ESRIUM

Grant Agreement No. 101004181

Deliverable 1.4
First Periodic Project Report

ESRIUM

SAFE AND EFFICIENT ROADS

Period covered by the report:
from 01.12.2020 to 31.05.2022

Periodic report: 1st

H2020-SPACE-EGNSS-2019-2020

ACKNOWLEDGEMENT:
This project has received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101004181.

ESRIUM – GA No. 101004181
EGNSS-ENABLED SMART ROAD INFRASTRUCTURE USAGE AND MAINTENANCE FOR INCREASED ENERGY EFFICIENCY AND SAFETY ON EUROPEAN ROAD NETWORKS

D1.4 First Periodic Project Report

Due date of deliverable:	31.05.2022
Date of submission:	03.10.2022
Lead beneficiary for this deliverable:	JRD
Authors:	All partners
Quality Reviewer	Loha Hashmi (ENI)
State:	Draft
Version:	1.0
Dissemination nature:	Public
Project Officer:	Dafni Dimoudi
Reviewer 1:	Josep Maria Salanova
Reviewer 2:	Gustavo Oyervides

Project partners

JOANNEUM RESEARCH Forschungsgesellschaft mbH – Institute DIGITAL (JRD), ASFINAG Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft (ASF), Virtual Vehicle Research GmbH (VIF), Finnish Geospatial Research Institute (FGI) of the National Land Survey (NLS) of Finland, FH OO FORSCHUNGS & ENTWICKLUNGS GMBH (FHO), Evolit Consulting GmbH (EVO), NNG Software Developing and Commercial LLC (NNG), ENIDE SOLUTIONS .S.L (ENI), Politecnico di Milano (POL)

Abstract

ESRIUM is a multi-national project with the common goal to increase the safety and resource efficiency of mobility on the road. The key innovation will be formed by a homogeneous, accurate and recent digital map of road surface damage and road wear. Further addressed as “road wear map”, it will contain unique information, which is of value to multiple stakeholders: road operators will be able to lower the road maintenance effort by optimal planning. Further, road operators will be able to lower road wear and increase traffic safety especially for heavy vehicles: considering the market introduction of partly automated truck fleets and platoons, the precise track of these vehicles can be adjusted by communicating precise routing recommendations in- and cross-lane. Truck fleet operators following these recommendations can receive tolling benefits, and increase the general safety for their vehicle fleet. Especially with the increasing levels of autonomy, systems will utilize infrastructure support to handle the requirements of the automated driving task and additional external requests. In ESRIUM, these opportunities are addressed by utilizing C-ITS infrastructure and EGNSS based localization in planning the trajectories of such automated vehicles. Key to the ESRIUM innovation is a precision localization service, which provides reliable locations of road damages and of the vehicles using the roads. Considering a European-level business-case, only Galileo may provide such a service in homogeneous quality, even at very remote locations on the European continent.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This interim report is identical to the deliverable "*D1.4 First periodic project report*", thus, its structure follows the template provided by the EC. The intention of this document is to describe the work that has been done in the first period (01.12.2020 – 31.05.2022) of the ESRIUM project. It gives some details what happened in the individual work packages, what goals have been achieved and what are the next steps.

Supplementary to the textual descriptions, milestones, deliverables and objectives are listed and the achieved results compared to the requirements from the Grant Agreement. All occurred deviations, their influence on the project and how this was handled are discussed.

Finally, changes in the use of resources are explained and the discussion with the project officer and the jointly agreed on solution are listed.

Overall, this overview can be seen as complement to the already submitted deliverables and serves as information, even to those parts that are outlined in confidential documents, for the public.

