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D.6.4

Roadmap towards fully automated transport systems

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Contents

Abbreviations and acronyms

Acronym	Definition
ACC	Adaptive Cruise Control
C-ITS	Cooperative Intelligent Transport Systems
CAD	Connected and Automated Driving
CAV	Connected and Autonomous Vehicles
GA	Grant Agreement
I2V	Infrastructure to Vehicle
ISAD	Infrastructure Support Classes for Automated Driving
M	Milestone
MTFC	Mainstream Traffic Flow Control
NRA	National Road Authority
ODD	Operational Design Domain
PPP	Public-Private Partnership
R&D	Research and Development
RSU	Roadside Unit
SAE	Society of Automotive Engineering
STRIA	Strategic Transport Research and Innovation Agenda
TMC	Traffic Management Center
TRL	Technological Readiness Level
V2I	Vehicle to Infrastructure
WP	Work Package
Y	Year

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Executive Summary

This document outlines the roadmap of necessary activities and concrete actions to be undertaken by different stakeholders in order to meet some most urging challenges in the field of automated transport systems through INFRAMIX proposed solutions.

The outcome of this activity will be the creation of a feasible roadmap to ensure the successful transfer of the INFRAMIX results to relevant stakeholders after the project's conclusion. After delineating the state-of-the-art ecosystem of automated transport, this document will stress the role played by INFRAMIX towards the achievement of fully automated transport system, especially regarding connected road infrastructure. Afterwards, this roadmap will match the relevant stakeholders' needs with the innovations introduced by INFRAMIX and explain how these latter will support each stakeholder in their commitment towards a safer, greener, more efficient automated transport system. Finally, the roadmap will recommend a viable timeline for an effective and timely implementation of the INFRAMIX solutions, matching the consortium commitment to their widest diffusion with the previously identified stakeholder's interests.

The activities required in the years to come will involve the INFRAMIX partners in the first place as leading models for other stakeholders whose expertise could advance the implementation of INFRAMIX solutions. According to different experts within the consortium, this will encompass several activities – ranging from the adoption of concepts to the actual and full deployment of solutions - at least in the ten years after INFRAMIX conclusion.

So far, INFRAMIX outcomes have been well received by the international community of CAD stakeholders, but they will be implemented incrementally, i.e. they will need constant and structured developments by all involved partners. Hence, some guidelines are needed to ensure the successful transfer of the INFRAMIX results to relevant stakeholders after the project's conclusion.

This roadmap provides a plan to ensure the sustainability of the INFRAMIX progresses achieved and will provide a pragmatic view in terms of necessary intermediate milestones. The future activities to be performed at least in the ten years to come – ranging from the adoption of concepts to the comprehensive deployment of solutions – will be led by the example given by the INFRAMIX partners. Nevertheless, it is intended to all actors involved in the development and management of connected road infrastructure towards a fully automated transport system. In other words, the roadmap will serve as a guide to the application of INFRAMIX developments towards the long-term vision of automated transport systems.

1. Introduction

1.1 INFRAMIX Introduction

The EU project INFRAMIX aims at preparing the road infrastructure to support the coexistence of conventional, connected and automated vehicles, targeting the transition period when the number of automated vehicles will gradually increase. Its main target is to design, upgrade, adapt and test both physical and digital elements of the road infrastructure, ensuring an uninterrupted, predictable, safe and efficient traffic.

The key outcome will be a “hybrid highway” able to handle the transition period and become the basis for future automated transport systems. In order to provide specific solutions with clear impact, INFRAMIX builds on selected traffic scenarios, namely dynamic lane assignment, roadworks zones and bottlenecks. Through these scenarios, the project outcomes have been assessed via simulations in real stretches of modern highways.

INFRAMIX activities and results have set ambitious targets for the adaptation of existing road infrastructure to mixed traffic and opened the way for the adoption of several measures advancing automated mobility. The project also aimed at establishing its tools as a reference point for the adaptation of existing road infrastructure to the emergence of automated vehicles. This aspect is increasingly important for the legacy of the project and strives for the actual take-up and deployment of the INFRAMIX solutions after the project’s conclusion. In view of the end of the project, a concise roadmap towards a fully automated transport system is of paramount importance for the maximization of the project’s impact among relevant stakeholders and for the successful deployment of its results. Not only intends the consortium to disseminate INFRAMIX results in Europe, but also internationally and globally, in order to confirm the European Union as a major actor in the relevant scientific and industrial field worldwide.

1.2 Purpose of the document

This document will outline the roadmap of necessary activities to be undertaken by all partners in order to meet relevant stakeholders’ needs through INFRAMIX proposed solutions. While at the early stages of the project the dissemination was concentrated on the idea and concept of the work to be deployed, at this later stage the dissemination task will focus on presenting the achieved developments and results and making sure that they will continue improving automated transport systems in Europe and beyond.

Quite expectably, implementing the roadmap will prove beneficial for each partner of the INFRAMIX consortium, since making their competencies and results widely known can promote their activities and prestige as well. This contribution can take several forms, ranging from the offering of new products to the publication of scientific papers, to the participation in events, etc. As such, the present document outlines the future work needed to promote the outputs of INFRAMIX among different stakeholders after the project is finished. More specifically, the roadmap aims at enabling relevant stakeholders to take effective actions toward the realization of a connected road infrastructure.

1.3 Intended audience

As one of INFRAMIX deliverables, this document is mainly addressed to INFRAMIX partners. However, the scope and content of the present Deliverable D6.4 call for a wider audience of relevant stakeholders as described in section 4. It is expected that all stakeholders could find the reading and implementing of this roadmap beneficial for the improvement of their activity towards a fully automated transport system.

