INFRAMIX

Grant Agreement Number: 723016

Project acronym: **INFRAMIX**

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

D.5.1

Plan for evaluation and users' engagement

Due delivery date: 31/07/2018
Actual delivery date: 15/12/2018
Organization name of lead participant for this deliverable: **ENI**

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:	D.5.1.
Deliverable responsible:	ENI
Work package:	WP5
Editor:	David Quesada

Author(s) – in alphabetical order		
Name	Organisation	E-mail
Anna Carreras	AAE	anna.carreras.ext@autopistas.com
Katia Pagle	ICCS	katia@iccs.gr
Ioannis Papamichail	TUC	ipapa@dssl.tuc.gr
Jacqueline Erhart	ASF	Jacqueline.Erhart@asfinag.at
Evdokia Papanikolaou	ICCS	evdokia.papanikolaou@iccs.gr
David Quesada	ENIDE	David.quesada@enide.com
Martin Rudigier	VIF	Martin.Rudigier@v2c2.at

Document Revision History			
Version	Date	Modifications Introduced	
0.1	02/07/2018	Layout	
0.9	08/12/2018	Final draft submitted for review	
1.0	14/12/2018	Final version	

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
AD	Automated Driving
AV	Automated Vehicle
AWC	Adverse Weather Conditions
C-ITS	Collaborative Intelligent Transport System
CAV	Connected and Automated Vehicle
CV	Conventional Vehicle
DGT	Dirección General de Tráfico – Spanish Authority on Traffic regulations
DoA	Description of Action
EC	European Commission
FESTA	Field opErational teSt supporT Action
FOT	Field Operational Test
GA	Grant Agreement
GDPR	General Data Protection Regulation
H	Hypothesis
ICT	Information and Communication Technologies
MAPEM	Road/lane topology and traffic maneuver message
MTFC	Mainstream Traffic Flow Control
NDS	Naturalistic Driving Studies
PI	Performance Indicator
PO	Project officer
RQ	Research Question
V2X	Communication from Vehicle to Everything
TMC	Traffic Management Center
TTC	Time to collision
UA	User Acceptance
VMS	Visual Variable-message sign
WP	Work Package

Table of Contents

List of Figures

List of Tables

Executive Summary

As described in the INFRAMIX DoA document, D5.1 includes the methodology and plan for evaluation as well as the process for engaging users. More than focusing on a detailed work plan for the evaluation activities, the focus has been set on the definition of all the concepts, methodologies and tools that are necessary to define the environment of the evaluation process. The structure of the document is as follows:

- Methodology for INFRAMIX evaluation.
- Definition of the evaluation key aspects to be developed in WP5 and the evaluation process.
- User engagement plan.
- Procedures and technical aspects for the implementation of evaluation beyond the framework of WP4 System Integration and Testing.
- Tools to support the data collection and analysis for evaluation.

The main conclusions of this document are as follow:

- FESTA has been selected to define the concepts and processes related to the fundamental methodology environment.
- Several evaluation domains have been defined to categorize the different aspects that need to be investigated in order to perform a proficient evaluation of the INFRAMIX outcomes: User acceptance, Traffic Efficiency and Traffic Safety.
- A full list of Research Questions (RQ), Hypothesis (H) and, finally, Performance Indicators (PI) have been defined. This analysis and the related debate have been of key importance in order to identify the focus and scope of the technical aspects of the project in terms of the priority and future expectations. In this sense Table 30 – Overview of the Performance Indicators for INFRAMIX evaluation gives a comprehensive view of the main topics of this process.
- Procedures and technical aspects beyond the scope of WP4 have been described in order to guide the execution and evaluation processes.
- A user engagement process has been defined, in order to gather the final user input and feedback related to the concepts developed in INFRAMIX. This process is based on the interaction with the INFRAMIX User Group; and on the recruitment for the participation on surveys and questionnaires using campaigns and networking to extend the involvement.
- Finally, some tools that could be used during the gathering and data analysis have been documented. Next activities in WP5 will be responsible for the selection of the appropriate tools.

After the finalization of T5.1, WP5 will use this document in order to further define the test scenarios in collaboration with the co-simulation platform, hybrid testing (WP2) and demonstration sites (WP3 and WP4), specifying the test cases to be applied and collecting the results generated to analyze the performance of the actions.

Also, it is important to mention that a specific task-force has been set-up for the Definition of common test protocols (based on the development in T4.5 and to reflect the required data which needs to be recorded - log data, user appreciation) and the INFRAMIX test/evaluation/demonstration plan in order to align the different technical activities with the execution and evaluation tasks.

On the other hand, concerning the PI related to User Acceptance (UA), the process defined for user engagement to build addressed interviews and surveys to retrieve the user feedback will be used. This will involve WP6 networking activities.

1. Introduction

1.1 Purpose of Document

As described in the INFRAMIX DoA document, D5.1 includes the methodology and plan for evaluation as well as the process for engaging users.

The methodology defines the research questions, tools to be used, test set-up, procedure to be followed, sample sizes, data to be collected, indicators to be calculated and ways of analysis. Three scenarios will be studied: i) dynamic lane assignment, ii) construction site / roadworks zones, iii) bottlenecks (on-ramps, lane drops, tunnels, bridges, sags).

This document also defines the process that will be followed for engaging users, whose appreciation in INFRAMIX developments will be later assessed in task 5.2. The feedback by the users, individual and corporate ones (e.g. transport operators) will be collected using online tools and forms, and in greater depth via dedicated workshops at the test sites.

The document is structured in the following way:

- Chapter 2 presents the objectives of the evaluation analysis and the methodology, it also provides the overview of the evaluation methodology, its structure and briefly explains its steps. Moreover, it outlines the infrastructure functionalities and services to be assessed based on the three traffic scenarios. In order to enhance readability, the scenarios description and selection criteria are included in this chapter, followed by an overview of the use cases definition and the process for defining the research questions and hypotheses for each use case. The use cases and the areas of assessing each of them, are briefly described (as there is an extended description of them in the deliverable D2.1“Requirements catalogue from the status quo analysis”). The extraction of the research questions for every use case as well as the hypotheses that will lead to specific performance indicators are categorized into the INFRAMIX evaluation fields. In turn, the following chapters provide the research questions and hypotheses for each evaluation field.
- Chapter 3 focuses on user ‘appreciation evaluation. The user’s acceptance of INFRAMIX developments are considered of high importance. This chapter presents the research questions, hypotheses, performance indicators, measurements and measurement tools that will be used for the scientific analysis of user’s appreciation towards INFRAMIX developments.
- Chapter 4 focus on the impact that the use cases have on traffic efficiency and safety. Research questions and hypotheses have been extracted for investigating the impacts on traffic efficiency and safety. Specific performance indicators to be measured through simulation are listed in this chapter.
- Chapter 5 provides a summary table of the aforementioned performance indicators, with a mapping to both the demonstrators that will be used for assessing them and to the evaluation domain that they will be used during the analysis phase.
- Chapter 6 describes the plan that the project will follow in order to engage the required user groups so as to understand the user’s appreciation towards the INFRAMIX developments.
- Chapter 7 is a description of the plan that will be followed in order to collect the necessary data for the calculation of the performance indicators defined in the previous chapters in the case of the real-life tests (demonstration and hybrid tests).
- Chapter 8 presents a list of available (commercial) evaluation tools that may be used during the analysis phase.
- Chapter 9 provides a list of conclusions emanating from the work performed, namely

the formulation of the evaluation and the user’s engagement plan, as well as the next steps and the way that this deliverable contributes to the overall INFRAMIX objectives.
- Finally, chapter 10 provides the list of references.

1.2 Intended audience

This document is addressed to the partners in INFRAMIX in order to be able to perform the following activities:

- Setup of the technical components of the project, demonstration sites and simulation platforms from the perspective of data gathering and collection for evaluation.
- Evaluation execution: the following activities of WP5 will detail the foundation aspects described in this document in order to establish the testing scenarios and data analysis.
- Use the evaluation experience to setup the steps for the technology deployment after the INFRAMIX project.

2. Evaluation methodology

The first step in the process to support the evaluation plan for INFRAMIX is to define a methodological approach that is suitable for the objectives of the project taking into account the resources available and timeframe. Hence, this section describes the methodology that has been designed to perform the INFRAMIX project evaluation. It will be later explained that as an initial step, FESTA approach has been selected but then has been adapted to the specific characteristics of the project.

So, in this chapter the general features of FESTA and the key aspects that have been used to define the evaluation methodology are presented, focused on the six-steps approach and Performance Indicators (PI) definition. In addition, an updated description of the use case of INFRAMIX that have been used as baseline for the characterization of the methodology is included.

The main specific features of the INFRAMIX case are described, especially concerning the input of data for the evaluation (from real testing/simulators as well as from user acceptance) as well as the categorization of the PI in three domains in order to facilitate the evaluation tasks.

Despite the vast recognition of the road impact in traffic, the road infrastructure development is not proportional to the rapid deployment of the new automated vehicle's technologies during the last decade. Consequently, the transportation research focuses mostly on the assessment of the novel automation functionalities (Barnard et al. 2015), (Innamaa & Kuisma 2018), rather than on the impact caused by road infrastructure upgrades.

Assessment of the impact that the road infrastructure development would impose in a potential mixed traffic flow is an endeavor, which implies multiple challenges. Firstly, the precise definition of such a complex system, that characterizes the road infrastructure which includes the required functionalities to accommodate conventional and AVs simultaneously, does not exist. Moreover, the lack of real data and existing statistics from interaction of automated vehicles with road infrastructure, due to the minimum AVs currently in the streets, is an additional issue. Another challenge is the fact that important parameters of a mixed vehicle traffic flow, such as the expected penetration rate of the AVs through the years, are based on assumptions. Additionally, a structured and concise evaluation methodology analogous to the ones for the automated functions (e.g. FESTA, (FESTA 2016)) is still under investigation.

This is exactly the purpose of the specific task in INFRAMIX, the formulation of an evaluation methodology suitable for a "hybrid" infrastructure where different types of vehicles are driving. This methodology is based on FESTA version 7 (FESTA 2016) originally developed for Field Operation Tests (FOTs), while addressing major transportation concerns which hassle the introduction of the AVs. The evaluation areas are the following:

- Impact on traffic efficiency and safety
- Users' appreciation

FESTA is adapted so as to evaluate the context of the traffic flows and not the Automated Driving (AD) functions of the vehicles. As a general rule the road infrastructure is considered as a system that provides specific services to the road users (conventional and automated vehicles) in order to facilitate the traffic flow. The components of this system, the so-called "hybrid" road infrastructure, are depicted in high-level at the following picture:

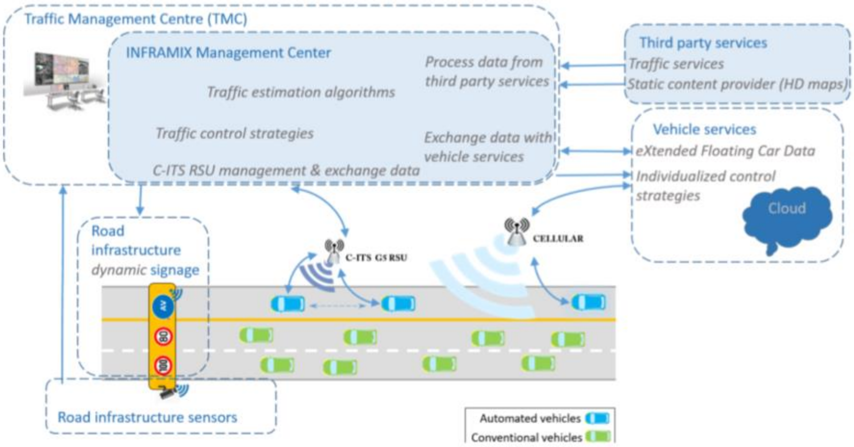


Figure 1 – "hybrid" road infrastructure concept

The "hybrid" road infrastructure in INFRAMIX is primarily designed to take care of three critical traffic scenarios (in terms of importance with regard to traffic efficiency and safety), without loss of generality (D2.1 "Requirements catalogue from the status quo analysis"). These scenarios will be the basis for the impact assessment and evaluation:

- Dynamic lane assignment
- Roadworks zone
- Bottlenecks

2.1 Methodological approach

As said before, the initial step in this process has been the definition of the methodology that will be used during the evaluation of INFRAMIX. The hybrid road infrastructure examined in INFRAMIX is a relatively new research domain, for which new evaluation methods might be needed. As a first step the evaluation method that is utilized in the project is the FESTA V-process methodology. However, the FESTA Handbook v.7 (2017), is formulated with the target to evaluate ADAS and in-vehicle information systems for vehicles through FOTs. The latest version of the handbook includes apart from in-vehicle systems also nomadic and cooperative ones, which are intended as a combination of hardware and software enabling one or more ICT functions in vehicle level.

The methodology formulated within INFRAMIX attempts to adapt FESTA, so as to be able to evaluate the so called "hybrid" infrastructure in terms of traffic safety, traffic efficiency and users' appreciation.

The V-model of the FESTA contains three main steps, namely, "preparing", "using" and "analyzing" in order to perform an evaluation analysis of an FOT (see next Figure)

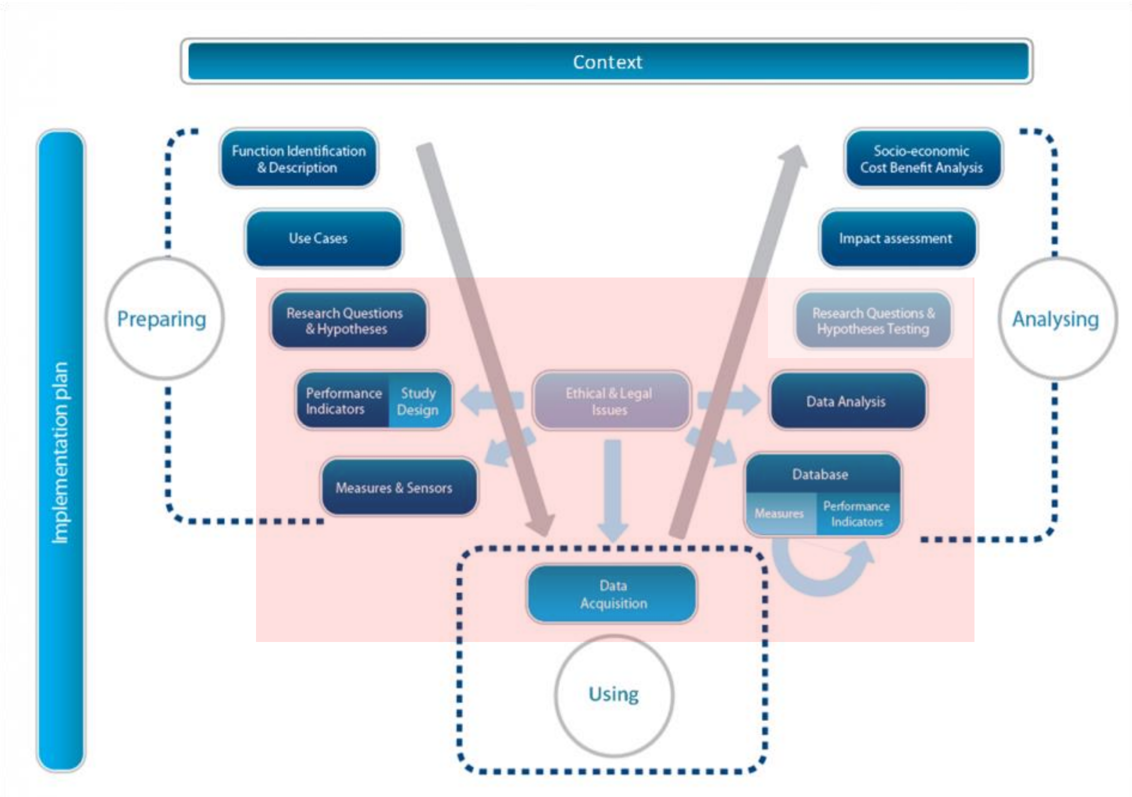


Figure 2 – FESTA V model (from FESTA Handbook)

Figure 2 reflects the steps that typically need to be considered when conducting an FOT. The large arrows indicate the time line (FESTA Handbook). In red it is shown the focus of INFRAMIX evaluation methodology.

INFRAMIX approach keeps the FESTA main steps on performing a study which contains an evaluation analysis while adapts several tasks according to the project objectives and the system that it is under assessment. The following table shows the steps as defined in FESTA along with the INFRAMIX adaptations:

Table 1 - INFRAMIX adaptation on FESTA steps

Main steps	**FESTA**	**INFRAMIX**
Preparing		
Defining the study:	Defining: functions, use cases and research questions and hypotheses	Defining: traffic scenarios[1] , use cases[2] and research questions and hypotheses
Preparing the study:	Determining: performance indicators, study design, and measures and sensors	Determining: performance indicators, study design, and measures and sensors
Using		

[1] infrastructure functions serving valuable traffic scenarios
[2] traffic flow situations based on the scenarios

Conducting the study:	Collecting data by performing: FOT	Collecting data by performing: simulation demonstration tests in real highways hybrid testing
Analysing		
Analysing the data:	Storing the data, analysing the data, testing hypotheses, answering research questions	Storing the data, analysing the data, testing hypotheses, answering research questions
Determining the impact:	Impact assessment and deployment scenarios, socio-economic cost benefits analysis	Assessment of the infrastructure classification scheme, impact assessment and deployment scenarios, socio-economic cost benefits analysis

This deliverable is written during a project phase which is related to the first step of the V-model. The document intends to report the work regarding the defining and preparing the study in order to provide the necessary guidance for the next steps.
The following chapter describe in brief the study definition which includes the traffic scenarios as well as the use cases based on each scenario. The description of the formulation and categorization of the research questions and hypotheses is also given in the following chapter. However, the research questions and the hypotheses that lead to the extraction of specific performance indicators at the next step – preparing the study -, are reported based on their categorization per evaluation field. As stated in the introduction, the evaluation analysis will be devised in two main evaluation fields in INFRAMIX: impact on traffic efficiency and safety (Chapter 4) and user's appreciation (Chapter 3).