DOCUMENT REVISION

Version	Changes to content	Author	Status	Date
V01	First version of document	Martina Uray (JRD)	Draft	19.05.2022
V02	Contents from partners added	All	Draft	12.07.2022
V03	WP5 finalized	Martin Rudigier (VIF)	Draft	14.07.2022
V04	WP1, WP3, WP6, WP7 finalized	Loha Hashimy (ENI) Jose Vallet (FGI) Gottfried Allmer (ASF) Martina Uray (JRD)	Draft	20.07.2022
V05	WP2, WP4 finalized	Manfred Klopschitz (JRD) Michael Astleitner (EVO) Wolfgang Schildorfer (FHO) Gergely Havas (NNG)	Draft	22.07.2022
V06	Final version to be sent to external reviewers	Martina Uray (JRD) Matthias Rüther (JRD)	Draft	27.07.2022
V1.0	Integrated feedback from external reviewers	Martina Uray (JRD) Selim Solmaz (VIF) Gergely Havas (NNG) Jose Vallet (FGI) Loha Hashimy (ENI)	Final	03.10.2022

SECTION 1: EXPLANATION OF THE WORK CARRIED OUT BY THE BENEFICIARIES AND OVERVIEW OF THE PROGRESS

1.1 Objectives

ESRIUM is a multi-national project with the common goal to increase the safety and resource efficiency of mobility on the road. The key innovation will be formed by a homogeneous, accurate and recent digital map of road surface damage and road wear. Further addressed as “road wear map”, it will contain unique information, which is of value to multiple stakeholders: road operators will be able to lower the road maintenance effort by optimal planning. Further, road operators will be able to lower road wear and increase traffic safety especially for heavy vehicles: considering the market introduction of partly automated truck fleets and platoons, the precise track of these vehicles can be adjusted by communicating precise routing recommendations in- and cross-lane. Truck fleet operators following these recommendations can receive tolling benefits, and increase the general safety for their vehicle fleet. Especially with the increasing levels of autonomy, systems will utilize infrastructure support to handle the requirements of the automated driving task and additional external requests. In ESRIUM, these opportunities are addressed by utilizing C-ITS infrastructure and EGNSS based localization in planning the trajectories of such automated vehicles.

Key to the ESRIUM innovation is a precision localization service, which provides reliable locations of road damages and of the vehicles using the roads. Considering a European-level business-case, only Galileo may provide such a service in homogeneous quality, even at very remote locations on the European continent.

As defined in the Annex 1 of the Grant Agreement, seven objectives are required to achieve the overall goal of the ESRIUM project. During the first period of the project, the following progress has been made towards achieving those objectives:

<table>
<tr><th colspan="2">O1 Create a highly detailed EGNSS-referenced “wear map”</th></tr>
<tr><td>A highly detailed EGNSS-referenced map of road damage and associated safety risks at centimetre-level resolution will be created, based on the data acquired. The map will hold information on damage location, damage type, recent repair efforts and the temporal evolution of specific damages.</td><td rowspan="2">Achievements:
• Creation of ground truth data with mobile-mapping systems in Austria and Finland
• Acquisition and storage of test data for wear map creation
• Categorization of damage types according to road damage catalogue
• Labeling of acquired road damage data for classifier training
• Basic structure of damage detection and classification algorithms

Status:
☐ Accomplished
☒ Partially achieved
☐ Second half of the project

Assessment:
• Expected achievement date: 31.05.2023</td></tr>
<tr><td>The objective is reached when map data from at least one test region in Austria is successfully captured, processed, classified and stored in a largely automated fashion.</td></tr>
</table>

<table>
<tr><td></td><td>

- Implementation plan: Development of the deliverables D4.3, D4.4 and D4.5
- Expected delays
  ☐ Yes
  ☒ No

</td></tr>
<tr><td colspan="2">O2 Create a novel mid-priced sensor system for detecting road damage</td></tr>
<tr><td>A novel, mid-priced road surface data acquisition system will be created which consists of a camera, a LiDAR and an EGNSS-enhanced GNSS/IMU localization system. In contrast to precision road surface scanners, it will rely on automotive-grade hardware (in contrast to survey-grade). This sensor system will be used to create a highly detailed EGNSS-referenced map.