1.4 Structure of the document

This document consists of five main sections. After outlining the state-of-the-art ecosystem of automated transport, this document will stress the role played by INFRAMIX towards the achievement of this goal, especially regarding connected road infrastructure. Consequently, this roadmap will analyse each stakeholder's objectives and motivations as well as their potential concerns and risks while supporting the connected road infrastructure. This will be useful to fully understand the transferring of value among the stakeholders, in order to build a business vision that responds to their needs and expectations. Most importantly, the roadmap will match the previous analysis with the innovations introduced by INFRAMIX and explain how they will support each stakeholder in their commitment towards a safer, greener, more efficient automated transport system. Finally, the roadmap will provide a viable timeline for an effective and timely implementation of the INFRAMIX innovations, matching the consortium commitment to their widest diffusion with the previously identified stakeholder's interests.

The outcome of this activity will be the creation of a feasible roadmap to ensure the successful transfer of the INFRAMIX results to relevant stakeholders after the project's conclusion. This roadmap will ensure the sustainability of the INFRAMIX progresses achieved and will provide a pragmatic view in terms of necessary intermediate steps. In other words, the roadmap will serve as a guide to the application of INFRAMIX developments towards the long-term vision of automated transport systems.

2. Connected Road Infrastructure towards a fully automated transport system

2.1 Ecosystem of automated transport

Connected and Automated Driving (CAD) represents a promising ecosystem, i.e. a network of interconnected technologies at the service of a safer, greener, more efficient automated transport system, not to mention other European objectives, such as decarbonization and social inclusion.

According to the STRIA Roadmap on Connected and Automated Transport by the European Commission, Europe plays a confident leading role regarding the technological readiness of its automotive companies, as well as traffic management measures and C-ITS. However, Europe still needs to improve its competitiveness in artificial intelligence and digital infrastructure, especially if compared to other world markets.

INFRAMIX contributes to the advancement of fully automated transport systems by focusing on connected road infrastructure, more specifically on highways. Among other advantages, INFRAMIX solutions will strengthen the position of the European activities related to new technologies, traffic management measures and bidirectional communication with the infrastructure. On the other hand, they will support the progress of physical and digital infrastructure and help Europe develop a well-positioned leadership in this sector as well.

2.2 INFRAMIX added value to connected road infrastructure towards a fully automated transport system

The main objective of INFRAMIX is to prepare the road infrastructure to support the transition period of coexisting conventional, connected and automated vehicles. This has been addressed through the design, upgrade, adaptation and test of the required “hybrid” (physical and digital) infrastructure elements, while ensuring an uninterrupted, predictable, safe and efficient traffic.

Towards this objective, INFRAMIX selected three challenges and then developed them as “scenarios”: “dynamic lane assignment”, “roadworks zones” and “bottlenecks”. On the one hand, these scenarios stand out as the most compelling for relevant stakeholders involved in infrastructure management. On the other hand, they represent a promising stepping stone to increase the capability of highway infrastructure. Each of these scenarios will be further described and analysed in section 3.

Additionally, advanced simulation tools have been adapted with new methods for traffic modelling for different automation levels and penetration rates, and new algorithms for traffic estimation and control have been implemented. Furthermore, the project has defined new visual and segregation elements, an infrastructure classification scheme and a roadmap to application of INFRAMIX developments towards the long-term vision for fully automated transport systems that will prove a valuable support for future mobility regulations.

3. INFRAMIX

3.1 The challenges met: INFRAMIX scenarios

As explained in INFRAMIX Deliverable D2.1, the project identified three scenarios to cover the needs for increased traffic flow efficiency and enhanced safety performance, namely “dynamic lane assignment”, “roadwork zones” and “bottlenecks”. The three scenarios were chosen based on the fact that connected and automated vehicles will share the same road infrastructure with traditional ones and must coexist in the same traffic. As a result, this co-existence may lead to degraded traffic flow efficiency, not to mention potential new safety problems, if not managed appropriately. The key traffic scenarios were selected through criteria set by project experts and based on their expected impact on traffic flows. The implementation of these scenarios could in fact provide valuable insight to make decisions concerning traffic safety and risk management.

3.1.1 Dynamic lane assignment

The assignment of a dedicated lane to automated traffic is expected to reduce the safety concerns around the penetration of the automated vehicles into conventional traffic. One of the targets of this scenario was to understand how to balance mixed traffic in order to maintain the traffic flow at least at the same level as in today’s traffic consisting of conventional vehicles only. During this process, parameters such as the penetration rate of automated vehicles and the prevailing traffic conditions have been considered. In addition, speed limits per lane or road segment have been dynamically adapted, also taking into account potential adverse weather conditions. The study of this scenario, in simulation and in real conditions, has resulted in insights on how to manage in an efficient manner mixed traffic flows on normal highway segments. It has provided proper indicators for activation and deactivation of lanes assigned to automated vehicles, customized speed and lane recommendations for all vehicles on this segment based on prevailing traffic conditions and also visual and electronic ways for informing all vehicles and drivers involved.

3.1.2 Roadwork zones

Roadworks zones are major safety hotspots with many potential accidents both for vehicles and for the staff on site. They pose interesting challenges for efficient coordination of mixed traffic flows, where the infrastructure should help the vehicles by providing extended real-time information, such as updated maps (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. Both the physical and the digital infrastructure should be prepared to accommodate such situations. The goal of this scenario has been to efficiently and safely guide mixed traffic through roadworks zones. Accurate information in these areas has in fact been provided to both conventional vehicles through guidance to their nomadic devices, visual signs and other physical elements (e.g. cones) and to automated vehicles through electronic signals and up-to-date digital maps (electronic horizon).

3.1.3 Bottlenecks

The aim of this scenario has been to

- investigate real-time controllers, involving a variety of control measures, such as dynamic speed limits, merge assistance and ramp metering;
- to manage mixed traffic situations in front of bottlenecks of various kinds (onramps, off-ramps, lane drops, tunnels, bridges, sags);
- to avoid traffic flow degradation.

