1_DLA_UC1_DPR_NF_01 S1_DLA_UC1_DPR_NF_02 S1_DLA_UC1_DPR_NF_03 S1_DLA_UC1_DPR_NF_06 S1_DLA_UC1_DPR_NF_10 S1_DLA_UC1_DPR_NF_11 S1_DLA_UC1_DPR_NF_12 S1_DLA_UC1_DPR_NF_13 are also applied in this use case.	
S2_RWZ_UC1_SLC_NF_01	V2I communication should permit real time data exchange.	
S2_RWZ_UC1_SLC_NF_02	V2I (air interface) communication latency should permit the lane guidance of an automated vehicle.	The exact seconds will be defined in the next phases of the project.

4.2.2 Roadworks zone in mixed traffic – New Lane Design

This use case investigates the necessary V2X communication, visual signs as well as physical elements when a roadwork zone covers more than one lane in a road segment and evaluates the efficiency of that communication in the aspect of safety and user's appreciation. The key aspect is to ensure that all kind of vehicles are timely and sufficiently informed about the roadworks zone to act accordingly.
The effect of different lane marking colours and the presence of multiple lane markings is one of the under-investigation aspects.

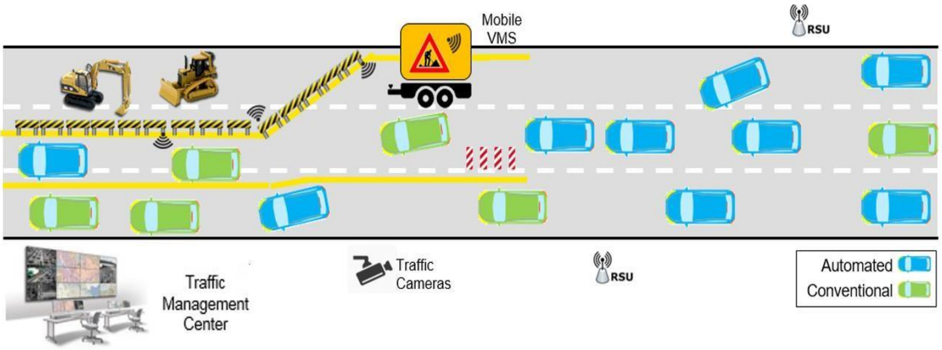


Figure 9 – Roadworks zone in mixed traffic – New lane design (e.g. long term constructions)

Table 8 – Description of the use case: Roadworks zone in mixed traffic – New lane design (e.g. long term constructions)

Name	Roadworks zone in mixed traffic – New lane design
Short name	NLD
ID	S2-RWZ-UC2-NLD
Overview	This use case investigates V2X communication, visual signs as well as physical elements in order to reassure a smooth and efficient traffic flow when roadwork zone covers more than one lane in a road segment. It is focused on the required visual signs that depict the new lane marking, the possible electronic horizon applications that help an automated vehicle to accurately follow the new lane markings and the establishment of the required interface. Sequence of actions ➢ Investigate the proper visual signs that determine the new lane route and width which would be visible to both automated and conventional vehicles. • Physical signs e.g. yellow lanes, mobile VMS that indicates the new lane arrangement. • AV can access real time information on roadworks and lane closures (e.g. via certain interfaces of an electronic horizon component) (through cellular network). • AV receives real time information on roadworks and lane closures from TMC (via ITS-G5 network). ➢ All vehicles are informed about the construction zone and the new road lane topology. Investigate the proper info sent from

		TMC to vehicles for their HMI. ➢ Extended information is provided to automated vehicles based on the updated traffic estimation and control (updated geometry, recommendations of changing lane or route if possible, speed recommendations provided etc.). ➢ The end-users response is noted. ➢ An automated vehicle passing by the construction zone. The accuracy in following the new lanes and speed recommendations are evaluated. ➢ One automated and one conventional vehicle passing by the construction zone, using different lanes, simultaneously. Their interaction is assessed. Are there any incidents?
Real world tested through this use case		(optional) Real test: The automated vehicle reaction and the user's appreciation on novel lane marking could be tested. (optional) Real test subcase[18]: V2X communication functionalities will be demonstrated and compared in the two situations: 1. Emulated automated vehicle passing through a construction zone with updated HD maps. 2. Emulated automated vehicle passing through a construction zone with HD maps which are not updated.
Key assumptions		An alternative route is possible if non-degradation of AV service level can't be guaranteed.
Realisation Prerequisites	• **Physical infrastructure**	• Traffic Management Center (TMC) extended with INFRAMIX Management Center (IMC)[19] (refer to Figure 15 – INFRAMIX high-level architecture). • RSUs for network connectivity coverage[20]. • Sensors for real-time traffic information. • Gantries or/and mobile VMS to provide information to conventional non-connected vehicles regarding the RWZ. • Vehicles equipped with OBU (ITS-G5). • Vehicles equipped with cellular communication device. • Infrastructure equipment to fence the construction zone.
	• **Digital infrastructure**	• Wireless messages: ○ IVIM (including single lane closure, lane guidance (need to be defined), Speed limits per lane) ○ CAM (Continuous broadcast of Vehicle, Speed, heading, Position in real time, awareness message about existence of other vehicles (optional), level of automation (has to be added to the data element “vehicle role” ETSI standards)) ○ DENM (road-works warnings), Basic safety warnings (e.g. braking) ○ MAPEM[21] (new road topology layout based on the roadworks ETSI Standard) • Communication technologies:

[18] In case of a current real roadworks installation, testing of perception of the new lane markings of the AVs and non-AVs via visual lane markings, HD map update and V2X communication for lane and speed restrictions via ITS-G5 (barrier: old and new lane markings).
[19] In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX Management Center (IMC).
[20] Connected to TMC and to OBUs.
[21] MAP (topology) Extended Message [22].

		○ Cellular network (communication to centralized backend servers ○ ITS-G5 (5.9 GHz Geobroadcast communication) ○ IP connectivity • static HD maps combined with real time information roadway layout (MAPEM)
	• Data availability	• Real-time information regarding the AV level of the AVs passing through the roadworks • Real road data: ○ Position of the beginning of roadwork zone ○ Driving direction and position of the closed lanes ○ Width of the roadworks ○ Position of the VMS
	• Simulators capability	Capability of: ○ Identification of the vehicle's level of automation and if it is connected or not with the TMC ○ Strategic lane/speed guidance
Challenges	**Technical**	• Identification of connected vehicles with respect to their actual level of automation. • On-time information for connected and non-connected vehicles with respect to safety, efficiency, traffic jam avoidance. • Strategic lane guidance (trucks, automated trucks, for automated vehicles, conventional connected and non-connected vehicles).
	Others e.g. operations, safety regulations	• Safety critical aspects/ regulations related to the correct timing of the information given to automated and to conventional vehicles.
Target/Evaluation metrics		• End-user response / compliance rate to guidance instructions • Roadway capacity degradation • AV level degradation • Traffic flow

Use case requirements

Requirement ID	Functional requirements	Comments
S2_RWZ_UC2_NLD_F_00	Requirements S1_DLA_UC1_DPR_F_02 S1_DLA_UC1_DPR_F_07 S1_DLA_UC1_DPR_F_08 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_12 S2_RWZ_UC1_SLC_F_01 S2_RWZ_UC1_SLC_F_02 S2_RWZ_UC1_SLC_F_04 S2_RWZ_UC1_SLC_F_05 S2_RWZ_UC1_SLC_F_06 S2_RWZ_UC1_SLC_F_07 S2_RWZ_UC1_SLC_F_08 are also applied in this use case.	
S2_RWZ_UC2_NLD_F_01	TMC should inform all road users for the new lane marking.	
S2_RWZ_UC2_NLD_F_02	Infrastructure should support the automated vehicles to pass through the construction zone without degradation of the level of automation.	
S2_RWZ_UC2_NLD_F_03	Real time road topology overlay update should contain information about new lane layout.	Real time road topology overlay update contains information about new lane layout (trajectory, width, merging, diverging waypoints, etc.)