The objective is reached when the sensor system is operable and is able to successfully provide the needed input for map creation.</td><td>

Achievements:

- Operable sensor system setup
- First Sensor Prototype finished
- Test data in Austria and Finland acquired

Status:

☒ Accomplished
☐ Partially achieved
☐ Second half of the project

</td></tr>
<tr><td colspan="2">O3 Implement EGNSS- localization system, which provides accurate, authenticated position information in real-time and at low cost</td></tr>
<tr><td>Reliable position information of vehicles is mandatory in order to utilize map information. While for standard car navigation systems a meter-accurate geoposition is sufficient to provide navigation directions, the task of circumventing road damage within a given lane requires a positioning accuracy in the range of centimetres. In ESRIUM, localization faces two principal challenges: (i) locating the data acquisition vehicles as accurately as possible to provide a reliable map and (ii) locating the user vehicles accurately in real-time in order to exploit the map information even at high speed. Therefore, the localization objective is also two-fold. First, a post-processing workflow will be established, which provides a fused localization from multiple sources for a service-vehicle: EGNSS, inertial measurement unit (IMU) and (optionally) odometer. Second, a localization system will be implemented, which provides accurate, authenticated position information in real-time and at low cost. This system will be integrated into a potential user-vehicle in order to demonstrate the project's impact.

The objective is reached, when acquired map data is successfully georeferenced at centimetre-level, and a potential user vehicle is localized relative to the map in real-time.</td><td>

Achievements:

- Selection of the EGNSS sensors and related software to be used in the project.
- Implementation of the core of the OSNMA service relevant to ESRIUM on the receiver side.

Status:

☐ Accomplished
☒ Partially achieved
☐ Second half of the project

Assessment:

- Expected achievement date: 31.03.2022
- Implementation plan: Development of D3.3 and D3.4
- Expected delays
  ☒ Yes (4 months)
  ☐ No

</td></tr>
</table>

<table>
<tr><th colspan="2">O4 Broadcast precision routing recommendations</th></tr>
<tr><td>Precision routing recommendations for broadcasting to automated vehicles will be developed, tested, and demonstrated. The intended recipients are especially highly automated heavy-duty vehicles. Given sufficiently precise EGNSS localization information, minimal changes of the vehicle trajectories will allow to avoid already damaged regions, increasing the road lifetime and lowering the risk of accidents.
Routing recommendations have to be made accessible by C-ITS messages. Therefore, if not yet specified, necessary messages and message formats will be proposed within the project. Algorithms will be developed to automatically create the message content from the road defect and safety map information. Message transfer is to be achieved via C-ITS communication links, which shall be developed and demonstrated during the project execution.</td><td rowspan="2">Achievements:
• Identification of a potential test region and time alignment with the rollout status of the C-ITS infrastructure.
• Concept of ESRIUM testing architecture, which has to run decoupled from operational C-ITS architecture.

Status:
☐ Accomplished
☒ Partially achieved
☐ Second half of the project

Assessment:
• Expected achievement date: 30.11.2023
• Implementation plan: Development of deliverable 5.1 and 5.3
• Expected delays
☐ Yes
☒ No</td></tr>
<tr><td>The objective is reached when a test drive has been performed utilizing an automated vehicle, where the routing recommendations are created by the map platform, sent by the road operator and received by the test vehicle for use in autonomous driving functions.</td></tr>
<tr><th colspan="2">O5 Broadcast potentially dangerous locations</th></tr>
<tr><td>Warning messages will be broadcasted to allow connected and partly automated vehicles, which support at least automated lane-following, avoiding damaged areas to mitigate the associated safety risks. The information containing the damage location will be transmitted to the vehicle either via an entire map layer or, especially for safety relevant locations, utilizing a C-ITS warning message to be broadcast by the road operator. This may also include strategic lane change advice if necessary.
Road users will be informed in advance and with low latency about potentially dangerous locations, which will lead to a reduction in the possibility of human errors, thereby increasing the overall road safety. This information broadcast is also regarded as essential for (partly) automated vehicles in order to be able to safely plan their trajectory.
The impact of the broadcasted potentially dangerous location will be evaluated with respect</td><td>Achievements:
• Identification of a potential test region and time alignment with the rollout status of the C-ITS infrastructure.
• Concept of ESRIUM testing architecture, which has to run decoupled from operational C-ITS architecture.