In addition, solutions for in-vehicle and on-road signals have been examined. An analysis of several use cases regarding different types of bottlenecks, with different penetration rates of automated vehicles has also been carried out. Furthermore, innovative control strategies have been investigated, such as the suggestion of an appropriate value for the time-gap parameter

and vehicle acceleration behaviour, the distribution of the vehicles across lanes so as to match a prespecified opportune lane distribution scheme depending on traffic, as well as the Mainstream Traffic Flow Control (MTFC). Proper guidance has been provided both for automated and for conventional vehicles (e.g. conventional vehicles with ACC (SAE level 2) that communicate with Traffic Management Center).

The identification of specific challenges represented an essential step towards the elaboration of targeted and efficient solutions, as described in the following section 3.2.

3.2 The INFRAMIX proposed solutions

After identifying the most urging challenges regarding connected road infrastructure as described in the previous section 3.1, INFRAMIX focused on the development and testing of effective improvements and solutions. These latter have been continuously evolving throughout the project, according to the feedback received from stakeholders and users during the testing days, the project workshops and the several conferences and events attended by the INFRAMIX partners.

In INFRAMIX deliverables D6.5 “Exploitation plans” and D6.11 “Exploitation plans – Final version”, a detailed analysis of the applied technologies has been conducted, during which all the elemental technologies have been identified, described, classified, and assessed with respect to their application, their expected impact, and their target markets. Building on the analysis elaborated in these deliverables, a list of solutions has been defined as follows in Table 1:

Table 1 – List of INFRAMIX solutions

No	INFRAMIX SOLUTIONS
1	Traffic management measures
2	Bidirectional communication (V2I and I2V)
3	Digital infrastructure
4	Physical infrastructure
5	Infrastructure classification scheme
6	Simulations and safety performance criteria
7	Hybrid testing
8	Use cases and evaluation methodologies
9	Roadmap towards connected road infrastructure

Turning to the detail, each solution encompasses several elemental technologies that specifically and concretely address the challenges rising from the three traffic scenarios. A correlation between the INFRAMIX solutions and the elemental technologies developed in the course of the project is provided in Table 2.

Table 2 – List of INFRAMIX technologies clustered by solution

No	SOLUTION	APPLIED TECHNOLOGIES
1	Traffic management measures	Traffic management strategies, C-ITS services, control strategies, control algorithms, traffic estimation algorithms, new methods for traffic modelling, advanced simulation tools.

2	Bidirectional communication (V2I and I2V)	Transport messaging protocols, routers for autonomous driving, enhancement to C-ITS G5 communication, co-simulation framework.
3	Digital infrastructure	Sensor technologies, new visual signs, RSUs.
4	Physical infrastructure	New visual signs, segregation elements, new electronic signs, sensor technologies
5	Infrastructure classification scheme	ISAD classes.
6	Simulations and safety performance criteria	Microscopic and submicroscopic simulations, framework of new safety performance criteria.
7	Hybrid testing	Mixed-reality vehicle-in-the-loop simulation platform for testing and validating CAD technologies.
8	Use cases and evaluation methodologies	Three traffic scenarios, evaluation methodologies.
9	Roadmap towards connected road infrastructure	Guidelines to implement INFRAMIX solutions.

It goes without saying, a detailed description of the technical and technological outcomes of the project, including the identification of their innovation potential and the problems they solve, is essential for identifying their target users. Such description is available in INFRAMIX deliverables D6.5 and D6.11, where the individual outcomes are each defined as a market-oriented asset, along with a comprehensive analysis of the related active markets as well as the synergies of the INFRAMIX foreground assets from a market-application perspective that reveals several possibilities of cooperation and collaboration among their owners.

As for now, what is worth highlighting of the INFRAMIX elemental technologies is their innovation potential in providing solutions for the envisioned scenarios and application domains with respect to challenges identified and addressed in the project. In other words, the INFRAMIX elemental technologies represent new effective tools at the service of relevant stakeholders dealing with the challenges of automated transport systems, especially in the context of mixed traffic. A closer look at the solutions may result in the following analysis:

1. <u>Traffic management measures:</u>
   This solution helps ensure smooth traffic flows effectively, responsively, and dynamically. It integrates technological advances in automation, connectivity and data intelligence with highway infrastructure in order to tackle congestion, transport energy consumption, and emissions. As such, it allows the real-time adaptation of driving behaviours. Furthermore, it updates traffic control strategies and traffic simulations through the inclusion of connected and automated vehicles.

2. <u>Bidirectional communication V2I and I2V:</u>
   This solution will provide new tools and strategies for mutual communication between connected infrastructure and connected and automated vehicles. It will update traffic protocols, routes recommendations and driving behaviours through the inclusion of connected and automated driving. In addition, the accuracy of INFRAMIX messages sent to and from the test vehicle are investigated with a vehicle-in-loop co-simulation framework.

3. <u>Digital infrastructure</u>
   This solution will embed new sensors and RSUs, as well as new digital visual signs, to provide real-time data. As such, the inclusion of connected and automated vehicles in

traffic control strategies and traffic simulations will be possible. Especially regarding both physical and digital infrastructure, INFRAMIX focuses on the need for incremental adaptation, which will enable the transition towards mixed traffic through minimal interventions to the highway infrastructure.

4. Physical infrastructure:
   This solution will introduce new visual signs, electronic signs and segregation elements to efficiently manage mixed traffic of traditional, connected and automated vehicles. Especially regarding both in physical and digital infrastructure, INFRAMIX focuses on the need for incremental adaptation, which will enable the transition towards mixed traffic through minimal interventions to the highway infrastructure.

5. Infrastructure classification scheme:
   This solution will apply Infrastructure Support levels for Automated Driving (ISAD) to the classification of connected infrastructure. As thoroughly described in INFRAMIX D5.4, the infrastructure classification scheme is not a regulatory framework, since several critical aspects need consideration, such as potential legal and financial concerns, introduction of new automated functions in a transport network and conflicts of interests among stakeholders. Nevertheless, this classification will support the design of new legislation on automated transport systems. Similarly, it will inform strategic decisions on investment priorities regarding connected road infrastructure.