2.1.1 Defining the study: traffic scenarios and use cases

In FESTA approach the first step: "function identification & description" concerns the description of the vehicle automated function, considering the vehicle as a concrete system. In INFRAMIX the road infrastructure is the system and its functions are traffic scenarios where the infrastructure provides its services to road users. Specifically, the infrastructure upgrades and developments, which are a combination of different technological components, are 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. INFRAMIX focus on three specific high-value (in terms of efficiency and safety) traffic scenarios. The scenarios are described in detail in deliverable D2.1. The next paragraphs give an overview of the three scenarios, the criteria with which they were selected, as well as the infrastructure developments through these scenarios.

These scenarios are identified for the transition period between pure human driving and automated driving (mixed traffic), to be tackled within the project duration, based on four criteria:

- the expected impact on traffic flow;
- the expected impact on traffic safety;
- 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 AVs on the roads;

- the ability to generalize the results (applicable in other scenarios and environments e.g. urban).

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).
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 situations 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 in the transition period while targeting to demonstrate and assess the innovation impact and the related novel solutions provided by INFRAMIX. Specifically, use case forms a field of research for the assessment of user's appreciation in INFRAMIX developments and for the effect of the project developments on traffic efficiency and traffic safety. In addition, use cases provide the circumstances and motives for identifying safety performance criteria for mixed traffic flows.
Based on these considerations, it is useful to describe the general idea for assessing each use case per evaluation field. Therefore, after the sort description of each scenario, every use case is described pointing out several relevant aspects for each evaluation domain; traffic safety, traffic efficiency and user's appreciation.
As a conclusion, Table 13 - List of use cases per scenario (source: D2.1) gives a short summary of the focal point for each use case.

Table 2 - Scenario 1: Dynamic Lane Assignment (incl. speed recommendations)

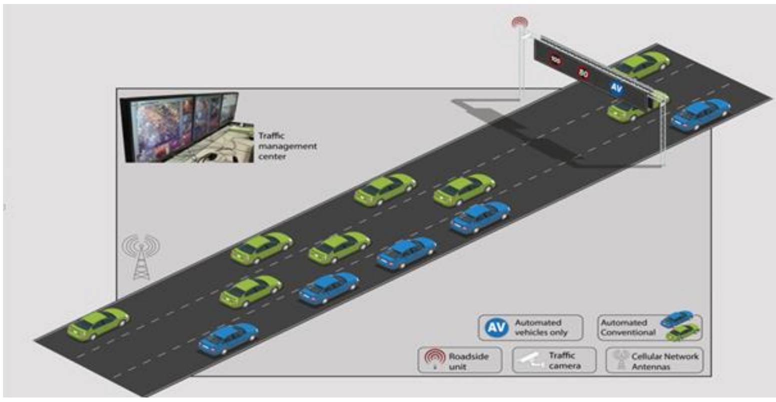
<table>
<tr><td>Name</td><td>Dynamic Lane Assignment (incl. speed recommendations)</td></tr>
<tr><td>Overview</td><td>Assign dynamically a lane or several lanes to automated traffic (either isolated automated vehicles or forming platoons), based on the currently prevailing traffic conditions, on the percentage of trucks / heavy vehicles and on the penetration rate of automated vehicles; decision on usage of specific segregation elements; dynamically adapt the speed limits per lane or road segment considering also potential adverse weather conditions.</td></tr>
<tr><td colspan="2">Schematic

</td></tr>
<tr><td>Derived Use Cases</td><td>1) Real-time lane assignment under Dynamic Penetration Rate of Automated Vehicles (AVs)
2) Exceptional traffic situations-Adverse Weather Conditions as an example
3) A conventional vehicle drives on a dedicated lane for AVs</td></tr>
</table>

Table 3 - Use case 1: Real-time lane assignment under Dynamic Penetration Rate of AVS

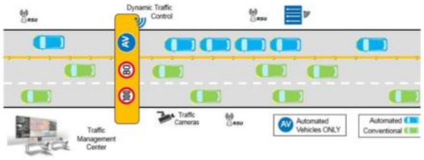
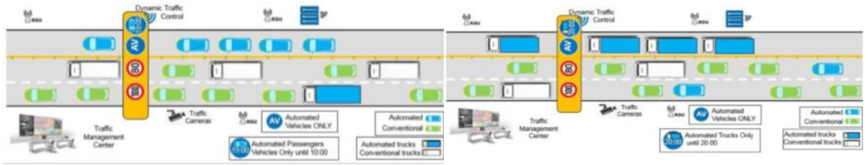
Name	Real-time lane assignment under Dynamic Penetration Rate of AVS
Overview	A lane is assigned dynamically to automated vehicles in mixed traffic, when their percentage is above a certain limit, taking also into account the capacity of the road portion left for conventional traffic.  The dynamic control of the traffic flow is attempted also 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. 
Technical feasibility	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
User's appreciation	Assessment of the visual and electronic ways for informing about the lane dedication and the varying speed limits, all vehicles and drivers involved, in the aspect of user's appreciation.
Traffic safety	Investigation of the deviation in speed limits based on safety considerations related to the lane dedication; e.g. • 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 when expecting high number of lane changes); • 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).
Traffic efficiency	The study of this use case, in simulation and in real conditions, will provide insights on how to manage in an efficient manner mixed traffic flows on standard highway segments. It will provide proper indicators for activation and deactivation of lanes assigned to automated vehicles,as well as speed and lane recommendations for all vehicles on this segment based on prevailing traffic conditions. 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 • Speed limit dynamic deviation per lane

Table 4 - Use case 2: Exceptional traffic situations-Adverse Weather Conditions as an example

Name	Exceptional traffic situations-Adverse Weather Conditions as an example
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 adverse weather conditions. The TMC should have specific criteria on the recommendation of degradation with respect to the level of automation to vehicles taking into account the individual vehicles thresholds of: • precipitation (in l/m²) • wind velocity (in m/s) • wind direction related to driving direction • road friction • visibility
Technical feasibility	The real-time logic for activating and de-activating the dedicated lane based on traffic conditions, which are reflected in appropriate traffic data and on ambient sensor data (measurements or estimates).
User's appreciation	Comparison of the amount of changes of the AV level degradation with and without the updates from the infrastructure (both physical infrastructure and information provided related to ambient conditions and recommended thresholds).
Traffic safety	• 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 TMC should perform in that case in order to reassure safety? • How overtaking is allowed under exceptional circumstances (considering mixed traffic)?
Traffic efficiency	Evaluate the decrease in 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)

Table 5 - Use case 3: A conventional vehicle drives on a dedicated lane for AVs

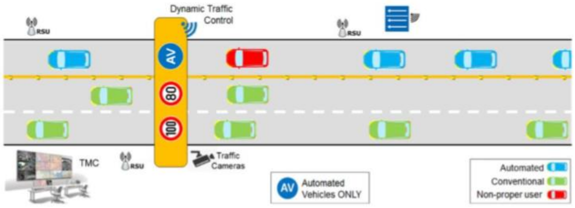
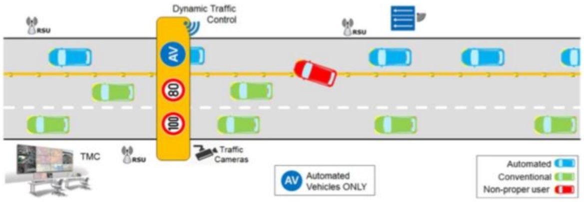
Name	A conventional vehicle drives on a dedicated lane for AVs
Overview	If a lane is dedicated to automated driving, a conventional vehicle is not allowed to use it. Moreover, automated vehicles (both passenger cars and trucks) that cannot be identified as automated due to missing real-time V2Icommunication are not allowed to use it either. Defining a vehicle which is not allowed to use the lane dedicated to automated driving due to the above-mentioned reasons, as “non-proper user” the following two subcases will be investigated: 1) Non-proper user is already on the dedicated lane  2) A conventional vehicle enters the dedicated lane 
Technical feasibility	Identification of AVs and non-proper users. Information chain from detecting a conventional vehicle until leaving the dedicated lane
User’s appreciation	• Signs and TMC messages to prevent a non-proper user from driving on or entering the AV-lane; • Information of AVs about the non-proper user on or entering the AV-lane via infrastructure communication;
Traffic safety	• 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);
Traffic efficiency	AVs on the dedicated lane are informed about a non-proper user in the front and will react in time to mitigate negative effects on traffic flow.

Table 6 - Scenario 2: Roadworks zones

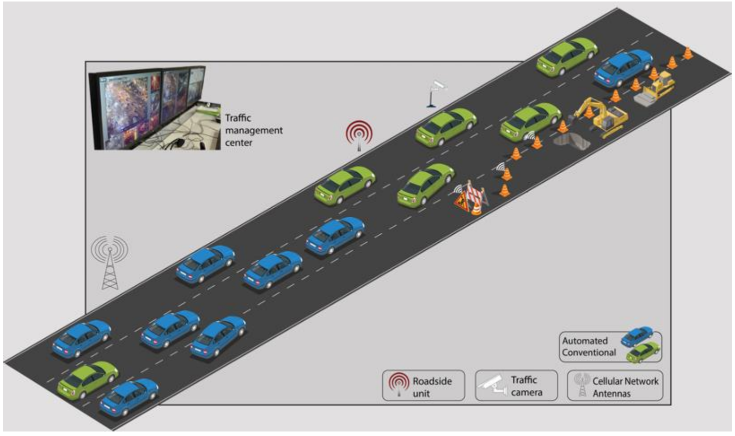
Name	Construction site / Roadworks zones
Overview	Roadworks zones are major safety hotspots with many accidents both involving vehicles and the staff on site. The infrastructure should help the vehicles by providing extended information in real-time, such as information that can be used to update HD maps in 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	4) Roadworks zone in mixed traffic – Single Lane Closure 5) Roadworks zone in mixed traffic – New lanes

Table 7 - Use case 4: Roadworks zone in mixed traffic – Single Lane Closure

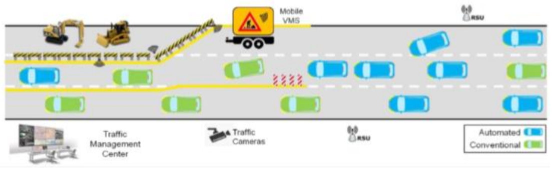
Name	Roadworks zone in mixed traffic – Single Lane Closure
Overview	In this use case the necessary infrastructure adaptations and upgrades are investigated in order to guide the mixed traffic through a construction zone (or optional around a broken-down vehicle) in a safe and traffic flow efficient way. 
Technical feasibility	• Identification of connected vehicles with respect to their actual AV-level. • Strategic lane guidance (trucks, automated trucks, for automated vehicles, conventional connected and nonconnected vehicles).
User's appreciation	End-user response / compliance rate to guidance instructions
Traffic safety	On-time information for connected and non-connected vehicles with respect to safety Consider recommendation of AV level degradation, dissolving AV-platoons. New protocol for roadworks at mixed traffic roads should be established.
Traffic efficiency	On-time information for connected and non-connected vehicles with respect to efficiency, traffic jam avoidance (considering roadway capacity degradation).

Table 8 - Use case 5: Roadworks zone in mixed traffic – New lanes

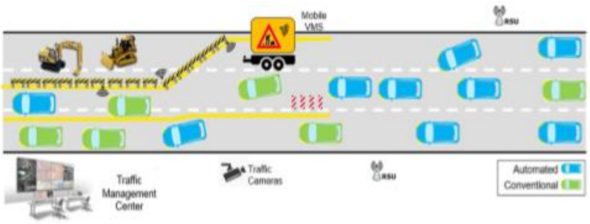
Name	Roadworks zone in mixed traffic – New lanes
Overview	This use case investigates V2X communication, visual signs as well as physical elements in order to reassure a smooth and efficient traffic flow when the roadworks zone covers more than one lane in a road segment. It is focused on the required 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. 
Technical feasibility	Infrastructure should support the automated vehicles to pass through the construction zone without degradation of the level of automation.
User's appreciation	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
Traffic safety	Safety critical aspects/ regulations related to the correct timing of the information given to automated and to conventional vehicles. V2X communication, visual signs as well as physical elements in order to reassure a smooth mixed traffic flow
Traffic efficiency	-

Table 9 - Scenario 3: Bottlenecks

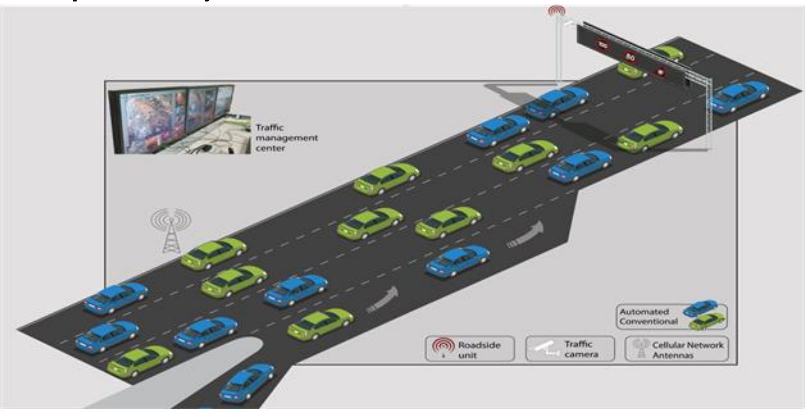
<table>
<tr><td>Name</td><td>Bottlenecks</td></tr>
<tr><td>Overview</td><td>The scope of this scenario is to investigate real-time controllers, involving a variety of control measures, such as dynamic speed limits, dynamic lane assignment, merge assistance and ramp metering to manage mixed traffic situations 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>6) Automated vehicles (AV) Driving Behavior Adaptation in Real Time at Sags (The use case is proposed for sags, but it could be applied to other bottleneck types as well.)
7) Lane-Change Advice to connected vehicles at Bottlenecks
8) Lane-Change Advice combined with flow control at Bottlenecks for all vehicles</td></tr>
</table>

Table 10 - Use case 6: Automated vehicles (AV) Driving Behavior Adaptation in Real Time at Sags (The use case is proposed for sags, but it could be applied to other bottleneck types as well

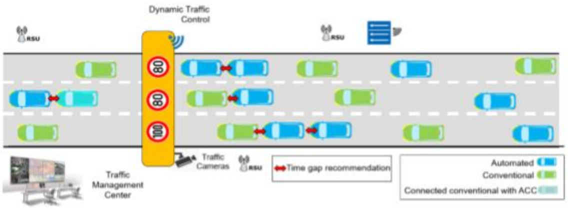
Name	Automated vehicles (AV) Driving Behavior Adaptation in Real Time at Sags (The use case is proposed for sags, but it could be applied to other bottleneck types as well)
Overview	The longitudinal driving behavior of automated vehicles is changed according to the traffic management requirements. The 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. 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 and downstream of a congested area. - Increased acceleration capabilities are employed at the head and downstream of a congested area. - AVs apply the ordered settings only if they are "stricter" than their current settings. 
Technical feasibility	TMC should be able to communicate specific ordered time-gaps to all AVs within specific sections. The wireless message (IVIM) content should be defined in order to contain parameters for minimum time gaps and acceleration for connected vehicles. AVs should be able to communicate their position and speed to TMC (CAM).
User's appreciation	Passenger feeling with reduced time-gaps (possible to be tested in real world using a small fleet of (3-4) ACC-vehicles). User's appreciation on the recommendations that they receive from TMC (for the connected vehicles).
Traffic safety	The recommended time-gaps are in the predefined range of the OEM, therefore the service conforms to the vehicles safety regulations. Further safety investigation might focus on the risk and consequences on the traffic.
Traffic efficiency	• 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). • Measure the throughput under different penetration rates of AVs and compare it to the baseline (conventional traffic).