Status:
☐ Accomplished
☒ Partially achieved
☐ Second half of the project

Assessment:
• Expected achievement date: 31.08.2023
• Implementation plan: Finalization of Task 5.2
• Expected delays
☐ Yes
☒ No</td></tr>
</table>

<table>
<tr><td>to a high-precision ground truth map of at least one test area. The test-vehicle will be equipped with C-ITS reception capability and real-time authenticated EGNSS localization capability. High-precision reference localization sensors will provide ground truth to evaluate the correct choice of the route.</td><td rowspan="2"></td></tr>
<tr><td>The objective is reached when at least one test drive has been performed, where a test vehicle has received a warning message and adapted its path, considering a potentially dangerous location.</td></tr>
<tr><td colspan="2">O6 Provide road damage state and evolution to the customer</td></tr>
<tr><td>Road damage information will be provided to customers, such as fleet operators and road operators.
To achieve this, the wear map, which is gathered frequently, will be hosted on a central data platform at the business owner. In the backend of this data platform, the identified objects (= damages) will be automatically classified according to the criticality of damage, potential safety risks and speed of evolution. A road damage prediction algorithm will estimate the time to a specific level of severity of the damages, depending on the environmental conditions and the level of traffic running over the damage. A business to business data interfaces will enable easy access to the data for customers.</td><td rowspan="2">Achievements:
• Start of the setup of the data platform

Status:
☐ Accomplished
☐ Partially achieved
☒ Second half of the project

Assessment:
• Expected achievement date: 31.05.2022
• Implementation plan: Development of D4.4, D4.5 and D4.7
• Expected delays
☐ Yes
☒ No</td></tr>
<tr><td>The objective is reached when the damage information has been transferred to the running data platform, a damage classification and maintenance prediction has been calculated and added to the data platform, and at least one road operator has the data interface and permissions to access the road damage information.</td></tr>
<tr><td colspan="2">O7 Develop a business-case based on the ESRIUM services</td></tr>
<tr><td>The innovative business-offering that will be developed in this project is the access to a completely new road surface wear map. By obtaining this information much more frequently and cost effective than the state-of-the-art, road operators will be able to plan repairs in a way that minimizes the construction effort and traffic disturbance. As a consequence, road repairs become smarter, cheaper and safer.</td><td>Achievements:
• The technical requirements are defined (D2.2)
• Business plan is worked out (D2.5)
• The commercial exploitation is set (D6.4)</td></tr>
</table>

Furthermore, precision routing recommendations can be broadcasted, especially to autonomous and highly automated heavy-duty vehicles. Given sufficiently precise EGNSS localization, minimal changes of the vehicle trajectories allow to avoid already damaged regions, increasing the road lifetime and lowering the risk of accidents. Routing recommendations can be broadcasted via C-ITS technology to let connected and (partly) autonomous vehicles in order to distribute the load of road surface usage. The current business-case, as displayed in the attached business-plan, will be continuously refined during the project.	Status: ☐ Accomplished ☒ Partially achieved ☐ Second half of the project Assessment: • Expected achievement date: 30.11.2023 • Implementation plan: Development of deliverable D6.6 • Expected delays ☐ Yes ☒ No
The objective is reached when the technical requirements document is finished and the commercial exploitation is defined within a contractual agreement of the consortium partners.	Comment: Basic documents were created mainly in WP2. WP2 is closed but the business cases will be further validated and worked on in WP6 (T6.3) being a living process.
O8 Demonstrate smart automated routing based on broadcasted information	
In order to demonstrate the key propositions and to support the business cases of the ESRIUM project, it is planned to showcase the infrastructure supported smart routing applications with a real-life demonstration during the course of the project. This demonstration will be based on a partly automated demonstrator vehicle, additionally equipped with a novel EGNSS receiver. It will be possible to initiate C-ITS based lane changes manoeuvres based on road damage data, that is broadcast by the road operator. Moreover, it will be possible to guide the vehicle within the lane to achieve an equal wear of the road surface between the road lines, based on the wear map data to be developed during the project.	Achievements: • Development of the infrastructure assisted ADAS functions • Implementation of the use case in a simulation framework and testing of the driving functions • Analysis of certain KPIs in simulation and dissemination of the results • Integration of the communication and localization hardware on the demonstrator vehicle Status: ☐ Accomplished ☐ Partially achieved ☒ Second half of the project Assessment: • Expected achievement date: 30.11.2022 • Implementation plan: Development of deliverables D5.1 and 5.3 • Expected delays ☐ Yes ☒ No
The objective is reached when the demonstrator vehicle setup (deliverable "*D5.1 Test vehicle specification and setup*") is finished and the use cases are demonstrated and reported in (deliverable "*D5.3 Test results analysis report*") is completed.	