6. Simulations and safety performance criteria:
   This solution will facilitate the simulation and validation of traffic scenarios and control strategies. By coupling microscopic and sub-microscopic models, more precision and fidelity are expected in traffic simulations. Among other applications, this solution will evaluate the impact of mixed traffic on the safety conditions on highways by providing updated performance criteria. This could potentially help inform the design of new legislation on automated mobility.

7. Hybrid testing
   This solution studies mixed real-life and virtual testing strategies of traffic with a single ego-vehicle in an enclosed proving ground. The surrounding traffic and the environment perception are purely simulated. Hybrid testing is particularly suitable and relevant when it is coupled with (or even replacing) on-road testing in the case that these tests are deemed risky or impracticable.

8. Use cases and evaluation methodologies:
   This solution will help improve road safety and efficiency by ensuring smooth traffic flows by sharing best practices on how to efficiently manage the three INFRAMIX traffic scenarios. Additionally, it will enable a more grounded evaluation of connected road infrastructure. Likewise, it will inform strategic decisions on investment priorities on connected road infrastructure.

9. Roadmap towards connected road infrastructure:
   This solution will provide guidelines for the implementation of the aforementioned solutions and applied technologies. It is intended to all actors involved in the development and management of connected road infrastructure towards a fully automated transport system.

Considerable awareness has been raised and consensus has been reached around the achievements, innovations and best practices of INFRAMIX throughout the project, as reported in INFRAMIX D6.7. This present roadmap completes the task by presenting the proposed solutions to the specific stakeholders who need them and by making sure that they will continue improving automated transport systems in Europe and beyond.

4. Stakeholders

The previous section focused on the INFRAMIX solutions and the developed elemental technologies, and how they are expected to advance the connected road infrastructure towards a fully automated transport system. Updating road infrastructure is a complex process involving several different stakeholders, each of them meeting a specific challenge towards the achievement of a specific goal. Despite these goals being complementary, they need detailed analysis and tailored solutions to guarantee their successful achievement. Likewise, all stakeholders need to coordinate their actions and jointly strive to a common objective. Otherwise, their efforts risk to be hindered or even blocked by other actors, in case of colliding interests.

Consequently, this section will delve more into the needs and potential of each stakeholder involved in the emergence of mixed traffic on connected infrastructure. Building on the relevant stakeholders previously identified in INFRAMIX deliverable D6.3, a more concise analysis was carried out and resulted in the following list, also summarised in Table 3 at the end of Section 4:

4.1 Industry

4.1.1 Stakeholders involved

This group comprises both business and technical experts. It includes the following sub-groups:

- Original Equipment Manufacturers (OEMs) / Vehicle manufacturers
- Vehicle technology suppliers
- Infrastructure technology suppliers
- Other ICT solutions providers

4.1.2 Stakeholders' main interests and needs

Industrial stakeholders are primarily interested in offering brand new products and improvement of the existing ones to their customers. One the one hand, they take advantage of the innovation constantly introduced by researchers, projects and initiatives. On the other hand, they represent the pioneers of new technologies to be applied by road operators and regulated by policy makers, such as CAV navigation and route optimization. In order to introduce such technologies, though, they lean on reliable real-time traffic information by TMCs and standardised national strategies regarding traffic control and management.

4.1.3 INFRAMIX applicable solutions

INFRAMIX could meet their expectations with its traffic management measures, bidirectional communication, digital and physical infrastructure, simulations and safety performance criteria and hybrid testing. These solutions will help them keep updated with the enhancement introduced by the project and offer state-of-the-art product complying with relevant regulations. The present roadmap's analysis and guidelines will contribute to raising awareness about other stakeholders' needs and potential, in order to jointly act towards the same goal of connected road infrastructure.

4.2 Infrastructure operators and Road authorities

4.2.1 Stakeholders involved

This group includes the organizations (public or private) responsible for the correct managing of the road infrastructure. It includes both individual organizations and/or associations (ERF, CEDR, ASECAP, ERTRAC, etc.).

4.2.2 Stakeholders' main interests and needs

Public and private infrastructure operators are primarily interested in providing a safe, reliable and efficient service to drivers. Therefore, they are concerned with the development and deployment of C-ITS solutions as a new model for transportation and mobility. One the one hand, they take advantage of the innovation and prototypical services constantly introduced by researchers and industrial stakeholders. One the other hand, they directly depend on public authorities designing new regulations and setting goals based on common standard and frameworks.

4.2.3 INFRAMIX applicable solutions

INFRAMIX could meet their expectations with its traffic management measures, bidirectional communication, digital and physical infrastructure, infrastructure classification scheme, simulations and safety performance criteria, hybrid testing, use cases and evaluation methodologies. These solutions will help them keep updated with the enhancement introduced by the project and offer a safe and efficient service to drivers complying with relevant regulations. The present roadmap's analysis and guidelines will contribute to raising awareness about other stakeholders' needs and potential, in order to jointly act towards the same goal of connected road infrastructure.

4.3 Local, national and European policy makers

4.3.1 Stakeholders involved

This group refers to decision makers, city planners and other public authorities at different geographical levels, such as urban areas, regional administrations, countries and European institutions. They are responsible for the design, construction, operation and/or legislation of the road transportation in public infrastructures.

4.3.2 Stakeholders' main interests and needs

Public administration staff at all levels are primarily interested in providing evidence-based policies and regulations to citizens. One the one hand, they take advantage of the innovation constantly introduced by researchers and industrial stakeholders. On the other hand, all stakeholders depend on them for regulations and strategic decisions on investments.

4.3.3 INFRAMIX applicable solutions

INFRAMIX could meet their expectations with its traffic management measures, infrastructure classification scheme and simulations and safety performance criteria. These solutions will help them keep updated with the enhancement introduced by the project and offer evidence-based policies. The present roadmap's analysis and guidelines will contribute to raising awareness about other stakeholders' needs and potential, in order to jointly act towards the same goal of connected road infrastructure. Also, it will facilitate a solid overall understanding of the topic and it will consequently provide an evident support for decision making activities.