Requirement ID	Feasibility requirements	Comments
S2_RWZ_UC2_NLD_FE_00	Requirements: S1_DLA_UC1_DPR_FE_02 S1_DLA_UC1_DPR_FE_03 S1_DLA_UC1_DPR_FE_04 S1_DLA_UC1_DPR_FE_05 S1_DLA_UC1_DPR_FE_06 S1_DLA_UC1_DPR_FE_07 S1_DLA_UC1_DPR_FE_09 S1_DLA_UC1_DPR_FE_10 S1_DLA_UC1_DPR_FE_11 S2_RWZ_UC1_SLC_FE_01 S2_RWZ_UC1_SLC_FE_02 S2_RWZ_UC1_SLC_FE_03 S2_RWZ_UC1_SLC_FE_04 are also applied in this use case.	
S2_RWZ_UC2_NLD_FE_01	Different coloured lane markings (white colour old markings, yellow colour new roadworks markings).	Can only be tested if real roadworks is planned during the period of

		testing.
S2_RWZ_UC2_NLD_FE_02	Long-term roadworks installation.	
S2_RWZ_UC1_NLD_FE_03	Wireless messages (MAPEM) from TMC to cellular backend server containing information about new lane layout (trajectory, width merging, diverging waypoints, etc.).	

Requirement ID	Non-functional requirements	Comments
S2_RWZ_UC2_NLD_NF_00	Requirements: S1_DLA_UC1_DPR_NF_01 S1_DLA_UC1_DPR_NF_02 S1_DLA_UC1_DPR_NF_03 S1_DLA_UC1_DPR_NF_06 S1_DLA_UC1_DPR_NF_10 S1_DLA_UC1_DPR_NF_11 S1_DLA_UC1_DPR_NF_12 S1_DLA_UC1_DPR_NF_13 S2_RWZ_UC1_SLC_NF_01 S2_RWZ_UC1_SLC_NF_02 are also applied in this use case	

4.2.3 Traffic Scenario conclusions and critical aspects

This section includes conclusions and critical aspects in matters of safety and performance mentioned during the process of use cases definition and requirements capture for the roadworks scenario.

In the scenario of roadworks, the main concern is the minimization of the possibility of an incident or accident. How should V2X communication be adapted/upgraded to avoid that?

For the case of new digital road lane topology, connected vehicles will receive detailed road lane topology which may be used as overlay to existing HD-maps. For the case of new physical lane markings, it should be reassured that these are visible by all kinds of vehicles simultaneously. The followings should be considered:

- New lane markings are visible to conventional vehicles (drivers) but not detected from automated vehicles (or detected too late).
- Vice versa, the automated vehicles detect the new lane markings, but conventional vehicles can't see them (maybe are not connected and new lane marking are only digital visual signs).

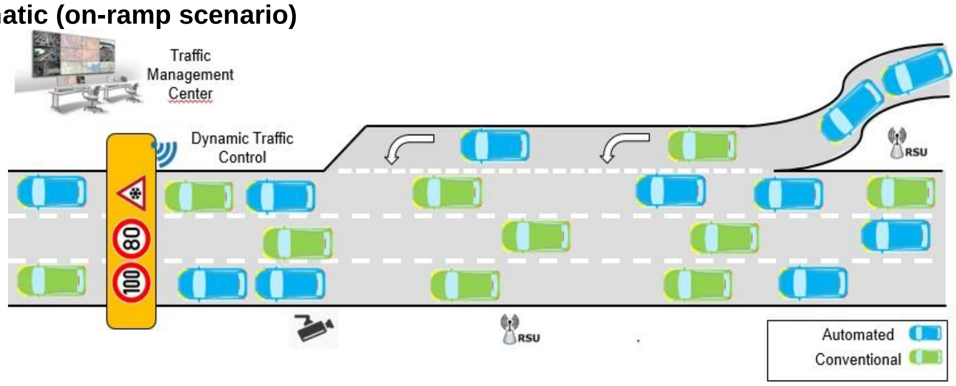
How does the communication efficiency for informing the vehicles about roadworks affect the traffic control strategy? Based on the conclusions from scenario 3, the traffic control strategy could be investigated also for the construction zones taking into account the time when the existence of the construction zone and the new lane arrangement are communicated to all vehicles. This is different from bottlenecks of scenario 3, as in the situation of construction zone, vehicles are informed later than in a permanent bottleneck, so traffic management should consider that delay.

Based on conclusions from the use case regarding the lane dedication to automated driving (S1-DLA-UC1-DPR), the aspect of having a construction zone in a lane that is permanently assigned to automated driving will be assessed.

4.3 Scenario 3: Bottlenecks

Analysis of several use cases regarding different types of bottlenecks, with different penetration rates of automated vehicles, takes place in this scenario, with the scope to investigate innovative real-time controllers. Control strategies, such as the exploitation of the automated vehicles capabilities by suggesting (real-time) an appropriate value for the time-gap parameter and for vehicle acceleration behaviour [15], the distribution of the vehicles across lanes so as to match a pre-specified opportune lane distribution scheme depending on traffic, as well as the Mainstream Traffic Flow Control (MTFC) [16], [17], are investigated, aiming to improve traffic efficiency and safety (e.g. avoid deadlocks) in such cases. Solutions for in-vehicle and on-road signage are examined in order to provide proper guidance both for automated and for conventional vehicles.

Table 9 – Description of scenario 3, Bottlenecks

<table>
<tr><td>Name</td><td>Bottlenecks</td></tr>
<tr><td>Short name</td><td>BTN</td></tr>
<tr><td>ID</td><td>S3-BTN</td></tr>
<tr><td>Overview</td><td>The scope of this scenario is to investigate real-time controllers, involving a variety of control measures, such as dynamic speed limits, dynamic lane assignment, merge assistance and ramp metering to manage mixed traffic situations at bottlenecks and avoid traffic flow degradation; examine solutions for in-vehicle and on-road signage.</td></tr>
<tr><td colspan="2">Schematic (on-ramp scenario)


</td></tr>
<tr><td>Derived Use Cases</td><td>1) Automated vehicles (AV) Driving Behaviour Adaptation in Real Time at Sags (The use case is proposed for sags, but it could be applied to other bottleneck types as well.)
2) Lane-Change Advice to connected vehicles at Bottlenecks
3) Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles</td></tr>
<tr><td>Objective</td><td>Innovative control measures to improve traffic efficiency and safety (e.g. avoid deadlocks) in such cases will be developed.</td></tr>
<tr><td>Expected impact</td><td>Proper guidance through the electronic horizon for automated vehicles and the nomadic devices for the conventional ones, as well as visual and electronic signals will be developed for the particular bottleneck areas.</td></tr>
</table>

4.3.1 Automated vehicles (AV) Driving Behaviour Adaptation in Real Time at Sags

This use case investigates a traffic management concept to exploit automated driving capabilities towards increased traffic flow efficiency by changing the AV longitudinal driving behaviour according to the traffic management requirements, i.e. when a traffic breakdown is imminent or has already occurred. More specifically, the control strategy receives real-time measurements (or estimates) of the current traffic conditions and suggests to the automated vehicle drivers (or imposes directly) an appropriate value for the time-gap parameter and possibly also a proper vehicle acceleration behaviour. The time-gap suggestion could be also provided to the connected conventional vehicles equipped with ACC (level of automation 2). It is assumed that traffic is mixed, without having assigned any lane to AVs.