Table 1: Status of objectives.

1.2 Explanation of the work carried per WP

1.2.1 Work Package 1

WP number	WP 1	Lead beneficiary	1 – JRD	Start month	1	End month	36
WP title	Project Management						

1.2.1.1 Description of performed activities

The present document was coordinated by JRD, supported by all WP leads, and written together with all partners, being identical to the deliverable "*D1.4 First periodic project report*".

<u>Task 1.1: Administrative management</u>

The first three tasks in WP1 were the organisation of the kick-off meeting, the writing and coordination of the consortium agreement and the setup of project rules and guidelines described in "*D1.1 Project Handbook and Project Quality Plan*".

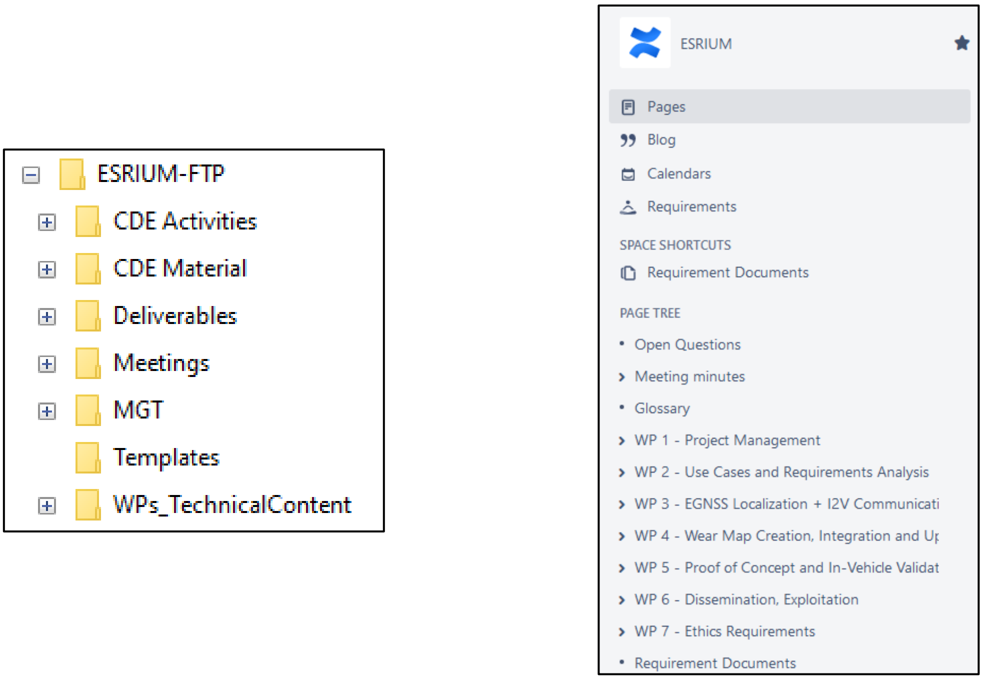
The kick-off meeting took place on 09.12.2020, due to COVID-19 regulations it was held online. Partners were introduced and an overview of each WP was given. The PO (Alberto Fernandez-Wyttenbach) participated in the meeting and presented the suggested external reviewers who accompany the project providing feedback on the deliverables and the overall progress.

The developed project handbook serves as reference for the overall project. It contains all links to the project master data (contracts, project organization, work description, administrative and financial planning data) and all information necessary to ensure uniform management procedures, communication streams, and quality management. It serves as a single-entry point to all information needed to manage the project in internal cooperation, and externally in relation to EC. The purpose the document is to provide all project partners with an overview of the most important project procedures (project monitoring, reporting tools, financial management, internal communication structures, etc.), and the European Commission with the assurance that the project management is taking place using state-of-the-art project management techniques, adequate and efficient in view of the size and content of the project.