4.4 Research community, policy advisors and key influencers

4.4.1 Stakeholders involved

This group encompasses a number of different stakeholders, such as:

- European and international universities and research centers;
- European and international standardization bodies: European Telecommunications Standards Institute, ETSI, or Society of Automotive Engineers (SAE), etc.;
- 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;
- European and international drivers associations, professional transport associations, safety groups: IRU World Transport Organization, Association for European Transport, Drivers associations at global level as FIA or FIM or national/regional level (as, for example, RACE Real Automovil Club España or RACC Real Automovil Club Catalunya), ETSC European Transport Safety Council, MOVINGs International Safety Association, ADAC, ERTICO TM2.0 platform, CEDR, ERTRAC, AIPCR, 3M, etc.;
- Relevant EU, national and international initiatives, such as: AutoMate, BRAVE, CARTRE/ARCADE, CoEXist, ConVeX, Dragon, InterACT, L3Pilot, MAVEN, PROVIDENTIA, SCOUT, SENSKIN, TRAMAN21, TransAID, TrustVehicle, Risk Assessment on Danube Area Roads /RADAR), trilateral cooperation of road operators in AUT/SLO/HUN.

4.4.2 Stakeholders' main interests and needs

Research and technical communities, associations and standardization bodies are primarily interested in advancing knowledge and innovation around the themes related to safe and efficient automated transport systems. Furthermore, they promote international cooperation in order to enhance methodologies, give visibility to achieved results, identify needs of relevant stakeholders and give them recommendations. On the one hand they are the pioneers of innovation and international standards and frameworks through groundbreaking projects and initiatives. On the other hand, they need to cooperate with industrial stakeholders and infrastructure operators to test their solutions, all while complying with regulations designed by public administration.

4.4.3 INFRAMIX applicable solutions

INFRAMIX could meet their expectations with its traffic management measures, bidirectional communication, digital and physical infrastructure, infrastructure classification scheme, simulations and safety performance criteria, hybrid testing, use cases and evaluation methodologies. These solutions will help them accelerate developments and avoid duplication of results by exchanging knowledge on the project's results. The present roadmap's analysis and guidelines will contribute to raising awareness about other stakeholders' needs and potential, in order to jointly act towards the same goal of connected road infrastructure.

4.5 General public

4.5.1 Stakeholders involved

The general public is referred to as all European and international drivers as the immediate end users of connected road infrastructure, as well as all laypersons interested in connected and automated mobility.

4.5.2 Stakeholders' main interests and needs

Significantly, the general public is primarily interested in a safe, efficient and sustainable road infrastructure and related services and technologies, i.e. the final goal of all stakeholders mentioned before. On the one hand, they do not necessarily have direct access to other stakeholders. On the other hand, all stakeholders' activity should be oriented to the fulfilment of the general public's needs.

4.5.3 INFRAMIX applicable solutions

INFRAMIX could meet their expectations with its bidirectional communication V2I and I2V and with digital and physical infrastructure. Quite evidently, these solutions are the most visible ones concretely impacting on the drivers' experience. The present roadmap's analysis and guidelines will facilitate a solid overall understanding of the topic and consequently raise awareness and foster societal debate around automated transport systems.

A visual summary of the analysis carried out in this section is provided in Table 3:

Table 3 – List of INFRAMIX solutions meeting stakeholders' needs

	Industry	Infrastructure operators	Policy makers	Researchers and key influencers	General public
Traffic management measures	x	x	x	x	
Bidirectional communication V2I and I2V	x	x		x	x
Digital infrastructure	x	x		x	x
Physical infrastructure	x	x		x	x
Infrastructure classification scheme		x	x	x	
Simulations and safety performance criteria	x	x	x	x	

Hybrid testing	x	x		x	
Use cases and evaluation methodologies		x		x	
Roadmap	x	x	x	x	x

5. The road ahead

As mentioned in section 1.2, the present document outlines the future work needed to promote INFRAMIX solutions among different stakeholders after the project's conclusion. The implementation of INFRAMIX results, especially those related to physical and digital infrastructure will be incremental, i.e. they will ease the transition towards fully automated transport system on highways through minimal interventions. Therefore, the roadmap will set a specific timetable to successfully implement the activities required to viably and timely realise the connected road infrastructure.

More specifically, the roadmap strategy is to align the relevant CAD stakeholders' interests by providing guidelines to combine investments and resources into a coherent and viable timeline (section 5.1). The overall economic sustainability of the INFRAMIX roadmap depends on the economic sustainability of each INFRAMIX solution exploited by the relevant CAD stakeholders (section 5.2). These players will be led by the pioneering action of the INFRAMIX partners in taking effective actions toward the realization of a connected road infrastructure (section 5.3).

5. 1 Timeline

Activities required in the years to come will involve all stakeholders whose expertise could advance the implementation of INFRAMIX solutions. Based on the opinion of different experts within the consortium, the following timeline has been proposed to implement these activities at least in the ten years following the end of the project. Figure 1 below shows the recommended development of each activity. For a correct reading of the figure, it should be highlighted that the time span of each activity is approximate and could extend both before the estimated starting date and/or after the estimated end date.