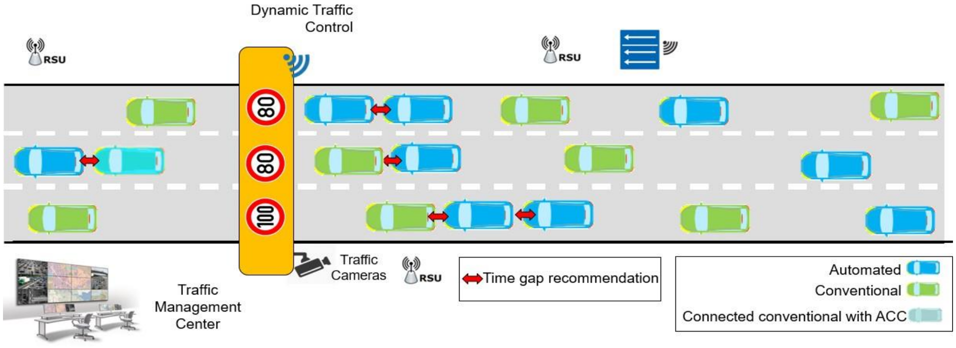


Figure 10 – Automated vehicle driving behaviour adaptation in real time at sags Table 10 – Use case description S3-BTN-UC1-DBAS

Name	Automated vehicles (AV) Driving Behaviour Adaptation in Real Time at Sags
Short name	DBAS
ID	S3-BTN-UC1-DBAS
Overview	The longitudinal driving behaviour of automated vehicles is changed according to the traffic management requirements. Sequence of actions: ➢ AV time-gaps are gradually reduced as traffic flow approaches capacity; a minimum time gap is employed before capacity is reached. ➢ A minimum time-gap is employed at the head of and downstream of a congested area. ➢ Increased acceleration capabilities are employed at the head of and downstream of a congested area. ➢ AVs apply the ordered settings only if they are “stricter” than their current settings.
Parts of the use case that will be tested in real world	• The main idea is that highway capacity may be increased if AVs are asked, when needed, to reduce their time-gap to the respective front vehicles. AVs may be ACC-vehicles, which are already on the streets, but full-scale testing in real-world conditions may be difficult. As a minimum, testing some aspects of the procedure is possible, including passenger feeling with reduced time-gaps, using a small fleet of (3-4) ACC-vehicles.

<table>
<tr><td colspan="2">Key assumptions</td><td>Mixed traffic conditions.
Only the connected vehicles with ACC can receive requests from TMC to adapt their driving behaviour.
The AVs comply automatically with the TMC advice.</td></tr>
<tr><td rowspan="4">Realisation Prerequisites</td><td>A. Physical infrastructure</td><td>Traffic Management Center (TMC)
RSUs for network connectivity coverage
Sensors for real traffic information.
Vehicles equipped with OBU (ITS-G5) or cellular communication device.
INFRAMIX Management Center (IMC) (Figure 7 “Real implementation high-level architecture”, Chapter 5)
Gantries or/and mobile VMS to provide information to conventional non- connected vehicles</td></tr>
<tr><td>B. Digital infrastructure</td><td>Communication technologies:
Cellular network (web based communication to data-server)
ITS-G5 (5.9 GHz Geobroadcast communication)
IP Connectivity
Wireless messages:
IVIM (recommended time-gap to be applied by the AVs)
CAM (continuous broadcast of vehicle, speed, heading, position in real time, awareness message about existence of other vehicles)
DENM (traffic condition, basic hazardous location warnings, basic safety warnings e.g. braking)</td></tr>
<tr><td>C. Data availability</td><td>Flow and speed measurements in real time (e.g. every 30-60 s).</td></tr>
<tr><td>D. Simulators capability</td><td>Realistic driving behaviour of automated vehicles (acceleration, deceleration, lane changes).
Naturalistic human driving style for the conventional vehicles (acceleration, deceleration, lane changes).
Communication links for messages between all entities (TMC, RSUs, vehicle services web servers, vehicles).
Sensor-models for road-sensors.
Automated driving functions with cruise control.</td></tr>
<tr><td rowspan="2">Challenges</td><td>Technical</td><td>Modelling of realistic driving behaviour of conventional and automated vehicles.
Imposing ordered time-gaps and acceleration to AVs.</td></tr>
<tr><td>Others e.g. operations, safety regulations</td><td>Passenger convenience in AVs vis-à-vis the external changes.
Safety implications for conventional vehicles.</td></tr>
<tr><td colspan="2">Target/Evaluation metrics</td><td>Delay or avoid altogether congestion creation (via capacity increase).
Reduce space-time extent of formed congestion (via increase of the discharge flow at the congestion head).
KPIs/ metrics: Measure the throughput under different penetration rates of AVs and compare it to the baseline (conventional traffic).</td></tr>
</table>

Use case requirements

Requirement ID	Functional requirements	Comments
S3_BTN_UC1_DBAS_F_00	Requirements: S1_DLA_UC1_DPR_F_07 S1_DLA_UC1_DPR_F_08 S1_DLA_UC1_DPR_F_10 are also applied in this use case.	
S3_BTN_UC1_DBAS_F_01	The control strategy should decide dynamically the time-gap to be applied by AVs per section based on real-time traffic flow information.	
S3_BTN_UC1_DBAS_F_02	TMC should be able to communicate with the AVs through wireless messages real-time.	

Requirement ID	Feasibility requirements	Comments
S3_BTN_UC1_DBAS_FE_00	Requirements: S1_DLA_UC1_DPR_FE_03, S1_DLA_UC1_DPR_FE_04, S1_DLA_UC1_DPR_FE_05, S1_DLA_UC1_DPR_FE_06, S1_DLA_UC1_DPR_FE_07, S1_DLA_UC1_DPR_FE_09, S1_DLA_UC1_DPR_FE_11 are also applied in this use case.	
S3_BTN_UC1_DBAS_FE_01	The number of sensors for real traffic information should be adequate for ensuring requirement S3_BTN_UC1_DBAS_NF_01.	
S3_BTN_UC1_DBAS_FE_02	Wireless messages from TMC to connected AVs should contain information for the time-gap parameter.	IVIM: Parameters for minimum time gaps and acceleration for connected vehicles (needs to be defined).
S1_DLA_UC1_DBAS_FE_03	The number of gantries or/and mobile VMS should be adequate for ensuring the functional requirement: S1_DLA_UC1_DBAS_F_03	The specific kilometric distance of the gantries will be determined during the next phases of the project.