Table 11 - Use case 7: Lane-Change Advice to connected vehicles at Bottlenecks

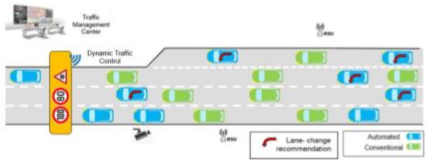
Name	Lane-Change Advice to connected vehicles at Bottlenecks
Overview	In this use case, a control strategy is fed with real-time lane-specific information about the prevailing traffic conditions and decides on the necessary lane-changing activities to achieve a pre-specified (possibly traffic-dependent) lane distribution of vehicles while approaching a bottleneck, aiming at increasing the bottleneck capacity. 
Technical feasibility	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. TMC should be able to communicate specific lane change advice to connected vehicles within specific sections.
User's appreciation	Driver compliance and passenger convenience while executing lane-change advice.
Traffic safety	Possible safety implications due to lane changes.
Traffic efficiency	Measure the throughput under different penetration rates of connected vehicles and compare it to the baseline (conventional traffic)

Table 12 - Use case 8: Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles

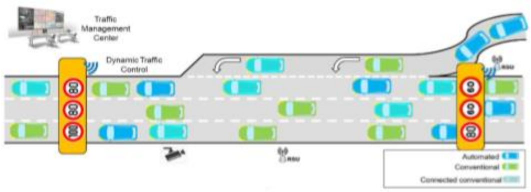
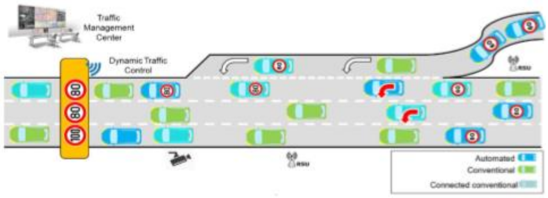
Name	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles
Overview	Investigation of improving the traffic flow at bottlenecks by controlling the upstream flow. In this use case, the following control strategies as well as their combination are investigated:  Mainstream Traffic Flow Control (MTFC): Control the traffic flow on the existing lanes. A realization 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).  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.
Technical feasibility	Assuming a sufficient number of compliant road users. Control strategies should assure that the throughput should always be at least at the same level as in the case of today's traffic consisting of only conventional vehicles. Ensure safe manoeuvres for fail modes: e.g. when vehicles do not follow advice from TMC.
User's appreciation	User acceptance of visual signs for conventional and connected vehicles
Traffic safety	Traffic safety (measured by sufficient vehicle time/distance gaps, reduced number of hard braking events)
Traffic efficiency	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 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)

Table 13 - List of use cases per scenario (source: D2.1)

Scenarios	Use cases	Associated benefit
Dynamic lane assignment (incl. speed recommendations)	Real-time lane assignment under Dynamic Penetration Rate of Automated Vehicles (AVs)	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).
	Exceptional traffic situations-adverse weather conditions as an example	Taking 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 is 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, the 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 the roadworks 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 Behavior 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 behavior 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 (SAE 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–change recommendations.
	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles	Investigation of improvement of 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).

2.1.2 Defining the study: research questions and hypotheses & Preparing the study: Performance indicators, Measures and Sensors

After the definition of the functions and the use cases, the research questions and hypotheses are formulated. The first step was the analysis of the original project objectives and visions. This work feeds top-down the definition of the research questions, hypotheses, performance indicators, and also measurements and tools for the acquisition of the needed data, which will be used to evaluate the functionalities under study. For the definition of the aforementioned elements a six-step approach presented here supports the development of a tailor-made evaluation framework. Figure 3 – Six-steps approach shows the six steps and an example.

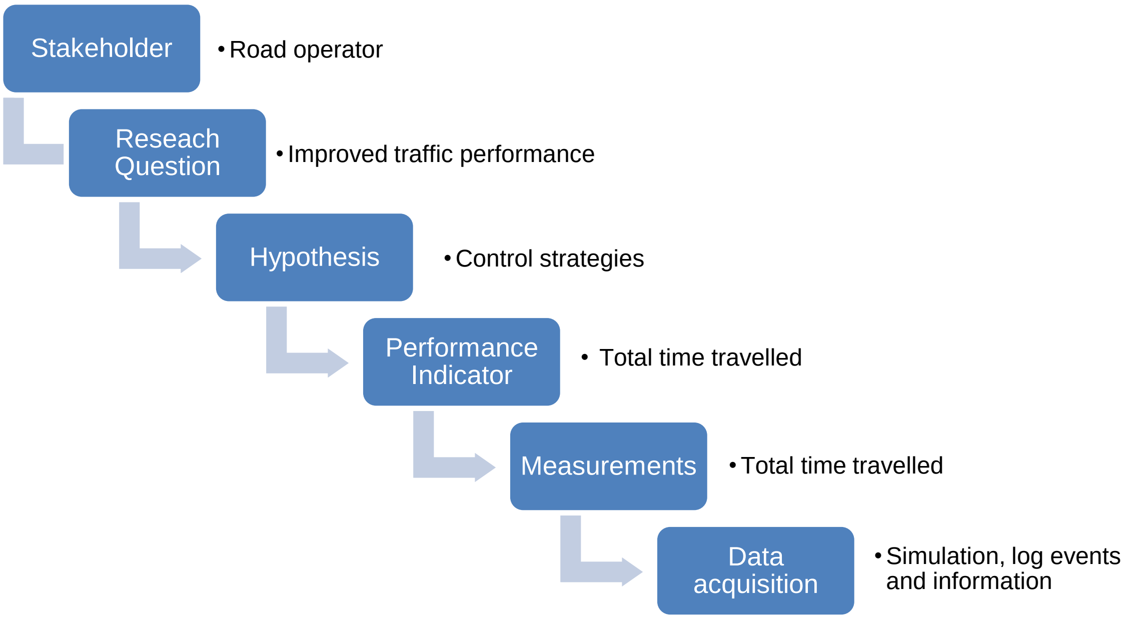


Figure 3 – Six-steps approach

The six steps are:

1. Identify the objectives of the stakeholders; what do they want to achieve? These high-level objectives are expressed in the form of Research Questions (RQs), which are grouped into the main INFRAMIX evaluation fields: The assessment of the impacts on traffic efficiency and traffic safety and the evaluation of the user appreciation, such as drivers/travelers and infrastructure operators.
2. Sharpen the objectives with the formulation of Hypothesis (H); Hypotheses are the formulation of the RQs to a scientific statement (that statement could be based on statistical outcome or assumption based on literature). This process leads to performance indicators. Making a scientific statement is challenging as it might be restricted based on research barriers e.g. disability to collect the required data in order to provide a solid answer (limited testing capabilities, lack of necessary historic data etc.). Specifically, a scientific statement related to mixed traffic flows includes several challenges and involves innovative solutions. For example, the lack of historic data from a fleet of AVs in real roads is a fact. FOTs are planned within the next years (e.g. L3pilot) while automotive research community, organizations, authorities and road operators promote the exchange of data (e.g. Trilateral ART: EU, US, Japan). Moreover, the simulation tools are of critical importance for (i) testing traffic control algorithms with increased densities in exceptional conditions, or with different rates of target vehicle types (conventional / automated) and (ii) investigating several cases with an expected safety critical impact.

3. Define Performance Indicators that can measure progress towards the objectives. The indicators should meet the following criteria:
    - *Relevance:* the indicator should be of significant importance for achieving the stakeholders' objectives;
    - *Reliability*: the indicator should be clearly defined;
    - *Measurability:* the indicator should be capable of being measured (objectively or subjectively) within the lifetime of the evaluation process;
    - *Interdependence*: a change in the indicator should be attributable to changes caused by the demonstrated solution.

    It should be noted however that the definition of a baseline which can be used to compare the results before and after the introduction of the system in this type of project is not trivial. In general, as a baseline in the INFRAMIX evaluation analysis, historical data on the current conventional traffic will be used. This is an outcome out of several considerations to use another baseline, for example a baseline that considers an amount of AVs already inserted in the real traffic. The following aspects contributed not to follow these considerations:
    - *There is uncertainty of the number of AVs expected to enter traffic, independently of infrastructure developments*
    - *Automated functionalities to operate have specific road requirements (ODD) otherwise the vehicles stay in no-automation mode*
    - *Key project objective is to support an incremental upgrade towards automation-appropriate infrastructure networks*
4. List the data that is required for the representation of the indicator.

    Whether an indicator is measurable depends on the required data and measurement methods. Step 4, step 5 and step 6 therefore run in parallel. Data can be qualitative or quantitative, subjective or objective.
5. Decide how you will collect the data in terms of method, frequency, period and target group.

Related to each Performance Indicator, an owner will be defined, referring to the main partner that will provide input and data related to it,

Finally, it is important to assign responsibilities for the data collection and to inform the people involved about the goal of measurement. Measuring and data collection for most people is not part of their day-to-day activities. Therefore, both the responsibility and the importance should be clear to make sure that this activity gets enough attention during the execution of the scenarios.

As explained previously, three domains have been defined to classify the RQ and PI and improve their understanding.

- User appreciation, which focuses on evaluating parameters related to the user perspective and involvement on the traffic (both in conventional as well as automated driving);
- Traffic Efficiency Impact;
- Traffic Safety

It is important to note that it may happen that the same use case and derived RQ can be measured with PI that are defined in different domains, as they are faced from different points of views.

On the other hand, during the evaluation the PIs and measurements will be fed using two main sources of information:

- Simulation and real testing, in the form of logs and data provided by technical systems
- Users input, in the form of surveys within target groups and interviews with key individuals and/or stakeholder's representatives

INFRAMIX will manage both origins of information, elaborating specific procedures for the retrieval of the data.

The evaluation activity is heavily related to several other aspects of the project: WP2 and WP3 concern the technical architecture and simulation aspects and their logging capabilities; and WP4 concerns the demonstration activities and the data generation and gathering.

2.2 Evaluation based on Simulation and Real testing

The following section describes the main steps that should cover the generation, collection, gathering and analysis of the measurements produced by the simulation and real testing.

The simulators delivered in WP2 (M18) will be used in T5.3 to evaluate Traffic Efficiency and Safety impacts. Details on the co-simulation platform and hybrid testing functionalities are published under INFRAMIX D2.3 Specification of submicroscopic modelling for intelligent vehicle behavior. Furthermore, WP4 is responsible for the preparation of the data recording and collection, homogenization and processing before analysis for the simulators, data collection and aggregation for Simulation and Demonstrators will be addressed in T4.5 starting in M19 of the project.

Regarding the real-testing it is important to finalize the Demonstrations plans (T4.1) due in M18 in order to identify the possible data sources for evaluation. Due to the characteristics of vehicles available (which include different technological levels concerning communication), the evaluation of traffic and safety impact will not be able to be evaluated in real traffic. Furthermore, the technical feasibility of the proposed solutions (including new C-ITS messages, hybrid communication, new signs, etc.) will be addressed in WP4. The evaluation based on user inputs detailed in the next section will also be conducted in Spain and Austria.

Finally, hybrid-testing will compensate the lack of vehicles with AD technologies on the test-sites and will be able to perform some technology evaluations with a strong impact on traffic efficiency and safety. Please refer to Section 7 for additional details.

Hereafter a summary of how the simulation and real testing data will be used is provided:

Simulation tests:
Flow, speed and density measurements per class of vehicles (e.g. car; truck; connected or not) per section-lane and per measurement time step will allow for any kind of aggregation necessary. And, for the calculation of most of the performance indexes (e.g. total travel time, total distance travelled, total delay) used for the evaluation of traffic impact for each one of the use cases. Additionally, some more simulation logs can provide directly some other performance indexes (e.g. the number of stops or the fuel consumption). In order to make sure that statistically meaningful results are reported, a high number of different replications (with a different seed used for any kind of random number generator used for sampling the parameters used by the microscopic simulator) will be necessary both for the before (without any control action) and after (with control actions defined in the corresponding use cases)

cases. Appropriate statistical tests (t-tests) can be used to check various hypotheses.

Real tests:
Flow speed and occupancy measurements per class of vehicles (e.g. car; truck; connected or not) per section-lane and per measurement time step will allow for any kind of aggregation necessary and for the estimation of most of the performance indexes used above for simulation evaluation. However, the extremely low penetration of connected vehicles for an extremely short period of time (i.e. a short slice of time within the peak period) will not allow for an evaluation of any use case that requires control actions to be realized by connected vehicles. Only control actions that use as actuators convectional means (e.g. VMSs) can be evaluated properly using the above measurements for periods of time before and after the application of the corresponding use case.

2.3 Evaluation based on users' input

The following section describes the main steps that cover the generation, collection and analysis of the measurements provided by the target users

1. Assess the usability of existing indicators and identify potential gaps for the evaluation
2. Preparation of a questionnaire for collecting data among user groups
    a. The questionnaire will be developed with the aim to collect both the users' opinions on INFRAMIX developments and the individual characteristics of the interviewees; this will provide a better understanding on how stakeholders with different characteristics respond to the use cases and is expected to provide more detailed information for the evaluation
    b. The questionnaires will be formulated so as to capture both ex-ante and ex-post opinions, so as to understand the difference between the user's expectations and the users' opinions after experiencing the system; these opinions will be compared during the analysis
3. Collection of data will be potentially fine-tuned through face to face interviews
4. Assess the findings

Hereafter a summary of the way the data collected from users will be utilized is provided: once data has been collected, the following process of data analysis represents a key step to produce a quality study. However, before starting the analysis, following the practices listed below is imperative to ensure the relevance of data towards the survey design:

1. **Look for suspicious answer patterns:** sometimes referred to as "Christmas Tree" or "straightlining," these type of responses to checkbox or single-choice questions follow a very clear pattern, and they don't reflect thoughtful, accurate answers.

2. **Discard full checkbox responses:** whenever someone consistently picks all the checkbox options it's often a sign that they're just speeding through the survey without reading all the choices. Typically, these responses can be thrown out of your data set.

3. **Exclude nonsense open-ended answers:** a look at what people type into required text boxes will often give immediate insight into which responses are valuable and which should be excluded.

4. **Edit** illegible, incomplete, inconsistent and ambiguous answers.

5. **Check completion times:** you should know your average survey completion time, and you should be suspicious of responses that come in well under that time.

6. **Discard** duplicate responses.

7. **Clean**: inconsistencies may arise from faulty logic, out of range or extreme values. Outliers are usually represented in boxplots so that it's easier to visually compare them to the normal distribution of other values.

8. **Statistical adjustments**: statistical adjustments apply to data that require weighting and scale transformations.

9. **Analysis strategy selection and preliminary reports**: selection of a data analysis strategy is based on earlier work in designing the research project but is finalized after consideration of the characteristics of the data that has been gathered. Writing preliminary reports could help to determine:
   - If the original questions are answered.
   - If the data is in the format expected.
   - Whether the respondents represent the population.
   - Whether the expected trends are detected.

Additional discussion on this process has been included in section 6.4

3. User Appreciation Hypotheses and Indicators

The key issues in the user-related domain are user reactions/behavior, usability and user's acceptance of the system. These issues include both the efficiency, with which the driver and system react to and interact in normal and in critical situations, as well as how the driver perceives, understands, accepts and trusts the system's operating principles.
The main objectives of user appreciation evaluation in INFRAMIX, are to study user acceptance about INFRAMIX developments. The evaluation focuses at measuring users' acceptance towards the new visual signs and the wireless messages extensions required for the implementation of the "hybrid" road infrastructure services. Depending on the possibilities to observe, control the scenario and ensure the safety of the user, the tests will be performed in real traffic on test sites. In the WP5 activities, it will be also analyzed if this can be done in simulated traffic conditions.
An appropriate degree of usability and acceptance is crucial since, for example an insufficient understanding of the system's functionalities or operating conditions may lead to a minimum number of users following the systems recommendations and therefore an efficient traffic management will not be possible.
The most reliable method of evaluating systems acceptance is Field Operational Tests (FOT), which investigates driver's interaction with the functions during natural driving conditions for a longer period of time. Besides the fact that FOT for INFRAMIX development would be challenging due to the novelty of the traffic management strategies, the method is time-consuming and will not be relevant for INFRAMIX due to the lack of time and resources.
In INFRAMIX user-related assessments will illuminate user's reactions to the developed functions by mainly using naïve subjects in the project traffic scenarios. Using naïve subjects means that the test drivers have equal experience and prior knowledge of the system as a later customer will have. All tests will be followed by questionnaires or interviews that also will give information about the test drivers' opinions on the functions in question.
Users involve apart from drivers also road operators acting in traffic management centers and other stakeholders who could benefit from the deployment of an "hybrid" road infrastructure system.
Data for user evaluation will mainly be collected at the test sites during the demonstrations and at the public events, *as mentioned in the chapter of users' engagement*, through questionnaires. Also experience of the system via visualization items from simulation, or depiction of the new visual signs e.g. in a tablet may be utilized. The following table summarizes the use cases mapped to the demonstrations that will take place in each test site:

Table 14 – Summary of use cases mapped to test sites

Use cases	Spanish test site	Austrian test site
S1_DLA_UC1_DPR	X	X
S1_DLA_UC2_AWC		
S1_DLA_UC3_CVDL	X	
S2_RWZ_UC1_SLC		X
S2_RWZ_UC2_NLD		
S3_BTN_UC1_DBAS	X	X
S3_BTN_UC2_LCA	X	X
S3_BTN_UC3_LCAFC	X	X

Differences are expected between test sites in the recruiting criteria of test people. In many cases the company employees of INFRAMIX partners might be test persons. To diminish the possible harmful effects, it is instructed that the test person should not be otherwise involved in INFRAMIX or in similar projects or in ICT or ITS development projects.
The motorway test sites (Girona and Graz) are encouraged to recruit general public with a balanced gender distribution. Some functionalities, specifically the ones related to electronic road horizon which will be demonstrated through a mobile application, could be implemented in company cars as mobiles with the specific app should be mounted.