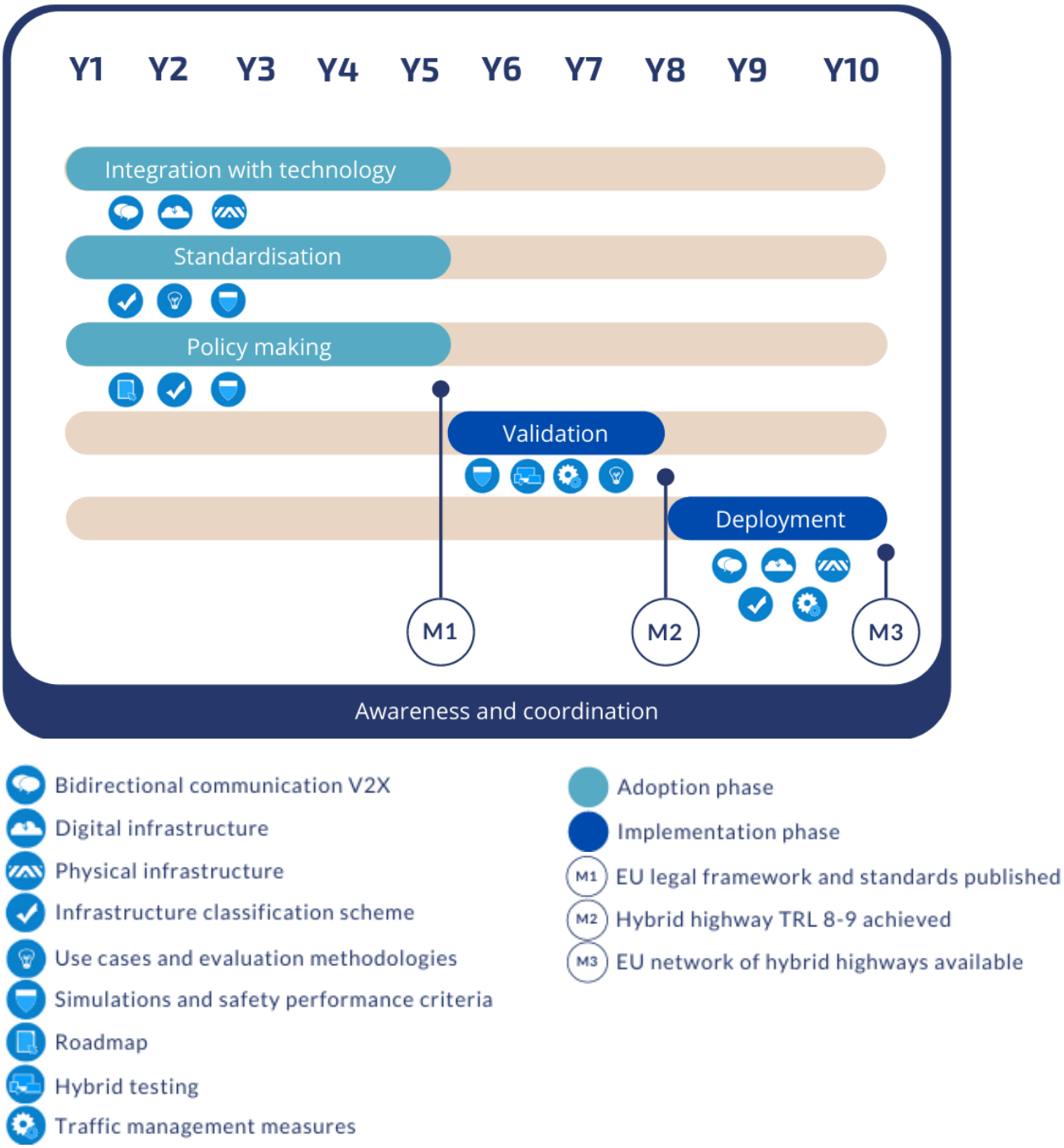

Figure 1 - Timeline of activities per year of implementation

5.1.1 Integration of technology

The adoption phase starting immediately after the INFRAMIX conclusion will secure a seamless integration of technology. In fact, new technologies developed by INFRAMIX, such as bidirectional communication and digital and physical infrastructure, need to be integrated with other solutions, including but not limited to those ensuring security and cybersecurity. This activity will prove crucial in view of final activities, such as validation and deployment.
This activity is recommended to start immediately after the end of INFRAMIX and to continue

approximately for five years.

5.1.2 Standardisation

Similarly to the integration of technology, other INFRAMIX solutions, such as ISAD classes evaluation methodologies and safety performance criteria need to reach and be accepted by European and international standardization bodies during the initial adoption phase. This step will prove fundamental to the widest diffusion, acceptance and interoperability of INFRAMIX results.

This activity is recommended to start immediately after the end of INFRAMIX and continue at least until year 5 after the conclusion of the project.

5.1.3 Policy making

Also during the adoption phase, the advancements in policy making need to take into account the time required for decision making at different levels, ranging from local to European. Additionally, the stakeholders involved in this activity need to develop awareness about adoption of concepts, integration of technologies and standards, especially ISAD classes and safety performance criteria. Therefore, much time will be allocated to shape and introduce policies and regulations regarding connected road infrastructure.

This activity is recommended to start immediately after the conclusion of INFRAMIX and is expected to last at least five years. At the end of this timeframe, the first milestone is expected to be reached, namely the publication of a European legal framework and a European set of standards for hybrid highways. This milestone will enable a shared and coordinated phase of implementation of the INFRAMIX solutions.

5.1.4 Validation

INFRAMIX carried out tests in its Austrian and Spanish sites during its last year. However, more tests are needed in different countries and scenarios, including different types and lengths of highways. A lesson learnt from INFRAMIX project is that a sufficient number of CAVs is essential to achieve valuable results from test activities.

The validation of INFRAMIX activities are the first of the implementation phase, stretching from year 6 to year 8 approximately. At the end of validation, INFRAMIX solutions are expected to reach a TRL high enough (milestone 2: TRL 8-9) to allow the actual deployment of the project innovations as the final step of the implementation phase.

5.1.5 Deployment

Deployment will be the second and last activity of the implementation phase and will consist in the final and concrete application of the INFRAMIX solutions in real settings, especially bidirectional communication, digital and physical infrastructure and traffic management measures to comply with ISAD classes. However, some applied technologies, such as the day-1 C-ITS messages, will be operative even earlier. Deployment will involve not only countries directly affected by INFRAMIX during the duration of the project, but also as many countries as possible in Europe and beyond, thus launching a network of hybrid highways (milestone 3).

This activity is recommended to start at the end of the validations and to last at least two years, from year 8 to year 10 approximately. After that, continuous maintenance will be required to preserve the good condition and adequate functioning of the new technological solutions created within INFRAMIX.