Requirement ID	Non-functional requirements	Comments
S3_BTN_UC1_DBAS_NF_00	Requirements: S1_DLA_UC1_DPR_NF_01 S1_DLA_UC3_CVDL_NF_05 are also applied in this use case.	
S3_BTN_UC1_DBAS_NF_01	Control strategies should assure that the throughput should always be at least at the same level as in the case of today's traffic consisted of only conventional vehicles.	Assuming a sufficient number of compliant road users.
S3_BTN_UC1_DBAS_NF_02	TMC should be able to communicate specific ordered time-gaps to all AVs within specific sections.	IVIM: Parameters for minimum time gaps and acceleration for connected vehicles (needs to be defined).
S3_BTN_UC1_DBAS_NF_03	AVs should be able to communicate their position and speed to TMC.	ITS-G5 through CAM message

4.3.2 Lane-Change Advice to connected vehicles at Bottlenecks

In this use case, a control strategy is fed with real-time lane-specific information about the prevailing traffic conditions and decides on the necessary lane-changing activities to achieve a pre-specified (possibly traffic-dependent) lane distribution of vehicles while approaching a bottleneck, aiming at increasing the bottleneck capacity.

The control strategy is based on the following principles:

- It is a feedback strategy, which reduces its sensitivity with respect to various unknown factors, such as penetration rate of connected vehicles, driver compliance and more.
- It attempts to distribute vehicles across lanes so as to match a pre-specified opportune lane distribution scheme, which may be traffic-dependent, i.e. different desired distributions could be pursued for different traffic conditions.
- It first produces appropriate lane-change flows, which are then disintegrated into individual messages to connected vehicles.

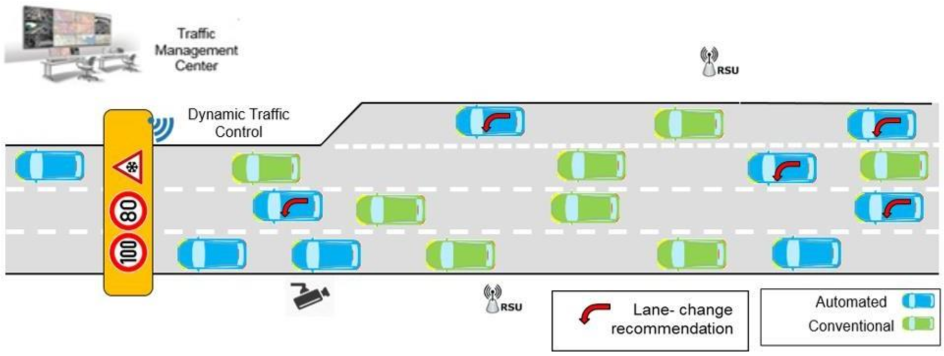


Figure 11 – Lane-change advice to connected vehicles at bottlenecks Table 11 – Use case description S3-BTN-UC2-LCA

Name	Lane-Change Advice to connected vehicles at Bottlenecks
Short name	LCA
ID	S3-BTN-UC1-LCA
Overview	The real-time control strategy for lane-change advice to connected vehicles is based on the prevailing traffic conditions in each lane, which are reflected in appropriate traffic data (measurements or estimates) to be specified.
Parts of the use case that will be tested in real world	• As a minimum, the technical feasibility of the use case could be tested in real conditions (connected vehicles that receive lane-change (or keep-lane) advice do not need to be AVs).
Key assumptions	• Mixed traffic conditions. • All vehicles which communicate with TMC receive suggestions for lane changing or keep lane.

Realisation Prerequisites	**A. Physical infrastructure**	• Traffic Management Center (TMC)[22] • RSUs for network connectivity coverage[23] • Sensors for real traffic information. • Vehicles equipped with OBU (ITS-G5) or cellular communication device.

	B. Digital infrastructure	• Communication technologies:
		  ○ Cellular network (web based communication to data-server)
		  ○ ITS-G5 (5.9 GHz Geobroadcast communication)
		  ○ IP Connectivity
		
		• Wireless messages:
		  ○ IVIM (lane change guidance)
		  ○ CAM (continuous broadcast of vehicle, speed, heading, position in real time, awareness message about existence of other vehicles)
		  ○ DENM (traffic condition, basic hazardous location warnings, basic safety warnings e.g. braking)

	C. Data availability	• Flow and occupancy per lane measurements in real time (e.g. every 30-60s).
	D. Simulators capability	• Realistic driving behaviour of automated vehicles (acceleration, deceleration, lane changes). • Naturalistic human driving style for the conventional vehicles (acceleration, deceleration, lane changes). • Communication links for messages between all entities (TMC, RSUs, vehicle services web servers, vehicles). • Sensor-models for road-sensors. • Apply the lane-changing (and keep-lane) advice with various compliance rates.
Challenges	**Technical**	• Disintegrate lane-change flows into individual messages to connected vehicles.
	Others e.g. operations, safety regulations	• Driver compliance and passenger convenience while executing lane-change advice. • Possible safety implications due to lane changes.
Target/Evaluation metrics		• Driver compliance and passenger convenience while executing lane-change advice. • Possible safety implications due to lane changes. KPIs/metrics: Measure the throughput under different penetration rates of connected vehicles and compare it to the baseline (conventional traffic).

[22] Connected to IMC
[23] Connected to IMC and to OBUs

Use case requirements

Requirement ID	Functional requirements	Comments
S3_BTN_UC1_LCA_F_00	Requirements S1_DLA_UC1_DPR_F_02 S1_DLA_UC1_DPR_F_07 S1_DLA_UC1_DPR_F_08 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_12 are also applied in this use case.	
S3_BTN_UC1_LCA_F_01	The control strategy should decide dynamically the lane-change flows to be applied by the connected vehicles per lane based on real-time traffic flow information.	

Requirement ID	Feasibility requirements	Comments
S3_BTN_UC1_LCA_FE_00	Requirements S1_DLA_UC1_DPR_FE_02 S1_DLA_UC1_DPR_FE_04 S1_DLA_UC1_DPR_FE_05 S1_DLA_UC1_DPR_FE_06 S1_DLA_UC1_DPR_FE_07 S1_DLA_UC1_DPR_FE_09 S1_DLA_UC1_DPR_FE_10 S1_DLA_UC1_DPR_FE_11 are also applied in this use case.	
S3_BTN_UC1_LCA_FE_01	Wireless messages from TMC to connected vehicles containing the lane change advice, ensuring S3_BTN_UC1_LCA_NF_02	IVIM: containing lane guidance for automated vehicles and conventional connected ones should be defined.

Requirement ID	Non-functional requirements	Comments
S3_BTN_UC1_LCA_NF_00	Requirements S1_DLA_UC1_DPR_NF_01 S1_DLA_UC1_DPR_NF_02 S1_DLA_UC1_DPR_NF_03 S1_DLA_UC1_DPR_NF_04 S1_DLA_UC1_DPR_NF_05 are also applied in this use case.	
S3_BTN_UC1_LCA_NF_01	TMC should be able to communicate specific lane change advice to connected vehicles within specific sections.	"specific" lane change advice will be defined based on the control strategy in the next phases of the project.
S3_BTN_UC1_LCA_NF_02	Control strategies should assure that the throughput should always be at least at the same level as in the case of today's traffic consisted of only conventional vehicles.	Assuming a sufficient number of compliant road users.