3.1 Research Questions / Hypotheses

High level research questions have been formulated in order to categorize the assessment of the main aspects that influence the usability and acceptance of the system by the users. The High-Level Research Questions (HL-RQs) were hence selected as follow:

- Behavior change:

Does the user act according to the “hybrid” infrastructure recommendations?

- Willingness to use:

How high is the willingness to use a motorway equipped with “hybrid” infrastructure?

- Perceived usability:

Do the users consider usability/ user experience to be good/high?

The research question whether the user agree to be an active input was also considered but found irrelevant to the project as the data will be anonymized. Moreover, the factor of user willingness to pay could be under investigation. However, the user’s willingness to pay expected to be increased with experience related to the benefits comparing with the cost and the travel. This experience is unfeasible to be provided to the users in the project timeframe and therefore the specific research question could not be evaluated.

The research of the project has been categorized from the beginning of the project into long- and short-term strategy regarding the time horizon. So low research relevance is related to long term strategy while short term strategy is of high research relevance. Consequently, the high-level research questions have been categorized as shown in the following table:

Table 15 – Categorization of the research questions

	long	short	Comments
Does the user act according to the “hybrid” infrastructure recommendations?		X	
Is willingness to use a motorway equipped with “hybrid” infrastructure high?	X		the willingness is expected to increase with experience
Do the users consider usability/ user experience to be good/high?		X	

The high-level research questions were further divided in detailed research questions. These questions are further prioritized by consortium experts based on the time horizon as it is performed with the high-level questions (previous table) but also based on the relevance for each use case (following tables).
The main criteria used for the prioritization were (1) the strength of contribution of each question to the acceptance evaluation and (2) the feasibility of collecting enough data to lead to meaningful results per use case.

The prioritization scores were 1=high, 2=medium, and 3=low importance.

Table 16 – Categorization of the research questions based on use cases: dynamic lane assignment

User acceptance	RQs	horizon	Dynamic lane assignment			site – specific comments
			DPR	AWC	CVDL	
Behavior change	RQ1.1 Do users state that they would consider following the sign suggestions?	short	1	2	1	
Willingness to use	RQ2.1 Do users state that they are willing to use the information provided by the signs?	long	1	1	1	
Perceived usability	RQ3.1 Do users perceive the traffic management functionalities/ app as useful and satisfying?	short	1	2	1	
	RQ3.2 Do users perceive the signs as easy to learn?	long	1	1	1	
	RQ3.3 Do users perceive the signs as intuitive?	short	1	1	1	
	RQ3.4 Do users perceive the signs as easy to understand?	short	1	1	1	
	RQ3.5 Do users appreciate the timing and number of signs (gantries) per kilometric distance?	short	1	3	1	
	RQ3.6 Do users believe that the signs provide correct information?	short	1	1	1	
	RQ3.7 Do users perceive that the signs are not distracting them from the driving task?	short	1	1	2	

Table 17 – Categorization of the research questions based on use cases: roadworks

User acceptance	RQs	Roadworks zone		site-specific comments
		SL C	NLD	
Behaviour change	RQ1.1 Do users state that they would consider following the sign suggestions?	1	1	
Willingness to use	RQ2.1 Do users state that they are willing to use the information provided by the signs?	1	1	
Perceived usability	RQ3.1 Do users perceive the traffic management functionalities/ app as useful and satisfying?	1	1	
	RQ3.2 Do users perceive the signs as easy to learn?	1	1	
	RQ3.3 Do users perceive the signs as intuitive?	1	1	
	RQ3.4 Do users perceive the signs as easy to understand?	1	1	
	RQ3.5 Do users appreciate the timing and number of signs (gantries) per kilometric distance?	1	3	
	RQ3.6 Do users believe that the signs provide correct information?	1	1	
	RQ3.7 Do users perceive that the signs are not distracting them from the driving task?	1	1	

Table 18 – Categorization of the research questions based on use cases: bottlenecks

		Bottlenecks			Site – specific comments
User acceptance	RQs	DBAS	LCA	LCAFC	
Behavior change	RQ1.1 Do users state that they would consider following the sign suggestions?	1	1	1	
Willingness to use	RQ2.1 Do users state that they are willing to use the information provided by the signs?	1	1	1	
Perceived usability	RQ3.1 Do users perceive the traffic management functionalities/ app as useful and satisfying?	1	1	1	
	RQ3.2 Do users perceive the signs as easy to learn?	3	2	2	
	RQ3.3 Do users perceive the signs as intuitive?	3	2	2	
	RQ3.4 Do users perceive the signs as easy to understand?	2	2	2	
	RQ3.5 Do users appreciate the timing and number of signs (gantries) per kilometric distance?	1	1	1	
	RQ3.6 Do users believe that the signs provide correct information?	1	1	1	
	RQ3.7 Do users perceive that the signs are not distracting them from the driving task?	1	1	1	

The next table gives a visual overview of the relation between user appreciation factors, research questions and their related hypothesis. The study is based on four main user appreciation factors, each of whom could be articulated into one or more research questions (RQs). The latter are related to specific hypothesis (Hs) that will be tested in different use cases. Furthermore, colours indicate the priority of each RQ, with darker shades standing for higher priority. A list of both RQs and Hs is given below, whereas more insightful information is provided in Annex 11.3 Performance Indicators

Table 19 – Performance Indicators for User Appreciation

User appreciation factor	Research question	Hypothesis	S1_UC1	S1_UC2	S1_UC3	S2_UC1	S2_UC2	S3_UC1	S3_UC2	S3_UC3
Behaviour change	RQ1.1 Behaviour change	H1.1	x	x	x	x	x	x	x	x
Willingness to use	RQ2.1 Willingness to use	H2.1	x	x	x	x	x	x	x	x
Perceived usability	RQ3.1 Traffic management	H3.1	x		x			x	x	x
	RQ3.2 Learnability	H3.2	x	x	x	x	x	x	x	x
	RQ3.3 Intuitiveness	H3.3	x	x	x	x	x	x	x	x
	RG3.4 Understandability	H3.4	x	x	x	x	x	x	x	x
	RQ3.5 Timing and number of signs	H3.5	x	x	x	x	x			
	RQ3.6 Correct information	H3.6	x	x	x	x	x	x	x	x
	RQ3.7 No distraction	H3.7	x	x	x	x	x	x	x	x

Low Medium High

The detailed list of Research Questions is included here:

Table 20 – Research Questions for User Appreciation

RQ1.1 Do users state that they would consider following the sign suggestions?
RQ2.1 Do users state that they are willing to use the information provided by the signs?
RQ3.1 Do users perceive the traffic management functionalities/ app as useful and satisfying?
RQ3.2 Do users perceive the signs as easy to learn?
RQ3.3 Do users perceive the signs as intuitive?
RQ3.4 Do users perceive the signs as easy to understand?
RQ3.5 Do users appreciate the timing and number of signs (gantries) per kilometric distance?
RQ3.6 Do users believe that the signs provide correct information?
RQ3.7 Do users perceive that the signs are not distracting them from the driving task?

The detailed list of Hypothesis is included here:

Table 21 – Hypothesis for User Appreciation

H1.1 Users state that they would consider following the sign suggestions
H2.1 Users state that they are willing to use the information provided by the signs
H3.1 Users perceive the traffic management functionalities /app as useful and satisfying
H3.2 Users perceive the signs as easy to learn
H3.3 Users perceive the signs as intuitive
H3.4 Users perceive the signs as easy to understand
H3.5 Users appreciate the timing and number of signs (gantries) per kilometric distance (or maybe just: Users appreciate the time when they have information from the infrastructure while driving in specific road segment)
H3.6 Users believe that the signs provide correct information
H3.7 Users perceive the signs are not distracting them from the driving task

3.2 Performance Indicators and Measurements

After having identified RQs and their related hypothesis, the evaluation process can evolve towards the selection of performance indicators and their specific measurements. Table 22 below represents the hypothesis' testing methods.

Table 22 – Performance Indicators and Measurements for User Appreciation

	Performance indicator			Measurements		
Hypothesis	**Behavior change**	**Willingness to use**	**Perceived usability**	**Questionnaire**	**Time driven in automation mode**	**Questionnaire/interview/focus group**
H1.1	x			x	x	
H2.1		x		x		
H3.1			x	x		
H3.2			x	x		
H3.3			x	x		
H3.4			x	x		
H3.5			x	x		X
H3.6			x	x		
H3.7			x	x		

3.3 Measurement Tools

Table **23** deals with the last step of the evaluation process - i.e. data acquisition - and outlines the roles and sites for hypothesis testing. A positive feature of this table is that each owner could easily trace its commitment in each testing site, be it physical, virtual or hybrid. Every hypothesis has a fixed position within the boxes. Annex 11.3 is included for additional reference.

Table 23 – Measurements for User Appreciation

	Austrian site				Spanish site				Virtual environment			
AAE				H2.1			H1.1	H2.1				H2.1
	H3.1	H3.2	H3.3	H3.4	H3.1	H3.2	H3.3	H3.4	H3.1	H3.2	H3.3	H3.4
	H3.5	H3.6	H3.7		H3.5	H3.6	H3.7			H3.6		
ASF				H2.1								H3.1
	H3.1	H3.2	H3.3	H3.4	H3.1	H3.2	H3.3	H3.4	H3.1	H3.2	H3.3	H3.4
	H3.5	H3.6	H3.7		H3.5	H3.6	H3.7			H3.6		
BMW												
	H3.1					H3.2					H3.4	
FOK												
	H3.1	H3.2	H3.3		H3.1	H3.2	H3.3		H3.1	H3.2	H3.3	
	H3.5	H3.6				H3.6				H3.6		
TOM				H2.1				H2.1				H2.1
	H3.1	H3.2	H3.3	H3.4	H3.1	H3.2	H3.3	H3.4	H3.1	H3.2	H3.3	H3.4
	H3.5				H3.5					H3.6		

Note: H1.1: It will be analyzed whether it could be based on questionnaires on rest areas for visual signs

4. Traffic Efficiency and Safety Hypotheses and Indicators

4.1 Research Questions / Hypotheses

The first and main research question that has been posed with respect to the impact on traffic flow efficiency is whether the performance of a freeway stretch/network, that includes a bottleneck which is activated recurrently, can be improved using CAVs. A freeway stretch/network is considered to be operated in a more efficient way if travel times are reduced. This is directly connected to the speed as well as the delay time observed on the network. INFRAMIX's hypothesis is that the use of appropriate control strategies that take into account CAVs can lead to efficiency improvement for a freeway stretch/network.

Another research question that has been posed with respect to traffic flow efficiency and that is indirectly connected with the answer to the previous research question is whether fuel consumption for a freeway stretch/network can be improved using AVs. INFRAMIX's hypothesis is that the use of appropriate control strategies that take into account CAVs can lead to fuel consumption reduction for a freeway stretch/network.

Finally, one of the main issues that need to be considered is safety and whether it can be improved using CAVs. Traffic safety is directly connected to the exposure of drivers to traffic conditions. As a result, related research questions can be posed. Is time spent on the road affected using control actions? Is the timing of journeys affected? Is the use of specific road types affected? Is the type of vehicles used affected? These research questions could be coupled with corresponding hypotheses. However, most of these research questions could only be answered if related control measures are applied on networks and for quite long periods of time, which is not applicable for INFRAMIX. The only hypothesis that INFRAMIX is going to validate is if travel times are reduced due to control strategies that take into account CAVs, which is a hypothesis that answers directly efficiency related research questions posed above.

Safety is also directly connected to risk. Research question related to risk can be posed as well. Is vehicles' speed affected? Is vehicles' proximity affected? Is vehicles' position affected? Are interactions between vehicles and drivers affected? Is the use of signals affected? Do users state that the drivers' condition/attention is affected? Again, only part of these research questions can be answered in the frame of INFRAMIX. INFRAMIX's hypotheses related to risk are the following. Mean speed will be increased due to the use of appropriate control strategies that take into account CAVs. However, the standard deviation from this mean speed will be decreased, which means that traffic conditions will be more homogeneous. Drivers' workload is expected to be increased due to the control actions that will be implemented in the bottleneck areas during the peak periods. As a result, drivers will have to follow more speed limit changes, perform more lane changes and adapt their time gap setting to the ordered ones. However, all the above will be performed in a less congested traffic and as a result will not increase the risk for an accident.

In the case of the identification of Performance Indicators for Safety domain, the paper *Ex-ante assessment of the safety effects of intelligent transport systems*[3] has been used in order to determine the full scope of the potential situations related to Traffic Safety. Then, these situations have been selected and adapted to the INFRAMIX context.

In conclusion, we believe that the use of appropriate control strategies that take into account CAVs can lead to safer conditions for all vehicles due to less congested freeway stretches.

The detailed list of Research Questions is included here:

[3] https://www.sciencedirect.com/science/article/abs/pii/S000145751000062X

Table 24 – Research Questions for Efficiency

TE-RQ1.1	At which % of automated vehicles a dedicated lane is more appropriate in terms of traffic efficiency?
TE-RQ1.2	How long in advance do we need to inform about the activation of a dedicated lane?
TE-RQ1.3	What should be length of the dedicated lane based on traffic conditions?
TE-RQ1.4	What is the effect of a different number of entrances and exits in the dedicated lane?
TE-RQ2.1	Can the performance of a freeway stretch, that includes a bottleneck which is activated recurrently, be improved by use of AVs?
TE-RQ6.1	Can fuel consumption for a freeway stretch, that includes a bottleneck which is activated recurrently, be improved by use of AVs?
TE-RQ3.1	Can safety be improved by use of AVs for freeway control?
TE-RQ4.1	At which traffic flows can an AV successfully merge into the traffic flow on remaining lanes?
TE-RQ4.2	At which traffic flows the merging of an AV causes critical situations?
TE-RQ4.3	What is the impact on the main traffic of an AV merging in the main traffic?
TE-RQ4.4	How long does it take an AV to merge into the main traffic?
TE-RQ4.5	Can an AV pass a roadworks zone with a new lane design?
TE-RQ4.6	Can an AV pass a roadworks zone with a new lane design without causing critical situations?
TE-RQ4.7	What is the impact on the traffic of an AV passing a roadworks zone with a new lane design?
TE-RQ4.8	At which traffic flow can an AV successfully merge into the flow on the main lane?
TE-RQ5.1	Is the relevance area of an ITS-Message sufficient for a vehicle to react timely?
TE-RQ5.2	Is the information of the MAPEM is sufficient to guide a vehicle through a roadworks zone?

Table 25 – Research Questions for Safety

SF-RQ1.1	Is time spent on the road affected?
SF-RQ2.1	Is vehicles' speed affected?
SF-RQ2.2	Is vehicles' proximity affected?
SF-RQ2.3	Is vehicles' position affected?
SF-RQ2.4	Are interactions between vehicles/drivers affected?
SF-RQ3.1	Is speed affected?

The detailed list of Hypothesis is included here:

Table 26 – Hypothesis for Efficiency

TE-H1.1	Traffic efficiency will increase if a dedicated lane for AV is set when AV % is over X
TE-H1.2	Traffic efficiency will increase if a dedicated lane is informed enough in advance
TE-H1.3	Traffic efficiency will increase if a dedicated lane for AV is set of a certain length
TE-H1.4	Traffic efficiency will increase if a dedicated lane is set with a number of entrances/exits
TE-H2.1	The use of appropriate control strategies that take into account AVs can lead to performance improvement for freeway stretch.

TE-H3.1	The use of appropriate control strategies that take into account AVs can lead to performance improvement for freeway stretch and as a result less congestion and safer conditions for the vehicles.
TE-H4.1	If the traffic density is high an AV will not be able to merge into the traffic on the remaining lanes.
TE-H4.2	The number of critical situations will increase when an AV merges into the traffic on the remaining lanes if the traffic density is high.
TE-H4.3	The merging of an AV can cause degradations of the traffic flow.
TE-H4.4	The distance to merge depends on the traffic flow on main lane.
TE-H4.5	An AV is able to pass a roadworks zone with a new lane design defined in a MAPEM message.
TE-H4.6	An AV is able to pass a roadworks zone with a new lane design defined in a MAPEM message.
TE-H4.7	There is impact in the traffic when an AV passing a roadworks zone with a new lane design
TE-H4.8	If the traffic density is high an AV will not be able to merge into the traffic on the main lane.
TE-H5.1	The AV is able to receive the ITS-Message which informs about an oncoming roadworks zone and can timely start to merge into the traffic on the remaining lanes.
TE-H5.2	The AV is able to receive a MAPEM message and can following the information provided with this message pass a roadworks zone with a new lane design.
TE-H5.3	The AV is able to receive a MAPEM message and can follow the information provided with this message to pass a roadworks zone with a new lane design.
TE-H5.4	The AV is able to receive an ITS-Message with a Speed information and is able to adapt the speed according the information.
TE-H5.5	The AV is able to receive a lane-change advice and is able to react on the advice if the traffic allows it.
TE-H6.1	The use of appropriate control strategies that take into account AVs can lead to fuel consumption reduction for freeway stretch.