Awareness of solutions

Unlike the previously described activities and similarly to coordination, awareness of solutions is an activity continuously requiring the highest effort from every partner. At any points in the years to come, INFRAMIX solutions need to be promoted and diffused among relevant stakeholders, in order to accelerate and facilitate other activities, such as integration, standardization and wider testing and demonstrations.

This activity is recommended to start immediately after the end of INFRAMIX and to continue

at least for the ten years to come.

Coordination with other automated mobility stakeholders
Unlike the previously described activities and similarly to awareness of solutions, coordination with other automated mobility stakeholders is an activity continuously requiring the highest effort from every partner. INFRAMIX focused on addressing scenarios and developing solutions related to highways. Nevertheless, INFRAMIX solutions could also be adapted to meet the challenges of other scenarios, for example the urban ones. At any points in the years to come, INFRAMIX solutions need to be promoted and diffused among automated mobility stakeholders, in order to accelerate and facilitate the management of mixes traffic flows in other settings as well.
This activity is recommended to start immediately after the end of INFRAMIX and to continue at least for the ten years to come.

5.2 Economic sustainability

The previous timeline has outlined the necessary activities to reach feasible milestones towards connected road infrastructure. As mentioned before, this timeline provides a viable framework for responsible investments towards the fulfilling the CAD stakeholders' interests. However, the sustainability of this timeline and its viable realisation in the future depend heavily on the economic sustainability of each INFRAMIX solution, as promoted by the INFRAMIX partners among a wider base of stakeholders. Since the INFRAMIX partners committed to exploiting the project outcomes throughout and beyond the lifetime of the project itself, they are also expected to become leaders of the implementation activities.

As thoroughly analysed in D6.11, INFRAMIX solutions can rely on different exploitation options (e.g. provision of services, consultancy, data, technology, etc.) that will generate revenues for the stakeholders undertaking them. Hence, the exploitation actions undertaken will guarantee the economic sustainability of the project solutions in the future.

Table 4 below provides an overview of exploitation actions supporting the economic sustainability of each INFRAMIX solution and points out the type of stakeholders involved in this process. The roadmap as the ninth INFRAMIX solution has not been included in the following table, because its economic sustainability depends on the economic sustainability of the other solutions.

Table 4 – Economic sustainability of INFRAMIX solutions

No	SOLUTION	STAKEHOLDERS INVOLVED	SOURCE FOR ECONOMIC SUSTAINABILITY
1	Traffic management measures	Public authorities	PPP
		Road operators	Service provision based on C-ITS
		Research centres	Consultancy
		Industry (OEM and technology)	Technology provision
2	Bidirectional communication (V2I and I2V)	Industry (OEM and technology providers)	Provision of services and data
		Road operators	Service provision based on C-ITS
3	Digital infrastructure	Public authorities	PPP
		Road operators	Product and service provision
		Research centres	Consultancy
		Industry (OEM and technology)	Provision of technology and data

No	SOLUTION	STAKEHOLDERS INVOLVED	SOURCE FOR ECONOMIC SUSTAINABILITY
4	Physical infrastructure	Public authorities	PPP
		Road operators	Product and service provision
		Research centres	Consultancy
		Industry (OEM and technology providers)	Provision of data and technology
5	Infrastructure classification scheme	Road operators	Private investments
6	Simulations and safety performance criteria	Road operators	Test site provision
		Research centres	Consultancy and technology provision
7	Hybrid testing	Road operators	Test site provision
		Research centres	Consultancy services and technology provision
8	Use cases and evaluation methodologies	Road operators	Test site provision
		Research centres	Consultancy services and technology provision

5.3 Stakeholders' commitment

As explained before, the economic sustainability of the INFRAMIX roadmap depends on the economic sustainability of each INFRAMIX solutions, depending on its turn on the commitment of CAD stakeholders in their adoption and implementation. This commitment can take the form of several actions, ranging from the offering of new products to the publication of scientific papers, to the participation in events, etc.

INFRAMIX partners are expected to perform a leading role in implementing these actions among relevant stakeholders. Implementing the roadmap will prove beneficial for INFRAMIX partners, since making their competencies and results widely known can promote their work and prestige as well. During the proposal phase of this project, each partner committed to exploiting INFRAMIX results throughout and beyond the lifetime of the project. Exploitation and impact maximisation have indeed been performed both collectively by the entire consortium and individually by every single partner. Thanks to their engagement, even actors outside the INFRAMIX consortium are understood to take a fully aware and active role in the exploitation of the INFRAMIX solutions.

Table 5 below outlines the actions tailored on each stakeholders' group that need to be taken towards the achievement of the milestones of hybrid highway described in section 5.1.

Table 5 – Actions needed from stakeholders to reach the hybrid highway milestones

Stakeholders	Milestone 1: EU legal framework and standards	Milestone 2: Hybrid highway TRL 8-9	Milestone 3: EU network of hybrid highways
Industry	Provision of new technologies, products and services; support to adoption by other stakeholders; promoting standards; requesting EU legal framework	Support to validation; evolution of products and services	Industrialised production of hybrid highway technology

Infrastructure operators	Adoption of new technologies, products and services; creation of new added value services for final users; promoting standards; requesting EU legal framework	cooperation with other stakeholders especially with OEM and research institutes	widespread deployment of hybrid highway; strategic private investments
Policy makers/ public authorities	Active listening of other stakeholders, evidence-based policies, new harmonised regulations at a European level	Monitoring of the validation process; awareness raising of the hybrid highway concept	Strategic public investments and further planning of the deployment
Researchers and key influencers	Exploitation of algorithms, enhancement of control strategies, development of new use cases and scenarios	Generation of data, further research; cooperation with Infrastructure Operators for the implementation and testing of new use cases	further research towards a new generation of technology
General public	Monitoring of the adoption phase, feedback to policy makers	Early adoption of specific technological solutions, Users' evaluation and experience feedback	Adoption of products and services related to hybrid highways

6. Conclusions

This document has outlined the roadmap of necessary activities and concrete actions to be undertaken by different stakeholders to meet some most urging challenges in the field of automated transport systems through INFRAMIX proposed solutions.