4.3.3 Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles

In general, the bottleneck scenario addresses road situations with a static capacity downstream, where due to high traffic the road is not capable to guarantee a smooth flow. The situation could be improved by controlling the upstream flow. This use case adds the possibility of flow control for on-ramps. The control strategies could have different stages of influence on the vehicles:

A. Macroscopic: Informing all vehicles with general information in the same way

B. Microscopic: Identifying and giving specific advice for individual vehicles (which only works for connected vehicles)

In this use case, the following control strategies as well as their combination are investigated:

I. Mainstream Traffic Flow Control (MTFC): Control the traffic flow on the existing lanes. A realisation could inform all vehicles via VMS on the usual gantries. Additionally, or even in absence of such gantries, communicate the common speed limit for all participants to connected vehicles (thus, impose the whole of traffic if the percentage of connected vehicles is sufficiently high and of course if connected conventional vehicles also follow the speed advice).

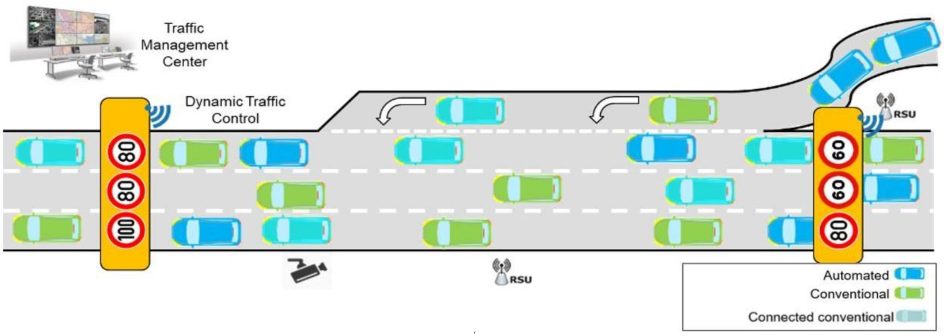


Figure 12 – Mainstream Traffic Flow Control (MTFC)

II. Individual Control: A more sophisticated approach could apply the control strategies with individually calculated lane change advice and speed limits. This approach is only possible for controlling communicating conventional connected vehicles or AVs.

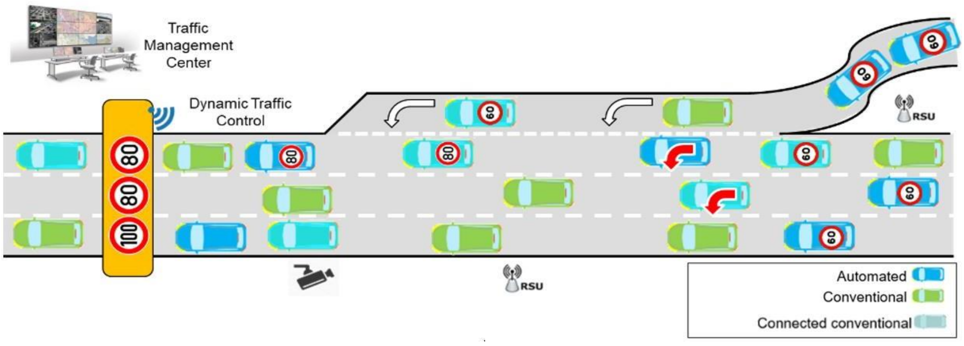


Figure 13 – Individual control

Table 12 Use case description S3-BTN-U3-LCAFC

<table>
<tr><td colspan="2"></td><td>Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles.</td></tr>
<tr><td colspan="2">Short name</td><td>LCAFC</td></tr>
<tr><td colspan="2">ID</td><td>S3-BTN-U3-LCAFC</td></tr>
<tr><td colspan="2">Overview</td><td>The lane-change control of the S3-BTN-UC2-LCA may increase the bottleneck capacity. However, if the arriving demand is higher than the increased capacity, traffic breakdown will occur, leading to congestion and degradation due to the capacity drop at the head of congestion. To avoid the traffic degradation, additional flow control measures may be applied, aiming to maintain the traffic flow approaching the bottleneck at capacity values. In this use case the traffic control is attempted via mainstream traffic flow control (Figure 12) and through individual control (Figure 13) as well as via their combination.

The real-time control strategy for combined lane-change advice and flow control is based on the prevailing traffic conditions, which are reflected in appropriate traffic data (measurements or estimates) to be specified. The strategy should be feedback based for lower sensitivity and improved robustness.</td></tr>
<tr><td colspan="2">Parts of the use case that will be tested in real world</td><td>The technological feasibility will be tested for solutions I and II. Specific subcases of real world tests will be defined in the next phases of the project.
Solution II could be tested with hybrid testing even with only one CV in real world.
The penetration rate dependency and the traffic density dependency should be tested for all solutions with simulation.</td></tr>
<tr><td colspan="2">Key assumptions</td><td>Sufficient number of drivers comply with the TMC advices.</td></tr>
<tr><td rowspan="2">Realisation Prerequisites</td><td>A. Physical infrastructure</td><td>• Road with multiple (3) lanes on main track and 1 on-ramp.
• Traffic Management Center (TMC) extended with INFRAMIX Management Center (IMC)[24] (refer to Figure 15 – INFRAMIX high-level architecture).
• Vehicles equipped with OBU (ITS-G5) or cellular communication device.
• Sensors for real-time traffic information (traffic flow per lane).
• Gantries or/and mobile VMS to provide information to conventional not connected vehicles (indicating lane changes and speed limits)
• RSUs for network connectivity coverage[25].
• Traffic signs for ramp metering (traffic light).</td></tr>
<tr><td>B. Digital infrastructure</td><td>• Communication technologies:
  o Cellular network (web based communication to data-server)
  o ITS-G5 (5.9 GHz Geobroadcast communication)
• Wireless messages:
  o DENM traffic conditions, Basic safety warnings (e.g. braking)
  o IVIM: lane change, speed limit
  o CAM: Continuous broadcast of Vehicle, Speed, heading, Position in real time, awareness message about existence of other vehicles</td></tr>
</table>

[24] In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX Management Center (IMC).
[25] Connected to TMC and to OBUs

	C. Data availability	• Traffic data from real traffic conditions (to use in simulation) o Lane change behaviour o Traffic flow and occupancy per lane • Traffic data real-time (measurements or estimates): o Traffic flow and occupancy per lane measurements in real-time o Kind of vehicle (automated or conventional) per lane • Infrastructure equipment positions (e.g. VMS, RSUs, Sensors)
	D. Simulators capability	Realistic traffic modelling for driving behaviour on basis of HD map (acceleration, deceleration, lane changes) for all types of vehicles • Behaviour: conventional • Automated Control: AV Usage of HD-Map information in simulation environment • Including RSU, VMS, and sensor positions Sensor-models for measurements of road-sensors • Number of vehicles, traffic flow Variable Message Signs • Variable speed limits, lane assignments Communication links for messages • ITS G5 (Vehicles <> RSUs) • Cellular (Vehicles <> Traffic Service Provider) Traffic Control Interface for coupling of traffic control algorithms • Traffic flow estimation • Control (speed advisories, lane recommendations)
Challenges	**Technical**	Algorithms for advices on lane changes and speed to work in real time. Manoeuvre implementation in AVs (the vehicles would not change their lanes directly based on the recommendation, but need to evaluate the situation on their own to ensure safe manoeuvres).
	Others e.g. operations, safety regulations	Efficiency question that Cooperative behaviour (including on-ramp behaviour) is already implemented in AV vehicles. Should this target be double implemented via infrastructure? Ensure safe manoeuvres for fail modes: e.g. when vehicles do not follow advice from TMC.
Target/Evaluation metrics		Traffic flow (measured by vehicle throughput with road sensors, on main lanes as well as on-ramp) • Depending on overall traffic density • Depending on penetration rates of different vehicle types Traffic safety (measured by sufficient vehicle time/distance gaps, reduced number of hard braking events) User acceptance of visual signs for conventional and connected vehicles Research questions to be replied: Which is the percentage of the connected vehicles necessary for the intended action to be effective? (assuming that there is a sufficient number of vehicles that comply to the TMC recommendations)