Table 27 – Hypothesis for Safety

SF-H1.1.2	Journey times increase/decrease because...
SF-H2.1.1	There is an increase/decrease in mean speed because…
SF-H2.1.2	There an increase/decrease in maximum speed because…
SF-H2.1.3	There an increase/decrease in median speed
SF-H2.1.4	There an increase/decrease in standard deviation of speed
SF-H2.1.7	There is an increase of the deceleration/negative acceleration rate
SF-H2.2.1	There is an increase/decrease in the probability of time headway less than 1s during following
SF-H2.3.1	There an increase/decrease in the number of lane changes
SF-H2.4.1	Drivers of conventional vehicles state that the interactions with an AV are perceived to be easier/intuitive
SF-H2.7.3	There is an increase/decrease in number of times a road sign in the in-vehicle HMI is missed
SF-H3.1.1	There is an increase/decrease in mean speed

4.2 Performance Indicators and Measurements

In order to evaluate the first hypothesis, the following performance indicators (average values and standard deviations) will be calculated for different classes of vehicles, either CAVs or not:

- Travel time

- Delay time, i.e. travel time minus free flow travel time
- Mean speed
- Harmonic speed

Also, the following aggregated performance indicators will be calculated:

- Total distance travelled
- Total time travelled

and will enable conclusions for the whole system/network under consideration.

As discussed also in Section 2 Evaluation methodology, the necessary measurements for the calculation of the above performance indicators are the flow, the speed and the density per class of vehicles for all segment-lanes per measurement time step.

The second hypothesis discussed above can of course be validated by calculating fuel consumption per kilometer travelled for different classes of vehicles. This requires the use of appropriate instant fuel consumption models that consider as an input the speed and the acceleration of each vehicle. As a result, it is necessary to either archive trajectory data for all vehicles or, in case of simulations, calculate the necessary quantities while performing the simulation steps.

In order to evaluate the set of hypotheses related to safety, the following performance indicators (average values and standard deviations) will be calculated for different classes of vehicles:

- Travel time
- Mean speed, median speed and maximum speed
- Number of stops (note that a vehicle can be considered to be stopped if its speed is below a specified threshold)
- Mean headway in correlation with the mean speed
- Total number of stops
- Number of control actions that must be implemented.

The table below gives a visual overview of the relation between traffic efficiency and safety factors, research questions (RQ) and their related hypothesis (H). These RQ are related to specific hypothesis (Hs) that will be tested in different use cases. Furthermore, colours indicate the priority of each RQ, with darker shades standing for higher priority. A list of both RQs and Hs is given below, whereas more insightful information is provided in Annex 11.3 Performance Indicators

Table 28 – Performance Indicators for Traffic Efficiency and Safety

Performance indicator	Research question	Hypothesis	S1_UC1	S1_UC2	S1_UC3	S2_UC1	S2_UC2	S3_UC1	S3_UC2	S3_UC3
Throughput of AV vs conventional vehicles	TE-RQ1.1	TE-H1.1	x							
	TE-RQ1.2	TE-H1.2	x							
	TE-RQ1.3	TE-H1.3	x							
	TE-RQ1.4	TE-H1.4	x							
Delay time, i.e. travel time minus free flow travel time, (average and deviation) for different classes of vehicles	TE-RQ2.1	TE-H2.1						x	X	x
Mean speed (average and deviation) for different classes of vehicles	TE-RQ2.1	TE-H2.1						x	X	x

Performance indicator	**Research question**	**Hypothesis**	S1_UC1	S1_UC2	S1_UC3	S2_UC1	S2_UC2	S3_UC1	S3_UC2	S3_UC3
Harmonic speed (average and deviation) for different classes of vehicles	TE-RQ2.1	TE-H2.1						x	X	x
Total distance travelled	TE-RQ2.1	TE-H2.1						x	X	x
Total time travelled	TE-RQ2.1	TE-H2.1						x	X	x
Travel time (average and deviation) for different classes of vehicles	TE-RQ2.1	TE-H2.1						x	X	x
Number of stops (average and deviation) for different classes of vehicles *A vehicle can be considered to be stopped if its speed is below a low threshold.	TE-RQ3.1	TE-H3.1						x	X	x
Total number of stops	TE-RQ3.1	TE-H3.1						x	X	x
Mean headway (average and deviation) for different classes of vehicles in correlation with the mean speed	TE-RQ3.1	TE-H3.1						x	X	x
Vehicle has merged successfully/not successfully	TE-RQ4.1	TE-H4.1				x				
	TE-RQ4.8	TE-H4.8								x
Criticality: Minimal TTC values, headway distances below threshold	TE-RQ4.2	TE-H4.2				x				X
	TE-RQ4.6	TE-H4.6					x			
	TE-RQ5.1	TE-H5.1				x				
Impact of main traffic (characteristics of simulated traffic, e.g. flow/density/degradations)	TE-RQ4.3	TE-H4.3				x				X
	TE-RQ4.7	TE-H4.7					x			
Distance to merge (distribution)	TE-RQ4.4	TE-H4.4				x				x
Vehicle has passed successfully/not successfully (i.e. has stopped)	TE-RQ4.5	TE-H4.5					x			
	TE-RQ5.2	TE-H5.3					X			
Time between sending and receiving the message	TE-RQ5.1	TE-H5.1				x				
	TE-RQ5.1	TE-H5.2					x			
	TE-RQ5.1	TE-H5.4								x
	TE-RQ5.1	TE-H5.5								X
The Vehicle has performed a lane change.	TE-RQ5.1	TE-H5.1				x				
Difference between traveled trajectory and MAPEM information	TE-RQ5.2	TE-H5.3					x			
Vehicle has adapted the speed.	TE-RQ5.1	TE-H5.4								x
Vehicle has started a lane change.	TE-RQ5.1	TE-H5.5								x

Performance indicator	Research question	Hypothesis	S1_UC1	S1_UC2	S1_UC3	S2_UC1	S2_UC2	S3_UC1	S3_UC2	S3_UC3
Fuel consumption per kilometer travelled	TE- RQ6.1	TE-H6.1						x	X	x
SAFETY										
Journey time per distance	SF-RQ1.1	SF-H1.1.2	x	x	x	x	x	x	X	x
Speed per segment	SF-RQ2.1	SF-H2.1.1	x	x	x	x	x	x	X	x
	SF-RQ2.1	SF-H2.1.2	x	x	x	x	x	x	X	x
	SF-RQ2.1	SF-H2.1.3	x	x	x	x	x	x	X	x
	SF-RQ2.1	SF-H2.1.4	x	x	x	x	x	x	X	x
Acceleration rate	SF-RQ2.1	SF-H2.1.7	x	x	x	x	x	x	X	x
Time gap	SF-RQ2.2	SF-H2.2.1	x	x	x	x	x	x	X	x
Number of lane changes	SF-RQ2.3	SF-H2.3.1	x	x	x	x	x	x	X	x
Behaviour change	SF-RQ2.4	SF-H2.4.1	x	x	x	x	x	x	X	x
Perceived usability	SF-RQ2.4	SF-H2.7.3	x	x	x	x	x	x	X	x
Mean speed	SF-RQ3.1	SF-H3.1.1	x	x	x	x	x	x	X	x

4.3 Performance Indicators and Measurements

After having identified RQs and their related hypothesis, the evaluation process can evolve towards the selection of performance indicators and their specific measurements. The table below represents the hypothesis' testing methods.

Table 29 – Performance Indicators and Measurements for Traffic Efficiency and Safety

Performance indicator	Measurement
Throughput of AV vs conventional vehicles	Throughput of AV vs conventional vehicles
Delay time, i.e. travel time minus free flow travel time, (average and deviation) for different classes of vehicles	Delay time
Mean speed (average and deviation) for different classes of vehicles	Speed
Harmonic speed (average and deviation) for different classes of vehicles	Speed
Total distance travelled	Total distance travelled
Total time travelled	Total time travelled
Travel time (average and deviation) for different classes of vehicles	Travel time
Number of stops (average and deviation) for different classes of vehicles *A vehicle can be considered to be	Number of stops

Performance indicator	Measurement
stopped if its speed is below a low threshold.	
Total number of stops	Total number of stops
Mean headway (average and deviation) for different classes of vehicles in correlation with the mean speed	Mean headway, Mean speed
Vehicle has merged successfully/not successfully	Vehicle has merged successfully/not successfully
Criticality: Minimal TTC values, headway distances below threshold	TTC; headway
Impact of main traffic (characteristics of simulated traffic, e.g. flow/density/degradations)	traffic flow/traffic density
Distance to merge (distribution)	Distance to merge
Vehicle has passed successfully/not successfully (i.e. has stopped)	Vehicle has passed successfully/not successfully
Time between sending and receiving the message	Transmission time
The Vehicle has performed a lane change.	position (trajectory)
Difference between traveled trajectory and MAPEM information	position (trajectory)
Vehicle has adapted the speed.	Speed
Vehicle has started a lane change.	position (trajectory)
Fuel consumption per kilometer travelled	Fuel consumption per kilometer travelled
Journey time per distance	journey time per distance
Speed per segment	Speed
Acceleration rate	Acceleration rate
Time gap	Time gap
Number of lane changes	Number of lane changes
Behaviour change	Data from answer to the questionnaire
Perceived usability	Data from answer to the questionnaire
Mean speed	Speed

5. Summary table of Performance Indicators

This following section includes a summary table with an overview of the detected Performance Indicators, the evaluation domain and their sources of information

Table 30 – Overview of the Performance Indicators for INFRAMIX evaluation

	Performance indicator	Users appreciation	Traffic efficiency	Traffic safety	Austrian Test Site	Spanish Test Site	Hybrid testing	Co-Simulation platform
User Input	Behavior change	x		x	X	x		
	Willingness to use	x		x	X	x		
	Perceived usability	x		x	X	x		
	Throughput of AV vs conventional vehicles		x					x
time	Travel time (average and deviation) for different classes of vehicles		x					x
	Journey time per distance			x				x
	Total time travelled		x					x
	Time gap			x			x	
	Time spent in a section/segment			x				x
	Time spent in a dedicated lane			x				x
	Harmonic speed		x					x
distance	Total distance travelled		x		x	x		x
	Distance to merge		x				x	
	Mean headway (average and deviation) for different classes of vehicles		x		x	x		x
	Time to Collision (TTC)		x	x	x		x	
speed	Mean speed (average and deviation) for different classes of vehicles		x	x	x	x		x
	Vehicle has adapted the speed		x				x	x
	Speed per segment			x				x
Lane change	Vehicle has started a lane change		x				x	x
	The vehicle has performed a lane change		x				x	x
	Vehicle has merged successfully/not successfully		x				x	x
	Number of lane changes			x				x
	Fuel consumption per kilometer travelled		x					x
	Number of stops (average and deviation) for different classes of vehicles		x					x
	Time between sending and receiving the message		x				x	
	Difference between travelled trajectory and MAPEM information		x		x		x	
	Vehicle has passed successfully		x				x	

6. User engagement Plan

This section describes the user engagement process that has been defined as part of the evaluation of INFRAMIX. This user engagement is important in order to gather and analyze the input from users and stakeholders' representatives concerning the assumptions, definitions, achievements and outcomes of INFRAMIX.

The objectives and process of these activities are highly related to the purpose of WP6, so a close collaboration is expected.

6.1 Objectives

The following paragraphs describe the main target of the user engagement process, as well as the features that have been defined for the process to fulfil the strategy of evaluation of INFRAMIX.

As already detailed, several aspects related to the evaluation plan (RQ and PI) needs to be measured by using direct input of the expected users, target groups and stakeholders of INFRAMIX. The reason is that several RQ cannot be answered with the technical simulations but only with user perspective.

To do so, a process to involve representatives and groups profiling the different involved stakeholders of INFRAMIX needs to be performed, addressing both individuals as well as groups, using different information gathering techniques: interviews and surveys. INFRAMIX names this process as *user engagement*.

In INFRAMIX, the user engagement process has been defined to have the following features:

- It needs to be inclusive, identifying a diverse range of users.
- It will use a variety of methods appropriate to them.
- Investigate and document the view of users, the use made of statistics and the decisions the users inform.
- It needs to be open and honest, publishing information about user experience, data quality and the timeliness of reports.
- It will give feedback and demonstrate the impact and influence of comments received.

6.2 Modes of engagement

The following table describes the main mechanisms that should be used to involve the target groups of INFRAMIX in the user engagement process:

Table 31 – Modes of engagement

Objective	Communication	Commitment	Examples of engagement approach	
Communicate	Inform or educate stakeholders	One-way: INFRAMIX to stakeholder	'INFRAMIX will keep you informed'	Marketing Communication
Consultation	Gain information & feedback from stakeholders to	Limited two-way: INFRAMIX asks questions and	INFRAMIX will keep you informed, listen to	Customer Contact Centre Web-based

	inform decisions made internally	stakeholders reply	your concerns, consider your insights and provide feedback on our decisions'	surveys One-to-one meetings
Dialogue	Work directly with stakeholders to ensure their concerns are fully understood and considered in decision making	Two-way or multi-way: between INFRAMIX and stakeholders	'INFRAMIX will work with you to ensure your concerns are understood, to develop alternative proposals and provide feedback about how stakeholders' views influenced our decision making'	Forums Roadshows Seek input into communication strategies One to one meetings
Partnerships	Partner with or convene a network of stakeholders to develop mutually agreed solutions and actions	Two-way or multi-way: learning, negotiation	'INFRAMIX will look to you for direct advice and participation in finding and implementing solutions to shared challenges'	Projects Memorandum of understanding
Collaborations	agreed upon collaboration between stakeholders to speed up developments.		E.g. data exchange between DGT & University of Zaragoza concerning signaling and new signs.	
Monitor	Monitor stakeholders' views	One-way: stakeholder to INFRAMIX	'INFRAMIX will monitor your views'	Research Media coverage

INFRAMIX process

The essence of survey method can be explained as "questioning individuals on a topic or topics and then describing their responses". Survey methods pursue two main purposes:

- Describing certain aspects or characteristics of population and/or
- Testing hypotheses about nature of relationships within a population.

Survey methods that will be used in INFRAMIX are divided into two categories: online survey and personal interview. The descriptions of each of these methods are briefly explained on the following table:

Table 32 – Survey methods in INFRAMIX

Survey method	Description	Purpose
Mail survey/questionnaire	A written survey that is self-administered	Conducted in order to gather large size of information in a short period of time
Personal interview	A face-to-face interview of the respondent	Conducted in order to reflect emotions and experiences, and explore issues with a greater focus

Interviews

In the scope of INFRAMIX evaluation process, concerning input from users, as mentioned before, it is planned to use personal interviews as a tool to retrieve information to compare to the objectives of the project (in terms of RQ/PI) against the opinion of individuals.

A semi-structured interview is a method of research used most often in the social sciences. While a structured interview has a rigorous set of questions which does not allow one to divert, a semi-structured interview is open, allowing new ideas to be brought up during the interview as a result of what the interviewee says. The interviewer in a semi-structured interview generally has a framework of themes to be explored.

However, the specific topic or topics that the interviewer wants to explore during the interview should usually be thought about well in advance (especially during interviews for research projects). It is generally beneficial for interviewers to have an interview guide prepared, which is an informal grouping of topics and questions that the interviewer can ask in different ways for different participants. Interview guides help researchers to focus an interview on the topics at hand without constraining them to a particular format. This freedom can help interviewers to tailor their questions to the interview context/situation, and to the people, they are interviewing. [Wikipedia]

This tool will be used in the scope of the evaluation process in order to get initial input on the topics of research of INFRAMIX. For this reason, the target individuals for these interviews must be experts in the addressed matters of the interviews and INFRAMIX topics and/or qualified representatives of key stakeholders. This view is important to confirm the strategy of the project as well as to prepare the later survey process that should extend and validate the initial analysis gathered from these interviews.

Later in WP5, definition of the scope and tailoring of the interviews depending on the addressed expert should be perform. It is advised that these individuals should be selected from the INFRAMIX user group, given their initial involvement in the project activities

The steps to be considered when implementing an interview process are as follows:

- Design an interview framework based on the RQ/PI tailored to the target expert. Make sure to focus on the field of knowledge of the individual.
- Record only brief notes during the interview. Immediately following the interview elaborate upon the notes.
- Analyze the information at the end of each day of interviewing. This can be done with the interview team or group.

- Discuss the overall results of the analysis with community members so that they can challenge the perceptions of the interview team. This can make the process even more participatory.

Surveys and questionnaire

A questionnaire is a set of questions for gathering information from individuals. They can be administered by mail, telephone, using face-to-face interviews, as handouts, or electronically (i.e., by email or through web-based questionnaires). In the case of INFRAMIX, online surveys will be used.

When should questionnaires for evaluation be used?
- When resources are limited and data from many people is needed. You can disseminate questionnaires relatively inexpensively. Your costs will increase if you need to do a lot of follow-up to get a sufficient response rate.
- When it is important to protect the privacy of participants. Questionnaires are helpful in maintaining participants' privacy because participants' responses can be anonymous or confidential.

Several aspects need to be addressed when preparing the plan for the distribution of the surveys:

- Define the objectives. The most critical part of developing a questionnaire is defining the scope and how the information will be used to answer the evaluation.
- Select the number and type of participants for the questionnaire, which is a fundamental part of the definition of the objectives.
- Develop questions that clearly communicate what you want to know. Some aspects that affect the result is the of closed-ended versus open-ended questions; include demographic questions; place questions in a logical order that flows well; communicate the value of your questionnaire to the participants.