After having outlined the state-of-the-art ecosystem of automated transport, this document has highlighted the role played by INFRAMIX towards the achievement of this goal, especially regarding connected road infrastructure. More specifically, INFRAMIX solutions encompass several innovative elemental technologies that concretely address the challenges of three traffic scenarios: dynamic lane assignment, roadwork zones, bottlenecks. INFRAMIX solutions range from traffic management measures to bidirectional communication, from physical and digital infrastructure to hybrid testing, from ISAD classes and safety criteria to evaluation methodologies and roadmap towards connected road infrastructure.

Considerable awareness has been raised and consensus has been reached around the achievements, innovations and best practices of INFRAMIX throughout the project. This present roadmap completes this endeavour by transferring the proposed solutions to the specific stakeholders who need them and by making sure that they will continue improving automated transport systems in Europe and beyond. Basically, this roadmap has matched the relevant stakeholders' needs with the innovations introduced by INFRAMIX and explained how these latter will support each stakeholder in their commitment towards a safer, greener, more efficient automated transport system.

So far, INFRAMIX outcomes have been well received by the international community of CAD stakeholders, but they will be implemented incrementally, i.e. they will need constant and structured developments by all involved partners to ease the transition towards fully automated transport system through minimal interventions. Hence, some guidelines are needed to ensure the successful transfer of the INFRAMIX results to relevant stakeholders after the project's conclusion.

The roadmap has provided a viable timeline for an effective and timely implementation of the INFRAMIX solutions, matching the consortium commitment to their widest diffusion with the stakeholder's interests. The activities required in the years to come will involve all stakeholders whose expertise could advance the implementation of INFRAMIX solutions, guided by the leading role performed by the INFRAMIX partners. Based on the opinion of different experts within the consortium, a timeline has been proposed to implement some activities – ranging from the adoption of concepts to the actual and full deployment of solutions - at least in the ten years following the end of the project.

To conclude, the INFRAMIX solutions have proved successful in improving the connected road infrastructure through the creation of valuable applied technologies meeting the stakeholders' expectation. As such, the implementation of the roadmap will accelerate and facilitate the realisation of fully automated transport systems.

7. References

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Annex I - H2020 roadmaps alignment

INFRAMIX has cooperated with several European R&D projects such as ARCADE, CoExist and TransAID in a number of occasions (cf. INFRAMIX D6.7 Communication strategy and plan – Final). These included a joint session on Connected & Autonomous Mobility at the World Road Congress in Abu Dhabi in October 2019. This event represented the kick-off of a deeper cooperation among these H2020 projects to align their strategic outcomes, especially roadmaps and guidelines for implementation. The aim of the cooperation was to

- identify what complementarities and peculiarities emerged from each project in order to encompass them into a more comprehensive approach;
- increase awareness of efforts by similar European projects towards connected and automated driving.

The coordination guidance by ARCADE was taken as a model to identify the unique point of view of each project and the potential gaps in the overall approach to CAD adopted by the European R&D projects. Taken this as a starting point, we focused on recommendations for future implementation of INFRAMIX solutions towards connected and automated driving. Table 6 below shows how INFRAMIX addressed ARCADE thematic areas:

Table 6 – INFRAMIX recommendations addressing ARCADE thematic areas

INFRAMIX recommendations	ARCADE thematic areas
• Infrastructure classification scheme • new safety performance criteria for assessment	Policy and regulatory needs, European Harmonisation Policy
• new visual signs, • new safety performance criteria, • new traffic estimation and control algorithms for mixed traffic environments • recommendations on simulation on and testing, simulation environments and hybrid testing for mixed traffic situations, • set of minimum interventions for infrastructure upgrades.	Digital and physical infrastructure
• Extensions of existing electronic messages to cover the INFRAMIX use cases • Architecture for a hybrid communication (ITS-G5 and cellular)	Connectivity

The coordination efforts resulted in a joint workshop at FEHRL in Brussels in early March 2020. An overview of the main results achieved by each project (CoEXist, ARCADE, INFRAMIX, TransAID, EU ITS Platform, DIRIZON, STAPLE) highlighted the complexity of the CAD panorama in Europe. Therefore, at least two approaches were proposed to address it:

- **Scenarios** as common challenges. For example, INFRAMIX addressed three scenarios, namely dynamic lane assignment, roadwork and bottleneck. Scenarios could be considered as laboratories for the implementation of combined solutions by different R&D projects.
- **Urban areas** as crucial pioneers of the introduction of CAD in real life scenarios. All R&D projects can share recommendations and solutions with public authorities committed to road safety to help them model and plan CAD in their urban areas, as well as take more informed decisions. As already mentioned in Section 5.1.9, INFRAMIX solutions are not directly applicable to urban scenarios, but they could be transferred from highways to urban roads provided that a thorough coordination is undertaken among automated mobility stakeholders.

Additionally, a third approach emerged during the discussion, namely the need for **standardisation and classification**. They are considered necessary for the actual interoperability of different R&D projects dealing with CAD. In this sense, the ISAD classes by INFRAMIX reached a wide audience in Europe and were adopted by other projects to build their results upon (DIRIZON, ERTRAC).

Finally, what is worth stressing is that the complexity of the CAD ecosystem calls for different approaches to the challenge that are sometimes difficult to align. Nevertheless, the commitment of the European R&D projects to cooperate shows the belief that each and every one of them is necessary to the overall development of a fully automated transport system. Even so, more awareness is needed of the results produced by similar projects, as well as more coordination among all involved stakeholders. For example, more participation is needed from the industry community and the national road authorities (NRA), that are considered the ultimate beneficiaries of the innovative solutions introduced by R&D projects. Therefore, more joint activities and events are encouraged to foster shared efforts towards a fully automated transport system.