Use case requirements

Requirement ID	Functional requirements	Comments
S3_BTN_UC3_LCAFC_F_00	Requirements: S1_DLA_UC1_DPR_F_02 S1_DLA_UC1_DPR_F_07 S1_DLA_UC1_DPR_F_08 S1_DLA_UC1_DPR_F_10 S1_DLA_UC1_DPR_F_12 S3_BTN_UC1_DBAS_F_01 S3_BTN_UC1_DBAS_F_02 S3_BTN_UC1_DBAS_F_03 S3_BTN_UC2_LCA_F_01 are also applied in this use case.	

Requirement ID	Feasibility requirements	Comments
S3_BTN_UC3_LCAFC_FE_00	Requirements: S1_DLA_UC1_DPR_FE_02 S1_DLA_UC1_DPR_FE_04 S1_DLA_UC1_DPR_FE_05 S1_DLA_UC1_DPR_FE_06 S1_DLA_UC1_DPR_FE_07 S1_DLA_UC1_DPR_FE_09 S1_DLA_UC1_DPR_FE_10 S1_DLA_UC1_DPR_FE_11 S3_BTN_UC1_DBAS_FE_02 S1_DLA_UC1_DBAS_FE_03 S3_BTN_UC2_LCA_FE_03 are also applied in this use case.	
S3_BTN_UC3_LCAFC_FE_01	An adequate number of sensors for real traffic information of the on-ramp.	Exact number per kilometric distance will be investigated during the next phases of the project.

Requirement ID	Non-functional requirements	Comments
S3_BTN_UC3_LCAFC_NF_00	Requirements: S1_DLA_UC1_DPR_NF_01 S1_DLA_UC1_DPR_NF_02 S1_DLA_UC1_DPR_NF_03 S1_DLA_UC1_DPR_NF_04 S1_DLA_UC1_DPR_NF_05 S1_DLA_UC1_DPR_NF_07 S1_DLA_UC3_CVDL_NF_05 S3_BTN_UC1_DBAS_NF_01 S3_BTN_UC1_DBAS_NF_02 S3_BTN_UC1_DBAS_NF_03 S3_BTN_UC2_LCA_NF_01 S3_BTN_UC2_LCA_NF_02 are also applied in this use case.	

4.3.4 Traffic Scenario conclusions and critical aspects

This section includes several conclusions and critical aspects in matters of safety and performance mentioned during the process of use cases definition and requirements capture for bottlenecks scenario.

The use cases of this scenario distinguish the vehicles to AVs and CVs. However, traffic control strategies taking into account the conventional vehicles with the AD function of ACC, for providing recommendations on the vehicle driving behaviour. The V2I communication is of high importance for the infrastructure design, in the aspect of providing the traffic management recommendations to vehicles (e.g. non-connected vehicles through gantries, connected vehicles via ITS-G5 messages).

A critical aspect of the bottlenecks scenario is the user compliance and appreciation of the traffic control recommendations. Moreover, the real test implementation of several innovative traffic control strategies might require performing a campaign. Even more specific description of subcases for real tests might be provided in the next phases of the project, based on the simulation analysis.

Another aspect that stimulates several critical questions is the inclined road (e.g. tunnel, sag). Vehicles lose their front visibility. How does this affect control strategy? Is it possible to maintain the suggested distance from the front car in this case? How can V2I communication help to mitigate that phenomenon? Ensure safe manoeuvres for fail modes: e.g. when vehicles do not follow advice from TMC.

5. Collection and mapping of hybrid infrastructure-level requirements to component –level requirements

As an outcome of the use cases definition per scenario and the requirements capture for each of them, a common concept should be formulated for the “hybrid” road infrastructure. For that purpose, a high-level architecture that depicts mainly the information flow of such an infrastructure is useful in order to detect the main components and their interfaces. A mapping of the use case-based requirements to these components makes more convenient the capturing of their specifications which is required at the next stages of the project when their design and integration will take place.

Figure 14 is a schematic of the current state-of-the-art highway based on the status quo analysis (Chapter 3). For implementing the use cases described at Chapter 4, INFRAMIX targets to upgrade the highway status by extending the capabilities of the Traffic Management Center in the sense of traffic estimation, traffic control, redundancy of traffic data and ability of RSUs management for ITS-G5 network (Figure 15). This extension of the TMC is mentioned in this document as INFRAMIX Management Center (IMC) in order to point out the added value. IMC could be implemented as a separated module with bidirectional communication with TMC, or as an incorporated part of the TMC based on the needs of each highway. Each one of the components illustrated in Figure 15 is described in Table 13.

A clustering of the use case - based requirements to each of the components depicted at Figure 15 was performed and shared among consortium for consideration in the next faces of the project. Since INFRAMIX targets to provide a co-simulation environment along with the proposed road infrastructure, the simulation requirements are also listed at Table 15. Figure 16 is a depiction of the hybrid test based on the high-level INFRAMIX architecture (Figure 15).