Surveys could be subject to different biases as shown in the next table:

Table 33 – Biases and solutions for surveys

Bias	Possible solutions
Sampling bias: mistakes in sampling the population	Thorough preliminary study about the survey's target
Ungiven answers	Blank spaces disable the online sending button
Biases related to questions (wording, order, etc.)	Pilot questionnaire
Biases related to answers (response set[4], social desirability, ignorance of the investigated phenomenon, etc.)	- often a "Don't know" option prevents from random answers - hierarchical questions[5] - control questions[6] - Ask to comment general trends instead of personal opinions

[4] A systematic tendency for respondents or subjects in psychological tests, questionnaires, etc., consistently to respond in a positive manner or to give the same answer to multiple-choice questions, despite their true beliefs. (Oxford dictionary)
[5] Respondents are asked to rank their preferences.
[6] Important questions should be controlled later in the survey by "control questions" that test the same content with different wording.

	- examples or simulations to give a hint of the investigated phenomenon

6.3 Engaging users

Based on the previous definitions, the process to engage users in the evaluation process of INFRAMIX will be executed in the following steps:

- Evaluation topics for users
- Matching of target user groups from stakeholders
- Multi-channel extended communication campaign

The following sections describes theses phases in detail.

6.3.1 Topics for evaluation

As said before, a first step in the process is the identification of the different topics that will be used during the evaluation based on users input. This is a key step as it will completely define many activities as for example:

- the target audience groups to be addressed;
- the definition of the characteristics of the desired sample;
- the communication strategy to create awareness of the surveys;
- the preparation of materials for interviews and surveys, etc.

Therefore, it is important that the topics for evaluation adequately cover the aspects raised during the PI process. This process will be developed later in WP5 tasks

6.3.2 Stakeholders

Once the specific topics for evaluation are clearly defined, it will be necessary to define and address the target groups. This analysis will be based on the general analysis of stakeholder developed in WP6, so a close collaboration during and after this analysis is expected.

Working from D6.3 we may summarize the current understanding of the INFRAMIX stakeholder's context as follows:

Table 34 – Stakeholder groups

<table>
<tr><td colspan="3">Stakeholder groups</td></tr>
<tr><td rowspan="4"></td><td colspan="2">End Users' Group</td></tr>
<tr><td></td><td>Industry
• OEMs / vehicle manufacturers
• Vehicle technology suppliers
• Infrastructure technology suppliers
• Other ICT solution providers</td></tr>
<tr><td rowspan="2"></td><td>Infrastructure and Road authorities
Organisations (public or private) responsible for the correct managing of the road infrastructure. It includes both individual organizations and/ or associations (ERF, CEDR, ASECAP, ERTRAC, BASt, etc).</td></tr>
<tr><td>Public administration
Decision makers, city planners and other public authorities at different geographical levels, as urban areas, regional administrations, countries and different country clusters. They can be responsible for the design, construction, operation and/or legislation of the road transportation in public</td></tr>
</table>

		infrastructures.
		Service providers
		Scientific and research community The results of the project will be broadly disseminated to the scientific community through participation in the most important academic conferences and related events.
		Standardisation bodies This target group will focus on entities as European Telecommunications Standards Institute, ETSI, or Society of Automotive Engineers (SAE).
	Groups and networks An overview on relevant projects, platforms and initiatives is provided in Section 3.0	
	European and international organisations and technical communities This is a wide group of individual associations (i.e. industry associations as EUCAR, OICA, ACEA, VDA, ANFAC, SAE; other relevant EC/national projects; ETP's such as ERTRAC; technology groups as FEHRL, ERTICO, Amsterdam Group, C2C-CC, TM2.0 Platform, ADASIS Forum, NDS Association, AASHTO, FHWA, AUVSI, TRB and the Trilateral EU-US-Japan Automation Working Group in Road Transportation), at European, national and international level, which have significant multiplier potential as associations representing transport authorities and members of the industry.	
	EC staff/politicians and relevant European Organizations This group includes EC staff/politicians, relevant European Organizations (ERTICO, etc), policy advisors and key opinion creators. This will facilitate a clearer overall understanding of the topic and consequently will provide an evident support for decision making activities at higher level. This group includes standardization fora and initiatives where the results and project recommendations will be communicated.	

6.3.3 INFRAMIX User group

In this process, it is important to highlight the role of the INFRAMIX user group in the Evaluation process. In the framework of Task 6.3 of the INFRAMIX project, an End Users' Group has been created for engaging as many stakeholders as possible, collecting their direct feedback and efficiently disseminate project results and evolutions.

The group will be open to joining and will give to its participants the choice of simply receiving information or being more actively involved in INFRAMIX development. The latter will comprise the core members of the End Users' Group. These core members will be requested to provide direct feedback on every opportunity (i.e. through participation at INFRAMIX Stakeholder Workshops), to assist the INFRAMIX consortium to efficiently evaluate the proposed technologies and perform the required corrections according to the end user needs and expectations. This group is also expected to help in reaching consensus regarding the proposed solutions for key issues such as infrastructure classification. The engagement activities are highly expected to increase user acceptance.

So, the Evaluation activities and the users' engagement process will share strategy and resources to maximize the impact, building a relationship with the members of End-user group so they could participate in the evaluation process; and at the same time, to share valuable information produced by the project to understand the challenges and opportunities derived from the devised infrastructure.

6.3.4 Communication campaign

In order to engage and recruit the necessary users and stakeholders for the evaluation activities, a communication campaign will be prepared and executed. Given the nature of the action, collaboration between WP5 and WP6 is expected in the different related aspects of the campaign. The main steps of the campaign will be as follows:

- Definition of message(s) for the addressed group(s)
- Promotion material preparation: press releases, web/digital materials
- Multi-layer and multi-channel broadcast of the materials
- Iteratively, impact assessment, correction of strategy and re-broadcast

On the one hand, the multi-channel approach consists of the use of all the potential communication channels that are available for INFRAMIX: web site, twitter, LinkedIn group but also press releases and participation at events. The different dissemination activities planned during the timeframe of the campaign will be also used for the purposes of evaluation engagement.

On the other hand, the multi-layer approach refers to the use of several intermediate stakeholders that could create additional extension of the campaign, by engaging them at corporate level: retweets, internal/external newsletters, repost, etc. These intermediate stakeholders will include the own INFRAMIX consortium, by involving the different marketing and communication departments, as well as their network of related contacts, to extend the impact. Annex 11.2 List of stakeholders contains a detailed list of organizations that will be used to extend the scope and impact of the communication campaign

6.4 Engaging process

As explained before, two main tools will be used for the data capture of the user inputs: semi-structured interviews and surveys. This section describes additional aspects of this process:

6.4.1 Interviews to INFRAMIX user group

Concerning evaluation, it is planned to involve the INFRAMIX user group in the activities of evaluation by using semi-structure interviews approach. Two main objectives are defined:

- To have an initial input on specific questions before extending the evaluation topic to larger groups
- To have a more direct and open communication concerning the relevant aspects of the discussed topics.

To ensure a success approach, in addition to the considerations made before, several additional aspects must be considered:

- The interviews should be tailored to the specific background of the interviewees, to maximize the quality of their comments. This means that it necessary to ensure that the topics are well distributed among the interviews, covering all the aspects with enough redundancy.

- It is important to profit of the interdisciplinary approach of INFRAMIX by also gathering input for the same topic from different points of views.

6.4.2 Surveys

Different channels will be used in order to engage users in the process, depending on the target of each survey (which will be analysed later in WP5):

- Demonstration sites: after the demonstration activities, direct participants will be engaged to provide their input in the areas and questions included in the demonstration. In addition, it will be analysed the organization of engagement activities among users in rest areas next to the demonstration sites. Also, the use of videos and other interactive tools will be analysed as it could improve the engagement as well as the perception of the concepts
- In addition, for online surveys, campaigns will be organized in order to maximize the recruitment of users, using all the available means: twitter, LinkedIn, website and networking with related entities (as drivers' associations, etc). Additional activities as advertising in specialized media will be analysed.
- Other engagement techniques as rewards and lotteries will be analysed, too.

6.4.3 User gender and background

According to INFRAMIX DoA, section 1.3.6 Gender Issues: *Gender specific mobility expectations, needs and requirements are well recognised by the consortium. Special attention will be paid to understand, and address users' appreciation based on their gender. Females and males will be* equally *present among the test groups. In INFRAMIX we also aim to have a balanced participation between women and men in research activities at different stages of the project.*

In this sense, during the surveys and interviews, information about the gender as well as other characterization factors of the background of the involved users (as education level and age) will be gathered to be used in order to detect different trends in their feedback depending on these aspects.

6.4.4 GDPR aspects

The following section details the aspects that should be taken into account concerning the compliance of the General Data Protection Regulation (GPDR) during the interviews and surveys procedures. Main questions to be considered are as follows:

Data protection officer[7]
The primary role of the data protection officer (DPO) is to ensure that her organization processes the personal data of its staff, customers, providers or any other individuals (also referred to as data subjects) in compliance with the applicable data protection rules. In the EU institutions and bodies, the applicable Data Protection Regulation (Regulation (EC) 45/2001) obliges them each to appoint a DPO. Regulation (EU) 2016/679, which obliges some organizations in EU countries to appoint a DPO, will be applicable as of 25 May 2018. Within INFRAMIX, it will be analyzed if it is necessary to appoint a DPO

Transparency

[7] https://edps.europa.eu/data-protection/data-protection/reference-library/data-protection-officer-dpo_en

The GDPR expands upon the concept of 'transparency'. In a nutshell, you need privacy policies which are: concise, transparent, intelligible and easily accessible, using clear and plain language (Article 12 of the GDPR). These policies should be responsibility of the INFRAMIX DPO, including all the information required by Article 13 of the GDPR.

Data processing principles

The GDPR defines the following 6 principles for processing personal data:
According to Article 5 of the GDPR, personal data shall be:

- processed lawfully, fairly and transparently;
- collected for specified purposes, and not processed for other purposes;
- "just the right amount" of data for the task at hand – not too much, but enough to do your job accurately;
- accurate and up to date;
- kept no longer than necessary;
- processed securely.

Consent

Consent must be "unambiguous", and in the case of sensitive data, "explicit".
"When the processing has multiple purposes, consent should be given for all of them" (Recital 32)
the request [for consent] must be clear, concise and not unnecessarily disruptive to the use of the service for which it is provided (Recital 32)
to obtain consent remember the following three points:

- For non-sensitive data, you need "unambiguous, affirmative" consent, not "explicit" consent. So rather than adding a checkbox, you can rely on a completely unmistakable notice along the lines of "by submitting this form you agree that we will process your data in line with our privacy policy".
- Once you've relied on consent, you can't double-back and switch to one of the other bases for processing. So, if someone says "no", you can't then decide that you're going to send a survey anyway because of "legitimate interests".
- The GDPR says "the controller shall be able to demonstrate that the data subject has consented to processing of his or her personal data". Meaning: you need to keep records of how and when consent was given.

In practical:

- Ask for consent before sending out an online survey.
- Opt-out option when replying to a survey.
- Processing data of underaged individuals.
- Integrating survey data with third-party applications.
- Storing personal data.
- The individual's right to their data.

7. Evaluation in real life environment

The following section describes additional aspects and features related to the implementation of evaluation scenarios real life environment, referring to the demonstration sites and hybrid testing,. Many of the pure technical aspects have been already described in D4.1, so this section refers to additional questions that are beyond the scope of D4.1. For additional information on the evaluation in real life environment please refer to D4.1 INFRAMIX plan for systems interaction, integration and testing and D2.3 Specification of sub-microscopic modelling for intelligent vehicle behaviour; Task 4.4 Hybrid Testing is focused on the technical issues related to the Hybrid Testing implementation while Task 4.2 and Task 4.3 deal with the implementation and integration of the Spanish and Austrian test sites.

For details on the simulation environment, please refer also to D2.2 Architecture and interface specification of the co-simulation environment D2.4 Specification of advanced microscopic traffic flow modelling and D2.5 Traffic state estimation and traffic control algorithms for mixed vehicle traffic.

Also, it is important to mention that a specific task-force has been set-up for the Definition of common test protocols (based on the development in T4.5 and to reflect the required data which needs to be recorded - log data, user appreciation) and the INFRAMIX test/evaluation/demonstration plan in order to align the different technical activities with the execution and evaluation tasks.

As stated previously in this deliverable, in real traffic demonstrators, the evaluation on the traffic and safety impact is not possible due to lack of vehicles with AD functionalities. The technical feasibility of the solutions will be addressed in WP4. Thus, in this section the main aim is to describe the procedure for collecting user inputs-based data in line with the process described in Section 2.3 Evaluation based on users' input.

7.1 Spanish Demonstration test site

In Spain, Scenario 1 and Scenario 3 will be demonstrated. Regarding Scenario 1 it is important to get feedback from users regarding the Dedicated Lane, and regarding Scenario 3 we need user to evaluate the speed, gap, and change lane recommendations.

The demonstration of Scenario 1 will involve one vehicle with an ITS-G5 C-ITS OBU with an HMI, one vehicle with the TOM App, and up to 5 rented BMWs. Furthermore, a new pictogram installed on top of the right lane will be projecting the new signs related to the dedicated lane. The complete demonstrator will be running during 5 days as the ITS-G5 C-ITS OBU. Rented BMWs have restrictions with respect their availability, but feedback from users about the TOM App could be running for 4 weeks.

The main idea for gathering user feedback in this Scenario would be to have users inside each of these vehicles and have them driving through the 20 km test-site asking them to look at the HMIs and to the new sign and new segregation elements on the road. After the drive they would be asked to reply a questionnaire. A user engagement campaign will be organized within the company to involve as much users as possible to participate in the demonstrator. The starting and end point of the drive would be at the rest area at the end of the test-site. Furthermore, in this rest area, some further questionnaires could be delivered to general public to get other feedback on the dedicated lane and especially on the new signs projected on the new pictogram.

The demonstrator of Scenario 3 will involve only the rented BMW cars as they are the only ones with AD functionalities that will allow to establish a speed and a gap or even activate a lane change with the necessary safety conditions. The same users engaged through the internal campaign could be used in a second drive through the test-site, and the same rest area could be used as starting and end point of the demonstrators where the questionnaires on user perception could be conducted and collected.

7.2 Austrian Demonstration test site

In Austria, Scenario 2 and Scenario 3 will be demonstrated. Regarding Scenario 1 it is important to get feedback from users regarding the new physical infrastructure elements.

The demonstration of Scenarios 2 and 3 will involve vehicles with an ITS-G5 C-ITS OBU and vehicles with the TOM App. Different aspects related to communication and traffic impact will be investigated using also new techniques for dynamic ground truth validation. Furthermore, the new pictogram will be displayed on a mobile trailer on a closed environment for user appreciation investigation.

The complete demonstrator will be offered to stakeholders for planned public testing.

7.3 Hybrid tests

Hybrid testing is a test method where real components and simulated components are combined. A real automated vehicle (AV), which is a demonstrator vehicle from VIF, is driven on an enclosed proving ground. The automated driving function is a SAE Level 3 function enabling automated adaptive cruise control, lane keeping and lane change functionalities. The sensors of the AV are simulated, and they sense the virtual objects created in the simulated environment and traffic. The virtual objects consist of the vehicles of the surrounding traffic and the static environment features like the road markings and traffic signs. The use of virtual sensors naturally imply that the vehicle is not able to sense real objects and road markings in the testing ground. Therefore, hybrid testing will be conducted on an open area, large enough to cover the virtual test track with an additional safety buffer zone, and which utilizes the real vehicle dynamics for the modelled virtual traffic situation on the real test site. Real infrastructure components are present in form of an RSU that sends ITS-G5 messages to an OBU, which is integrated in the vehicle. Moreover, using the OBU the status of the real vehicle can be sent back to the RSU for further processing.
A test run consists of three phases. The first phase is the initialization. The vehicle is brought to a defined speed and is driven to a predefined lane manually. The second phase is the maneuver phase where the AV drives automatically through the area of interest e.g. the road work zone or the on-ramp. This phase, as dependent on the actual vehicle speed and the exact test track length, takes approximately 20 to 30 seconds; and this is the specific phase that we are interested in, where the vehicle movement and data transmissions are logged for later processing and interpretation. The third phase is the deceleration phase were the AV is brought to standstill.
Before hybrid testing starts, the scenarios are investigated in co-simulation of the microscopic and sub-microscopic models. The messages defined by the traffic control algorithms in this simulation are used as predefined ITS-messages that are sent in the respective scenario via RSU.
When approaching the area of interest e.g. the road works zone, the AV receives an ITS-message. The AV will then react according to this message, considering the surrounding virtual traffic. The position and other vehicle states of the AV will be sent to the traffic simulation, where the simulated vehicles in the traffic simulation will react to the AV.

The results of the hybrid tests are logs of positions and velocities of the AV and the simulated traffic and logs of the ITS-G5 message transmission. Out of these logs, behavior of the AV can be investigated. The data logged either come from the simulation tool used for the virtual traffic (SUMO/VSimRTI), the ADAS function tool (Matlab/Simulink) or the vehicle sensors itself (acceleration, yaw rate, etc.). Signal processing and evaluation tools will be Matlab and Microsoft Excel. The resulting investigations can be used to verify the vehicle behavior in the simulation (parameters of the car-following and lane change model in SUMO) or lead to adaptions of the vehicle behavior in the real vehicle. With the findings of hybrid testing both the simulation as well as the automated driving function can be validated and improved. Conclusions about the sufficiency of the defined infrastructure measures can be drawn from the combined results from hybrid testing and simulation.

During the test a qualified test driver supervises the automated vehicle regarding its behavior on the proving ground, while a test engineer observes the simulation and its modules. It should be noted that the test driver in this setup is not aware of the virtual traffic but is only responsible to keep the vehicle within the confinements of the proving ground and to take over vehicle control if needed. Behavior of the AV in context with the virtual test track and the virtual traffic can only be observed virtually. Only after the test, it would be possible to use the logged data, to make a visualization, where the whole scenario can be observed."

With Hybrid demonstration and testing following use cases are addressed:

- Scenario 2 Use Case 4, Single Lane Closure (see also Table 7 - Use case 4: Roadworks zone in mixed traffic – Single Lane Closure)
- Scenario 2 Use Case 5, New Lane Design (see also Table 8 - Use case 5: Roadworks zone in mixed traffic – New lanes)
- Scenario 3 Use Case 8, Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles (see also Table 12 - Use case 8: Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles)

Scenario 2 Use Case 4, Single Lane Closure (e.g. short term constructions)

A single real AV approaches an area with a single lane closure. The vehicle must change the lane and to merge into the simulated traffic of the remaining lanes. First this is simulated without support with I2V communication as a baseline. After that, simulations where the AV is supported by I2V communication is will be conducted. An RSU submits ITS-Messages to inform the AV about the lane closure. After receiving the ITS-message, the AV will change the lane, considering and respecting the surrounding virtual (simulated) traffic. The AV sends its state via CAM-Messages to the RSU.

This use case will be investigated at low and medium traffic densities. The results will be compared with the results of the co-simulation of microscopic and sub-microscopic simulation. The differences will be analyzed and may lead to adaptation of simulation parameters, such as for the ADAS driving function in the sub-microscopic simulation. Additionally, the transmission of the ITS-G5 messages and the reaction on these messages is demonstrated.

Scenario 2 Use Case 5, New Lane Design (e.g. long-term constructions)

A single real AV is reaching a road work zone with a new road layout. An RSU is sending MAPEMs with the new road layout. When receiving the MAPEM the AV follows the new trajectory sent out via MAPEM. The AV sends its position, speed and heading via CAM-messages.

This use case also will be investigated at low and medium traffic densities. The results will be compared to results of the co-simulation and analyzed, which may lead to adaptations of parameters as described in scenario 2, use case 1. With this use case it can be verified if the content of the transmitted MAPEM is sufficient for an automated vehicle to pass a road works zone with a new lane design.

Scenario 3 Use Case 8, Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles

A single real AV drives through a bottleneck. The AV is informed via ITS-G5 messages and follows the advices, considering the traffic. The AV sends its position, speed and heading via CAM-messages.

This use case also will be investigated at low and medium traffic densities. The results will be compared to results of the co-simulation and analyzed and may lead to adaptions of parameters of the vehicle behavior in SUMO or parameters of the driving function.

8. Tools

8.1 Data loggers

The main source of information for the evaluation in INFRAMIX will be provided either by technical infrastructure in the demonstration site either by the simulation environments (co-simulation platform and hybrid testing).

All these technical components will include data logging capabilities: its output will be then collected, harmonized before the actual analysis may happen. Please refer to D2.2 Architecture and interface specification of the co-simulation environment and D4.1 Methodology for demonstrations and testing to have detailed input on this aspect.

8.2 Analysis tools

The following section describes some available tools for the management and analysis of the data gathered either from the simulation platforms, the test sites or the input from users. Quotes have been extracted from Wikipedia and/or their own web-sites, please check Section 10 References.

8.2.1 Matlab

From the web: *MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python. It was created by Cleve Moler, the chairman of the computer science department at the University of New Mexico, in the late 1970s. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK. As of 2018, MATLAB has more than 3 million users worldwide. MATLAB users come from various backgrounds of engineering, science, and economics.*

The heart of Matlab is the Matlab language, a matrix-based language allowing the most natural expression of computational mathematics. Matlab combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly. Matlab is particularly suited for data analysis, algorithm development and model and application creation.

8.2.2 SPSS

From the web: *SPSS Statistics is a software package used for interactive, or batched, statistical analysis. Long produced by SPSS Inc., it was acquired by IBM in 2009. The current versions (2015) are named IBM SPSS Statistics. The software was released in its first version in 1968 as the Statistical Package for the Social Sciences (SPSS) after being developed by Norman H. Nie, Dale H. Bent, and C. Hadlai Hull.*

The IBM SPSS software platform offers advanced statistical analysis, a vast library of machine-learning algorithms, text analysis, open-source extensibility, integration with big data and seamless deployment into applications. Widely used in social sciences, the software spread among other organizations, such as health and marketing centres, that need to understand data, analyze trends, forecast and plan to validate assumptions and drive accurate conclusions.

8.3 Tools for online survey management

In the following section, some available tools for the managing of online surveys are described. Quotes have been extracted from Wikipedia and/or their own web-sites, please check Section 10 References.

8.3.1 Survey Monkey

From Wikipedia: *SurveyMonkey is an online survey development cloud-based software as a service company, founded in 1999 by Ryan Finley. SurveyMonkey provides free, customizable surveys, as well as a suite of paid back-end programs that include data analysis, sample selection, bias elimination, and data representation tools. In addition to providing free and paid plans for individual users, SurveyMonkey offers more large-scale enterprise options for companies interested in data analysis, brand management, and consumer-focused marketing. Since releasing its enterprise in 2013, business-focused services, SurveyMonkey has grown dramatically, opening a new headquarters in San Mateo.*

SurveyMonkey provides data collection, data analysis, brand management, and consumer marketing for Facebook, Virgin America, Salesforce.com, Samsung, and Kraft Foods, among others.

8.3.2 Type Form

From Wikipedia: *Typeform (typeform.com) is a Barcelona-based online software as a service (SaaS) company that specializes in online form building and online surveys. Its main software creates dynamic forms based on user needs. Typeform's software has been used by Apple Inc., Airbnb, Uber and Nike, Inc. Typeform produces millions of forms every month.*

The "typeforms" present questions which slide down one after another showing only one question at a time to keep users engaged and can include images, and GIFs or videos. The tool includes "Calculator," custom "Thank You" screens, "Question Groups" which allow questions to be added to sections or include sub-questions and "Logic Jump" which customizes the questions a user sees based on their selections. The form can be embedded into a website, open in a pop-up, or be accessed through a unique URL. The form-builder uses a freemium business model.

Typeform I/O is a developer API which creates forms based on user data. The API allows users to generate forms using code rather than the traditional Typeform tool.

8.3.3 EUSurvey

From the web: *EUSurvey (https://ec.europa.eu/eusurvey/) deployed by the European Commission's Informatics Directorate-General (DG DIGIT) is widely used by the European institutions and in Member States for consulting citizens and businesses and collecting key information needed for the European decision-making process.*
The tool enables surveys to be created and answers to be collected via a web-based user interface. It is an open source, multilingual application that is widely accessible and provides support for either identification or anonymity, depending on the survey requirements. The application features all the steps involved in a survey life cycle, such as design, testing, translation, launch, collection of replies and analysis of results. It handles different types of single- or multiple-response questions and free text fields. Results can be displayed as histograms, percentages or in full detail and can be exported to Excel files.

The EUSurvey open source software can be downloaded free of charge on Joinup under the European Union Public Licence (EUPL). It can be installed anywhere as a standalone application.
The tool is used by the European Parliament the European Council and the Court of Auditors. It is one of the most popular downloads from the JOINUP software repository.

8.3.4 Comparison table

The following table includes and compares the advantages and disadvantages of the different tools for creating and managing online surveys:

Table 35 – Comparison table of online survey tools

	Pro	Cons
SurveyMonkey	• Easy user interface • Customizable templates • Integration with brand website, social media and email • Compliant surveys	• Limited functionalities for extra team members • Results separate from other metrics • Expensive pro functions
Typeform	• Customizable templates • Reasonable price • Conversational interface (natural progression of follow-up questions)	• Upgrade to get pro functions • No automated response to participants • Confused logic mapping
EUSurvey	• Free • Advanced form features (customization, question logic, scheduled publishing, 23 languages, advanced security and privacy, etc.) • Multiple users	• Basic result analysis capabilities, but export options • Unsuitable for multiple participants on the same contribution • No validation of contributions before they are submitted
Surveygizmo	• Automatic overall report • More complicated questions, more insightful results	• Only 3 surveys per account
Google forms	• Free • Ad-free • Integrated with Google sheets	• No question logic (customized questions according to the previous answer)

9. Conclusions

In D5.1 Plan for evaluation and users' engagement, more than focusing on a detailed work plan for the evaluation activities, the focus has been set on the definition of all the necessary concepts, methodologies and tools that are necessary to define the environment of the evaluation process:

- FESTA has been selected to define the concepts and processes related to the fundamental methodology environment.
- Several evaluation domains have been defined to categorize the different aspects that need to be investigated in order to perform a proficient evaluation of the INFRAMIX outcomes: User acceptance, Traffic Efficiency and Traffic Safety.
- A full list of Research Questions (RQ), Hypothesis (H) and, finally, Performance Indicators (PI) have been defined. This analysis and the related debate have been of key importance in order to identify the focus and scope of the technical aspects of the project in terms of the priority and future expectations. In this sense Table 30 – Overview of the Performance Indicators for INFRAMIX evaluation gives a comprehensive view of the main topics of this process.
- Procedures and technical aspects beyond the scope of WP4 have been described in order to guide the execution and evaluation processes in real environments.
- A user engagement process has been defined, in order to gather the final user input and feedback related to the concepts developed in INFRAMIX. This process is based on the interaction with the INFRAMIX User Group; and on the recruitment for the participation on surveys and questionnaires using campaigns and networking to extend the involvement.
- Finally, some tools that could be used during the gathering and data analysis have been documented. Next activities in WP5 will be responsible for the selection of the appropriate tools.

After the finalization of T5.1, WP5 will use this document in order to further define the test scenarios in collaboration with the co-simulation platform, hybrid testing (WP2) and demonstration sites (WP3 and WP4), specifying the test cases to be applied and collecting the results generated to analyze the performance of the actions.

Also, it is important to mention that a specific task-force has been set-up for the Definition of common test protocols (based on the development in T4.5 and to reflect the required data which needs to be recorded - log data, user appreciation) and the INFRAMIX test/evaluation/demonstration plan in order to align the different technical activities with the execution and evaluation tasks.

On the other hand, concerning the PI related to User Acceptance (UA), the process defined for user engagement to build addressed interviews and surveys to retrieve the user feedback will be used. This will involve WP6 networking activities.

10. References

- FESTA Handbook, Version 7, FOT-Net (Field Operational Test Networking and Methodology Promotion), 20 December 2016
- INFRAMIX D2.1 Requirements catalogue from the status quo analysis
- INFRAMIX D2.3 Specification of sub-microscopic modelling for intelligent vehicle behavior
- INFRAMIX D2.2 Architecture and interface specification of the co-simulation environment
- INFRAMIX D2.4 Specification of advanced microscopic traffic flow modelling
- INFRAMIX D2.5 Traffic state estimation and traffic control algorithms for mixed vehicle traffic
- INFRAMIX D3.1 Design and development of infrastructure elements
- INFRAMIX D4.1 INFRAMIX plan for systems interaction, integration and testing
- Ex-ante assessment of the safety effects of intelligent transport systems - https://www.sciencedirect.com/science/article/abs/pii/S000145751000062X
- T. Dingeldein, “The 12 Best Free and Open Source Survey Tools to Power Your Research” in Sales & Marketing Tech, (09/04/2018) https://blog.capterra.com/best-free-survey-tools-power-your-research/
- N.a. “Comparing the top 10 most popular customer survey tool” in The Robly email marketing blog, (13/02/2018) http://roblysupport.com/marketing/top-10-survey-tools/
- N.a. “About EUSurvey” in EUSurvey, (12/09/2018) https://ec.europa.eu/eusurvey/home/about
- N.a. “Help page for authors” in EUSurvey, (30/08/2018) https://ec.europa.eu/consultation/home/helpauthors
- “What is MATLAB?” in Mathworks https://uk.mathworks.com/discovery/what-is-matlab.html
- “MATLAB” in “Wikipedia The Free Encyclopedia” (last edited 11/10/2018) https://en.wikipedia.org/wiki/MATLAB
- “IBM SPSS software” in IBM https://www.ibm.com/analytics/spss-statistics-software
- “SPSS” in “Wikipedia The Free Encyclopedia” (last edited 19/09/2018)
- Barnard, Y., Fischer, F., & Flament, M. (2015). Field Operational Tests and Deployment Plans. C. Campolo, A. Molinaro, & R. Scopigno, Vehicular ad hoc Networks: Standards, Solutions, and Research. (pp. 393-408). Springer
- Innamaa, S., & Kuisma , S. (2018). Key performance indicators for assessing the impacts of automation in road transportation Results of the Trilateral key performance indicator survey. VTT.

11. Annexes

11.1 Template of Performance Indicator analysis

The following template has been used during the identification of the PI:

Code	Related use case	UC Code	Research Question	Hypothesis	Performance Indicators	Measurements	Data acquisition	Owner
			Related to: Technical evaluation; User appreciation; Impact on Traffic (to be split in 3 files)	*Hypotheses translates the general research questions into more specific and statistically testable hypotheses*	*PI will allow answering the hypotheses*	*Direct Measures, Indirect Measures, Self-Reported Measures, and Situational Variables*	*Sensors, Tools, Surveys*	
	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	*S1-DLA-UC1-DPR*	*At which % of automated vehicles a dedicated lane is more appropriate in terms of traffic efficiency?*	*Traffic efficiency will increase if a dedicated lane for AV is set when AV % is over X*	*Throughput of AV vs convencional vehicles*	*Number of AV in a highway section // Number of conventional vehicles in a highway section*	*Logs from simulation*	

11.2 List of stakeholders

The following section contains the relevant contacts and networks that will be used during the user engagement process.

- FIA
- Ertico ITS Europe
- EuroRAP.
- European Road Safety Observatory https://ec.europa.eu/transport/road_safety/specialist/erso_en
- Road Safety EU https://ec.europa.eu/transport/road_safety/
- European Observatory on Health Systems and Policies (WHO) http://www.euro.who.int/en/about-us/partners/observatory
- European Observatory for Clusters and Industrial Change https://www.clustercollaboration.eu/eu-initiatives/european-cluster-observatory
- Observatorios de empresas, por ej. Abertis https://www.abertis.com/media/news/2018/06/07/07062018_ObservatorioGlobalAbertis_ENG.pdf
- University Observatories as https://www.nrso.ntua.gr/european-commission-traffic-safety-synthesis-2016/
- EU blockchain https://www.eublockchainforum.eu/
- Observatorio de movilidad urbana Eltis (urban mobility observatory)

http://www.eltis.org/discover/about-us

- Directorate General for Mobility and Transport https://ec.europa.eu/transport/about-us_en
- European Transport Observatories (ETO)
- European Mobilities Observatory https://www.ipsos.com/sites/default/files/2017-05/European_Mobilities.pdf, https://eu-smartcities.eu/ https://eu-smartcities.eu/sites/default/files/2017-09/SUM_European_Mobilities%20%281%29.pdf
- United Nations Economic Commission for Europe (UNECE) https://www.unece.org/trans/main/wp5/international_transport_infrastructure_observatory.html
- European Comission – Transport https://ec.europa.eu/transport/index_en
- European Professional Drivers Association EPDA http://www.epda.ie/# https://www.ereg-association.eu/
- European Driving Schools Association https://efa-eu.com/
- European Road Haulers Association http://www.uetr.eu/en/
- European Automobile Manufacturers Association - Connected and Automated Driving (ACEA) https://www.acea.be/industry-topics/tag/category/connected-and-automated-driving
- International Drivers Association – IDA http://i-d-a.net/
- European Transport Workers Federation https://www.etf-europe.org/
- Connected Automated Driving https://connectedautomateddriving.eu/
- The Automobile Association (UK) https://www.theaa.com/
- Driving Simulation Association https://www.driving-simulation.com
- DGT
- RACE: Real Automovil Club de España.
- RACC: Reial Automobil Club de Catalunya.
- Servei Català de Trànsit (SCT)
- Pacto por la movilidad (ayuntamiento de Barcelona) y ATM
- AESLEME

Also, the networks and consortium of the following projects will be used:

- AdaptIVe, www.adaptive-ip.eu
- AutoMate, www.automate-project.eu
- AutoNet2030, www.autonet2030.eu
- BRAVE, www.brave-project.eu
- CARTRE, www.connectedautomateddriving.eu/about-us/cartre

- CoEXist, www.h2020-coexist.eu
- ConVeX, www.qualcomm.com/news/onq/2017/02/24/accelerating-c-v2x-toward-5g-autonomous-driving
- Dragon, www.cedr-dragon.eu
- interACT, www.interact-roadautomation.eu
- L3Pilot, l3pilot.eu
- MAVEN, www.maven-its.eu
- PROVIDENTIA, www.fortiss.org/forschung/projekte/providentia/
- SCOUT, www.connectedautomateddriving.eu/about-us/scout/
- SENSKIN, www.senskin.eu
- TRAMAN21, www.traman21.tuc.gr
- TransAID, www.transaid.eu
- TrustVehicle, www.trustvehicle.eu
- CEDR, http://www.cedr.eu/
- ERF
- EUCAR, http://www.eucar.be/
- ASECAP, http://www.asecap.com/
- FEHRL, http://www.fehrl.org/
- Amsterdam Group, https://amsterdamgroup.mett.nl/
- C2C-CC, https://www.car-2-car.org/
- ERTRAC, http://www.ertrac.org/
- ERTICO, http://ertico.com/
- TM2.0 Platform, http://tm20.org/
- ETSI, https://www.etsi.org/
- ADASIS, http://adasis.org/
- NDS
- AASHTO, https://www.transportation.org/
- FHWA, https://www.fhwa.dot.gov/
- Trilateral EU-US-Japan Automation Working Group in Road Transportation
- Coordination and Support Action on Vehicle and Road Automation (VRA), http://vra-net.eu/
- relevant TRB Committees and Sub-committees
- AUVSI, https://www.auvsi.org/

11.3 Performance Indicators

This annex includes the full tables of Performance Indicators developed during the discussions of task 5.1 for the defined domains: Section 3 User Appreciation Hypotheses and Indicators; and Section 4 Performance indicators for Traffic Efficiency and Safety.