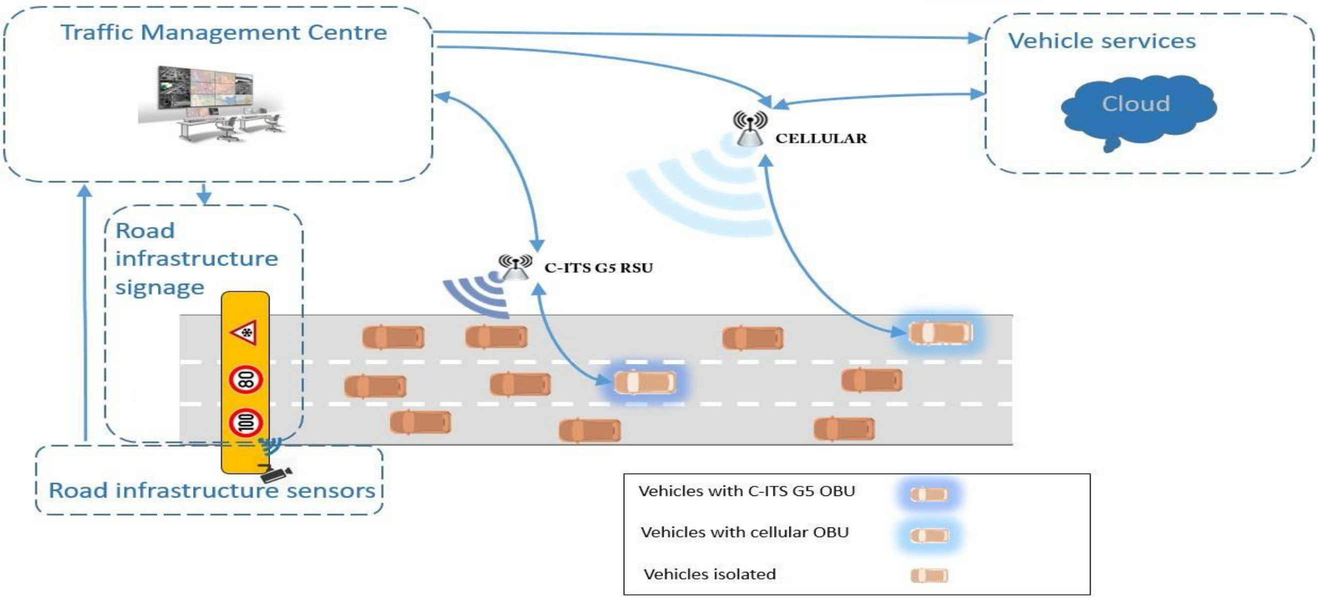


Figure 14 – State-of-art highway

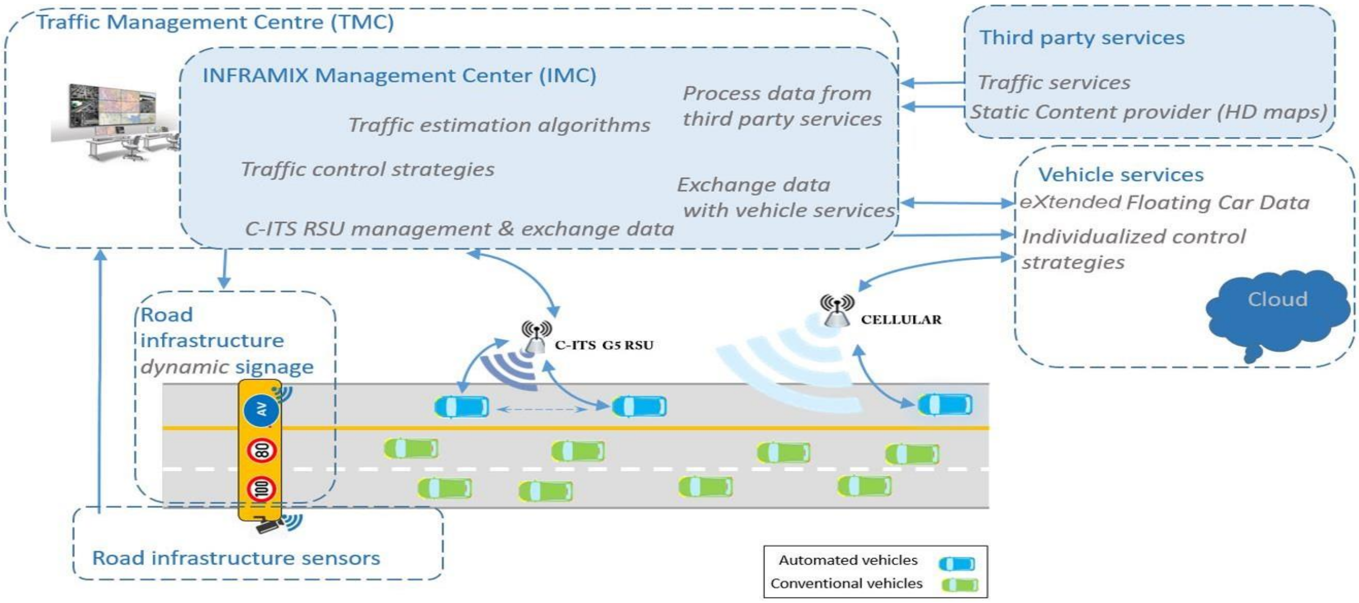


Figure 15 – INFRAMIX high-level architecture[26]

[26] The HD maps will not be integrated in the TMC in the timeframe of INFRAMIX and the figure refers to the information exchange with the vehicles.

The following table presents an overview and description of the main components of the high-level architecture.

Table 13 – Description of the major components of the high level architecture

Component	Description of the component
INFRAMIX Management Center (IMC)	Extension of the Traffic Management Center (TMC) (incorporated to the TMC or separated module with bidirectional communication to the TMC). • Traffic control strategies implementation • Traffic estimation • Exchange of data with ITS-G5 RSU • Management of ITS-G5 RSUs • Exchange data with vehicle services • Receives data from third party services
Vehicle Services	• Provides data to IMC • Receives traffic content by IMC • Data exchange with cellular OBU (Individualized control strategies implementation)
Third party services	• Provides aggregated traffic information (Traffic services) • Provides static data (Static content provider e.g. static HD map)
C-ITS RSU	• Data exchange with IMC • Data exchange with ITS-G5 OBU of vehicles
Road Infrastructure dynamic signage	• Receives messages from TMC (including new visual signs e.g. dynamic lane assignment sign codes, roadworks new lane marking)
Road Infrastructure sensors	• Provides real-time traffic data.

Table 14 – Overview of the communication data exchange

	Sender	Receiver	Content
IMC / Cellular	Vehicle Services	IMC	Real-time eXtended Floating Car Data (XFCD)
IMC / Cellular	IMC	Vehicle Services	Traffic content based on: • Traffic situation • Traffic control strategies
IMC / Cellular	Third party services	IMC	• Aggregated traffic information • Traffic flow information • Incident Information • Static HD maps[27]
Cellular	Vehicle services	Cellular OBU	• Traffic information • Individualized traffic control
Cellular	Cellular OBU	Vehicle services	Real-time eXtended Floating Car Data (XFCD)
ITS-G5	IMC	ITS-G5 RSU	DENM, IVIM, MAPEM
ITS-G5	ITS-G5 RSU	IMC	CAM Aggregation
ITS-G5	ITS-G5 RSU	ITS-G5 OBU	DENM, IVIM, MAPEM
ITS-G5	ITS-G5 OBU	ITS-G5 RSU	CAM

[27] The HD maps will not be integrated in the TMC in the timeframe of INFRAMIX and the content here refers to the information exchange with the vehicles in the concept of a “hybrid” road infrastructure.