Section 3 User Appreciation Hypotheses and Indicators

Hypothesis	Performance Indicators	Measurements		Owner	Data acquisition
H1.1 Users state that they would consider following the sign suggestions	(1) Data from answer to the questionnaire (2) Proportion in driving time in automation mode TO BE REMOVED	(1) Questionnaire (2) Time of driving in automation mode during tests at the German test site/and or hybrid test (applicable for S1-DLA-UC1-DPR (during transition period), S1-DLA-UC3-AWC, S2-RWZ-UC1-SLC , S3-BTN-UC3-LCAFC	1) Spanish test site 2) German test site	1) AAE 2) BMW ? 2) VIF?	1) rest areas /questionnaires and /or tablet for visual signs ?
H2.1 Users state that they are willing to use the information provided by the signs	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site Virtual environment	AAE, ASF, FOK (video or driving simulator ?) , TOM?	...
H3.1 Users perceive the traffic management functionalities /app as useful and satisfying	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site Virtual environment	AAE, ASF, FOK ?, TOM?	...
H3.2 Users perceive the signs as easy to learn	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site Virtual environment	AAE, ASF, FOK ?, TOM?	...
H3.3 Users perceive the signs as intuitive	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site Virtual environment	AAE, ASF, FOK ?, TOM?	...
H3.4 Users perceive the signs as easy to understand	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site Virtual environment	AAE, ASF, FOK?, TOM?	...
H3.5 Users appreciate the timing and number of signs (gantries) per kilometric distance (or maybe just: Users appreciate the time when they have information from the infrastructure while driving in specific road segment)	Data from answer to the questionnaire or/and interview	Questionnaire /interview/ focus group (e.g. during the hybrid test the participant i.e. the "driver" will be asked regarding his/her appreciation on the time he/she was informed about a imminent vehicle movement which was suggested by the infrastructure)	Spanish test site Austrian test site Hybrid testing?	AAE, ASF, VIF?,TOM?	...
H3.6 Users believe that the signs provide correct information	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site Virtual Environment	AAE, ASF, FOK?	...
H3.7 Users perceive the signs are not distracting them from the driving task	Data from answer to the questionnaire	Questionnaire	Spanish test site Austrian test site	AAE, ASF	...

User Appreciation Factor	#	RQ priority high -middle- low (high priority= short term strategy , low priority = long term strategy)	Research Question	Related use case S1_DLA_UC1_DPR	S1_DLA_UC2_CVDL	S1_DLA_UC3_AWC	S2_RWZ_UC1_SLC	S2_RWZ_UC2_NLD	S3_BTN_UC1_DBAS	S3_BTN_UC2_LCA	S3_BTN_UC3_LCAFC	Hypothesis
Behaviour change	1	high	RQ1.1 Do users state that they would consider following the sign suggestions?	1	1	1	1	1	1	1	1	H1.1 Users state that they would consider following the sign suggestions
Willingness to use	2	middle	RQ2.1 Do users state that they are willing to use the information provided by the signs?	1	1	1	1	1	1	1	1	H2.1 Users state that they are willing to use the information provided by the signs
Perceived usability	3	high	RQ3.1 Do users perceive the traffic management functionalities/ app as useful and satisfying?	1		1			1	1	1	H3.1 Users perceive the traffic management functionalities /app as useful and satisfying
	4	middle	RQ3.2 Do users perceive the signs as easy to learn?	1	1	1	1	1	1	1	1	H3.2 Users perceive the signs as easy to learn
	5	high	RQ3.3 Do users perceive the signs as intuitive?	1	1	1	1	1	1	1	1	H3.3 Users perceive the signs as intuitive
	6	high	RQ3.4 Do users perceive the signs as easy to understand?	1	1	1	1	1	1	1	1	H3.4 Users perceive the signs as easy to understand
	7	high	RQ3.5 Do users appreciate the timing and number of signs (gantries) per kilometric distance?	1	1	1	1	1				H3.5 Users appreciate the timing and number of signs (gantries) per kilometric distance (or maybe just: Users appreciate the time when they have information from the infrastructure while driving in specific road segment)
	8	high	RQ3.6 Do users believe that the signs provide correct information?	1	1	1	1	1		1	1	H3.6 Users believe that the signs provide correct information
	9	high	RQ3.7 Do users perceive that the signs are not distracting them from the driving task ?	1	1	1	1	1	1	1	1	H3.7 Users perceive the signs are not distracting them from the driving task

Section 4 Performance indicators for Traffic Efficiency and Safety

Code	Related use case	UC Code	Research Question	Hypothesis	Performance Indicators	Measurements	Data acquisition	Owner
			Related to: Technical evaluation; User appreciation; Impact on Traffic (to be split in 3 files)	*Hypotheses translates the general research questions into more specific and statistically testable hypotheses*	PI will allow answering the hypotheses	*Direct Measures, Indirect Measures, Self-Reported Measures, and Situational Variables*	*Sensors, Tools, Surveys*	
	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	S1-DLA-UC1-DPR	TE-RQ1.1 At which % of automated vehicles a dedicated lane is more appropriate in terms of traffic efficiency?	TE-H1.1 Traffic efficiency will increase if a dedicated lane for AV is set when AV % is over X	Throughput of AV vs convencional vehicles	Number of AV in a highway section // Number of conventional vehicles in a highway section	Logs from simulation	TUC/FOKUS
	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	S1-DLA-UC1-DPR	TE-RQ1.2 How long in advance do we need to inform about the activation of a dedicated lane?	TE-H1.2 Traffic efficiency will increase if a dedicated lane is informed enough in advance	Throughput of AV vs convencional vehicles	Throughput of AV vs convencional vehicles	Logs from simulation	TUC
	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	S1-DLA-UC1-DPR	TE-RQ1.3 What should be lenght of the dedicated lane based on traffic conditions?	TE-H1.3 Traffic efficiency will increase if a dedicated lane for AV is set of a certain lenght	Throughput of AV vs convencional vehicles	Throughput of AV vs convencional vehicles	Logs from simulation	FOKUS
	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	S1-DLA-UC1-DPR	TE-RQ1.4 What is the effect of a different number of entrances and exits in the dedicated lane?	TE-H1.4 Traffic efficiency will increase if a dedicated lane is set with a number of entrances/exits	Throughput of AV vs convencional vehicles	Throughput of AV vs convencional vehicles	Logs from simulation	TUC
	This and the following apply to all S3 use cases	S3-*	TE-RQ2.1 Can the performance of a freeway stretch, that includes a bottleneck which is activated recurrently, be improved by use of AVs?	TE-H2.1 The use of appropriate control strategies that take into acount Avs can lead to performance improvement for freeway stretch.	Delay time, i.e. travel time minus free flow travel time, (average and deviation) for different classes of vehicles	Delay time	Logs from simulation	TUC/FOKUS
					Mean speed (average and deviation) for different classes of vehicles	Mean speed		
					Harmonic speed (average and deviation) for different classes of vehicles			
					Total distance travelled	Total distance travelled		
					Total time travelled	Total time travelled		
					Travel time (average and deviation) for different classes of vehicles	Travel time		
			TE-RQ6.1 Can fuel consumption for a freeway stretch, that includes a bottleneck which is activated recurrently, be improved by use of AVs?	TE-H6.1 The use of appropriate control strategies that take into acount AVs can lead to fuel consumption reduction for freeway stretch.	Fuel consumption per kilometer travelled	Fuel consumption per kilometer travelled	Logs from simulation	TUC/FOKUS
			TE-RQ3.1 Can safety be improved by use of AVs for freeway control?	TE-H3.1 The use of appropriate control strategies that take into acount AVs can lead to performance improvement for freeway stretch and as a result less congestion and safer conditions for the vehicles.	Number of stops (average and deviation) for different classes of vehicles *A vehicle can be considered to be stopped if its speed is below a low threshold.	Number of stops	Logs from simulation	TUC/FOKUS
					Total number of stops	Total number of stops		TUC/FOKUS
					Mean headway (average and deviation) for different classes of vehicles in corelation with the mean speed	Mean headway, Mean speed		FOK to check if all this information can be produced (all PI). Initial agreement already

The following research questions are investigated with use of the submicroscopic simulation. The microscopic traffic consists only of conventional vehicles. Only one Vehicle, the vehicle which is simulated with the submicroscopic simulation, is an AV. The submicroscopic simulation observes only a small time slot: approaching the area of interest(bottleneck, roadworks zone), passing the area and settling of the situation.

Roadworks zone in mixed traffic – Single lane closure	S2-RWZ-UC1- SLC	TE-RQ4.1 At which traffic flows can an AV successfully merge into the flow on remaining lanes?	TE-H4.1 If the traffic density is high a AV will not be able to merge into the traffic on the remaining lanes.	Vehicle has merged successfully/not successfully	*Vehicle has merged successfully/not successfully*	Logs from simulation	ViF
Roadworks zone in mixed traffic – Single lane closure	S2-RWZ-UC1- SLC	TE-RQ4.2 At which traffic flows the merging of an AV causes critical situations?	TE-H4.2 The number of critical situations will increase when a AV merges into the traffic on the remaining lanes if the traffic density is high.	Criticality: Minimal TTC values, headway distances below threshold	TTC; headway	Logs from simulation	ViF
Lane-change advice combined with flow control at bottlenecks for all vehicles	S3-BTN-U3-LCAFC						
Roadworks zone in mixed traffic – Single lane closure	S2-RWZ-UC1- SLC	TE-RQ4.3 What is the impact on the main traffic of an AV merging in the main traffic?	TE-H4.3 The merging of a AV can cause degradations of the traffic flow.	Impact of main traffic (characteristics of simulated traffic, e.g. flow/density/degradations)	traffic flow/traffic density	Logs from simulation	ViF
Lane-change advice combined with flow control at bottlenecks for all vehicles	S3-BTN-U3-LCAFC						
Roadworks zone in mixed traffic – Single lane closure	S2-RWZ-UC1- SLC	TE-RQ4.4 How long does it take an AV to merge into the main traffic?	TE-H4.4 The distance to merge depends on the traffic flow on main lane.	Distance to merge (distribution)	Distance to merge	Logs from simulation	ViF
Lane-change advice combined with flow control at bottlenecks for all vehicles	S3-BTN-U3-LCAFC						
Roadworks zone in mixed traffic – New lane design	S2-RWZ-UC2-NLD	TE-RQ4.5 Can an AV pass a roadworks zone with a new lane design?	TE-H4.5 An AV is able to pass a roadworks zone with a new lane design defined in a mapem message.	Vehicle has passed successfully/not successfully (i.e. has stopped)	*Vehicle has passed successfully/not successfully (i.e. has stopped)*	Logs from simulation	ViF
Roadworks zone in mixed traffic – New lane design	S2-RWZ-UC2-NLD	TE-RQ4.6 Can an AV pass a road-workzone with a new lane design without causing critical situations?	TE-H4.6 An AV is able to pass a roadworks zone with a new lane design defined in a mapem message.	Criticality: Minimal TTC values, headway distances below threshold	TTC; headway	Logs from simulation	ViF
Roadworks zone in mixed traffic – New lane design	S2-RWZ-UC2-NLD	TE-RQ4.7 What is the impact on the traffic of an AV passing a roadworks zone with a new lane design?	TE-H4.7 What is the impact on the traffic of an AV passing a roadworks zone with a new lane design?	Impact of main traffic (characteristics of simulated traffic, e.g. flow/density/degradations)	traffic flow/traffic density	Logs from simulation	ViF
Lane-change advice combined with flow control at bottlenecks for all vehicles	S3-BTN-U3-LCAFC	TE-RQ4.8 At which traffic flow can an AV successfully merge into the flow on the main lane?	TE-H4.8 If the traffic density is high an AV will not be able to merge into the traffic on the main lane.	Vehicle has merged successfully/not successfully (i.e. has stopped on ramp)	Vehicle has merged successfully/not successfully (i.e. has stopped on ramp)	Logs from simulation	ViF

The following research questions are addressed with the use of hybrid demonstration. The microscopic traffic consists only of conventional vehicles. Only the VUT is an AV. The VUT and the communication infrasturcture are real. With hybrid demonstration no statical data is gathered.

	Roadworks zone in mixed traffic – Single lane closure	S2-RWZ-UC1- SLC	TE-RQ5.1 Is the relevance area of an ITS-Message sufficient for a vehicle to react timely?	TE-H5.1 The AV is able to receive the ITS-Message(DEMN) which informs about an oncomming roadworks zone and can timely start to merge into the traffic on the remaining lanes.	Time between sending and receiving the message	Transmission time	measurements from VUT and logs of the simulation	ViF
					The Vehicle has performed a lane change.	position (trajectory) of the vehicle		
					Criticality: Minimal TTC values, headway distances below threshold	headway, TTC		
	Roadworks zone in mixed traffic – New lane design	S2-RWZ-UC2-NLD		TE-H5.2 The AV is able to receive a mapem message and can following the information provided with this message pass a roadworks zone with a new lane design.	Time between sending and receiving the message	Transmission time	measurements from the VUT and logs of the simulation	ViF
	Roadworks zone in mixed traffic – New lane design	S2-RWZ-UC2-NLD	TE-RQ5.2 Is the information of the mapem sufficient to guide a vehicle trough a roadworks zone?	TE-H5.3 The AV is able to receive a mapem message and can follow the information provided with this message to pass a roadworks zone with a	Difference between traveled trajectory and mapem information	Vehicle position	measurements from VUT and logs of the simulation	ViF
					Vehicle has passed successfully/not successfully (i.e. has stopped)	*Vehicle has passed successfully/not successfully (i.e. has stopped)*		
	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles.	S3-BTN-U3-LCAFC	TE-RQ5.1	TE-H5.4 The AV is able to receive a ITS-Message with a Speed information and is able to adapt the speed according the information.	Time between sending and receiving the message	Transmission time	measurements from VUT and logs of the simulation	ViF
					Vehicle has adapted the speed.	Vehicle speed		
				TE-H5.5 The AV is able to receive a lane-change advice and is able to react on the advice if the traffic allows it.	Time between sending the message receiving the message	Transmission time		
					Vehicle has started a lane -change.	position (trajectory) of the vehicle		

Safety								
			SF-RQ1.1 Is time spent on the road affected?	SF-H1.1.2 Journey times increase/decrease because...	journey time per distance	journey length in hours/min	logs from simulation	ViF
			SF-RQ2.1 Is vehicles' speed affected?	SF-H2.1.1 There is an increase/decrease in mean speed because...	Speed per segment	speed	logs from simulation	TUC/FOKUS
				SF-H2.1.2 There an increase/decrease in maximum speed because...	Speed per segment	speed	logs from simulation	TUC/FOKUS
				SF-H2.1.3 There an increase/decrease in median speed	Speed per segment	speed	logs from simulation	TUC/FOKUS
				SF-H2.1.4 There an increase/decrease in standard deviation of speed	Speed per segment	speed	logs from simulation	TUC/FOKUS
				SF-H2.1.7 There is a increase of the deccelaration/negative accelaration rate	acceleration rate	acceleration rate	logs from simulation	FOKUS
			SF-RQ2.2 Is vehicles' proximity affected?	SF-H2.2.1 There is an increase/decrease in the probability of time headway less than 1s during following	Time gap	Time gap	logs from simulation	TUC/FOKUS
			SF-RQ2.3 Is vehicles' position affected?	SF-H2.3.1 There an increase/decrease in the number of lane changes	Number of lane changes	Number of lane changes	logs from simulation	TUC/FOKUS
			SF-RQ2.4 Are interactions between vehicles/drivers affected?	SF-H2.4.1 Drivers of conventional vehicles state that the interactions with an AV are perceived to be easier/intuitive	behaviour change	Data from answer to the questionnaire	Questionnaire	ICCS
			SF-RQ2.7 Do users state that the drivers attention is affected?	SF-H2.7.3 There is an increase/decrease in number of times a road sign in the in-vehicle HMI is missed	perceived usability	Data from answer to the questionnaire	Questionnaire	ICCS
			SF-RQ3.1 Is speed affected?	SF-H3.1.1 There is an increase/decrease in mean speed	Mean speed	mean speed	logs from simulation	TUC/FOKUS