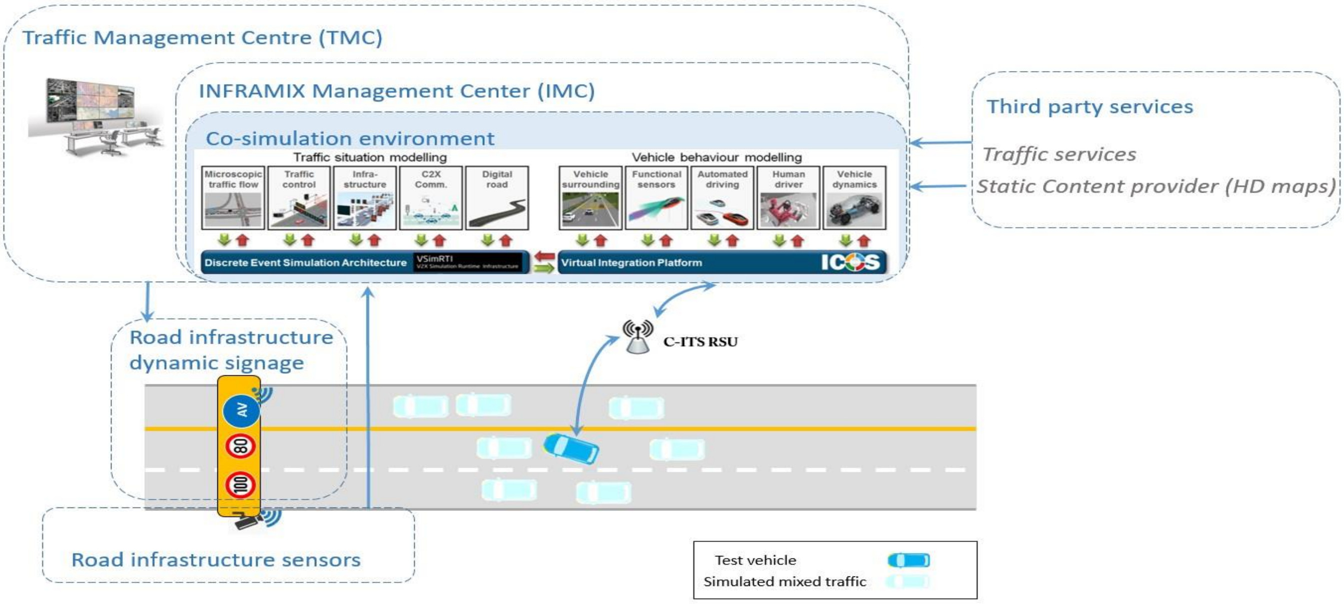


Figure 16 – Hybrid testing high-level architecture [28]

Table 15 – Co-Simulation environment requirements

	Component	Require ment	Use case
Traffic situation modelling	Microscopic Traffic	HD map of test site with number of lanes, road geometry (e.g. OpenDrive format) should be provided as the basis of the scenario	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
		Traffic flow definition in number of vehicles per minute per lane (e.g. real data from sensors in test site) should be provided to set up and calibrate the microscopic traffic	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
		Information about roadwork areas, especially positions (in or projectable to WGS84 coordinates) extent, should be provided if not included in HD map	S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD
		Environment data (e.g. snow, rain) and their implication on traffic flow behaviour, VMS recognition and possibly communication characteristics (packet errors) should be agreed	S1_DLA_UC3_AWC

[28] The HD maps will not be integrated in the TMC in the timeframe of INFRAMIX and the figure refers to

the information exchange with the vehicles.

	Infrastructure Sensors	Positions (in or projectable to WGS84 coordinates) and types of infrastructure sensors on test site (e.g. counting stations, cameras, infrared sensors, induction loops)	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
	Variable Traffic Signs	Positions (in or projectable to WGS84 coordinates) and types of variable traffic signs on test site (variable speed signs, variable lane assignment)	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
	Traffic Control Interface	Specific traffic control parameters should be provided by Traffic Control Algorithms (e.g. speed limits, lane recommendation, distance gap instructions) to traffic control interface model.	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
	Communication	Positions of Road Side Units (in or projectable to WGS84 coordinates) should be provided.	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
		ITS-G5 messages as defined in use cases should be included in the communication model.	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
Vehicle behaviour modelling	Static Environment Model	• Requires detailed information about road section like an HD-Map (e.g. Open Drive format) ○ number of lanes ○ lane type ○ lane width ○ lane markings ○ sign positions ○ sign types ○ sign orientation	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
		• Detailed information about roadwork zones	S2-RWZ-UC1-SLC S2-RWZ-UC2-NLD

	Driving Function Model	• Requires ITS-G5 and traffic messages from *Communication Model* • Information about weather conditions from *Infrastructure Sensors*	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC
	Vehicle Dynamics Model	• The current position and velocity of the ego- vehicle belongs to the output of the *Vehicle Dynamics model* ○ position e.g. in WGS84 coordinates • The *Microscopic Traffic Flow Simulation* has to be informed about the current ego-position and velocity	S1_DLA_UC1_DPR S1_DLA_UC2_CVDL S1_DLA_UC3_AWC S1_DLA_UC1_DPR S2_RWZ_UC1_SLC S2_RWZ_UC2_NLD S3_BTN_UC1_DBAS S3_BTN_UC2_LCA S3_BTN_UC3_LCAFC

	Sensor Model	• Requires current information from the *Microscopic Traffic Flow Simulation* about other vehicles in the near surrounding of the ego- vehicle
		    ○ position of other vehicles, e.g. in WGS84 coordinates
		    ○ velocity of other vehicles
		• Information about weather conditions from *Infrastructure Sensors*
			S1_DLA_UC1_DPR
			S1_DLA_UC2_CVDL
			S1_DLA_UC3_AWC
			S1_DLA_UC1_DPR
			S2_RWZ_UC1_SLC
			S2_RWZ_UC2_NLD
			S3_BTN_UC1_DBAS
			S3_BTN_UC2_LCA
			S3_BTN_UC3_LCAFC

6. Terms and definitions

Terms	Definitions
Conventional Vehicle (CV)	A vehicle with SAE level of automation [11] equal to 0, 1 or 2, which doesn't communicate with the TMC via wireless messages.
Connected conventional vehicle (CCV)	A conventional vehicle that communicates through wireless messages with Traffic Management Center (through cellular or ITS communication).
Automated Vehicle (AV)[29]	A vehicle with SAE level of automation equal to 3, 4 or 5 that communicates through wireless messages with the TMC (via cellular or ITS communication) and sends its level of automation to TMC at least every 10 seconds [30].
Non-proper user	The term "non-proper user" is used in this document to describe a vehicle that it intends to enter or drives on a lane dedicated to automated driving and Its level of automation is lower than the one that the lane is dedicated to or it has not communicate its level of automation to TMC for the last 10 seconds [30].
INFRAMIX Management Center	In the frame of INFRAMIX, TMC is upgraded with capabilities in order to perform specific use case driven functionalities. The extension of the TMC related to INFRAMIX, is named INFRAMIX Management Center (IMC).
AV-lane	A lane dedicated to the automated vehicles (only AV).
ITS-G5	A European set of protocols and parameters for V2V and V2I communications based on the IEEE standard 802.11p on wireless access in vehicular environments
V2V	Vehicle-to-Vehicle communication (via ITS-G5 and/ or cellular)
V2I	Vehicle-to-Infrastructure communication (via ITS-G5 and/ or cellular)
V2X	Vehicle-to-X (X represents any entity capable of receiving C-ITS communications)
"Hybrid" road infrastructure	This term is used to describe the concept of an infrastructure capable to handle the challenges of a mixed traffic.
Hybrid testing	Testing that performed with a real vehicle (automated or conventional driven) that communicate its accurate lane-specific position back to the virtual environment. This hybrid testing enables detailed and realistic investigations of real driving behaviour in a complex but safe virtual traffic to demonstrate the potential of INFRAMIX.
RSU	Road Side Unit necessary for ITS-G5 network coverage

[29] This definition implies that an automated vehicle which doesn't inform the TMC regularly about its level of automation, it is treated as a conventional one.

[30] The number of seconds will be defined under the investigation of S1-DLA-UC3-CVDL, this is a draft assumption.

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