The project itself is managed using two main tools. The ESRIUM-Confluence® space (hosted by the project partner NNG, *Figure 1*b) for all interactive communications and the projects document store (ESRIUM-Cloud hosted by JRD, *Figure 1*a).

The Consortium Agreement (CA), including the rules for IPR management and background IP, was signed by all members of the consortium in December2020. This is closely related to Task 6.3, dealing with optimization of the knowledge transfer as described in the corresponding WP6 Section (see Section 1.2.6.1).

In order to enable the coordinator to follow the project progress as well as providing a rough estimation of costs the consortium agreed on an internal reporting on a half-year basis (*Figure 2*). For this activity, a specific document was created that allows extracting all relevant information in a textual and graphical form to be approved by work package leaders and the coordinator.



(a) (b)

Figure 1: Structure of ESRIUM MGT-Tools. (a) ESRIUM-Cloud and (b) ESRIUM Confluence Space.

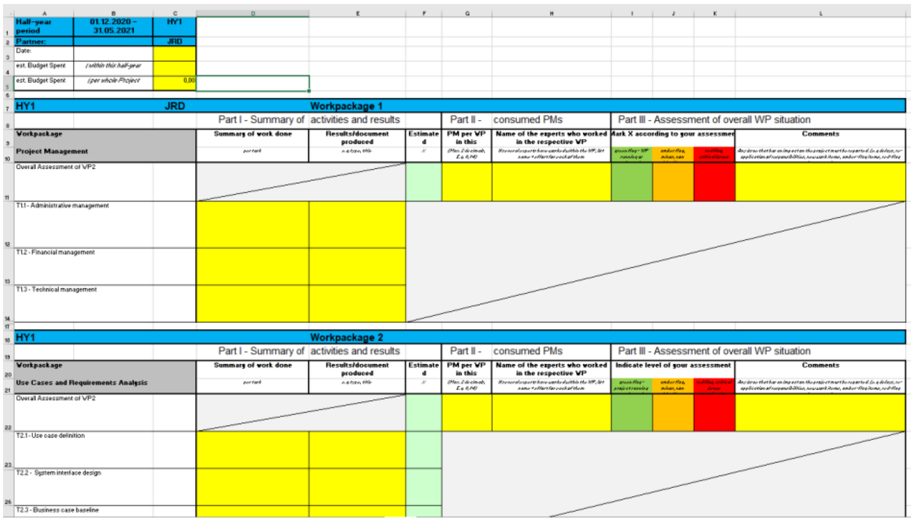


Figure 2: Biannual Reporting Template.

In addition to the documented work, there have been three biannual meetings on 08.06.2021, 21.12.2021 and on 28.06.2022 (being the interim meeting). In all these meetings, the PO as well as the external reviewers participated giving valuable feedback of the projects progress. All these meetings took place online but it is planned to organize the next consortium meeting as face-to-face meeting.

The agenda and the connection-links for all meetings were sent via e-mail to all participants prior to each meeting. A few days after the meeting, the meeting minutes were distributed to participants and uploaded to the ESRIUM Cloud.

Task 1.2: Financial management

JRD is responsible for monitoring the financial administration. This is done via the above-mentioned biannual reports (currently 3 documents available) where an approximation of spent costs and person months is provided by the partners. The idea here is to be able to react to deviations from the grant agreement on time.

As coordinator, JRD handled the forwarding of the pre-financing of the EC. In the consortium agreement, it was agreed to split this payment into two separate instalments. This was a security measure in case that partners do not provide content as expected. Since all partners are very motivated and work efficiently on the project both payments were forwarded as planned (75% of the pre-financing when received from the Funding Authority and 25% of the pre-financing by the end of Month 15).

Finally, JRD reviewed all cost statements provided by the partners in the participant portal. Minor mistakes were corrected and explanations of deviations in costs were collected to use them in Section 5.2 of this document. This cost information is also documented in the deliverable "*D1.2 First Financial information required by EC*".

Task 1.3: Technical management

At the beginning of the project, the ESRIUM Executive Board (EEB) was assigned. That is, organisations responsible to lead a work package assigned a leader by name. This person is responsible to guide the work package activities (organisation of regular meetings, execution of the work in the different tasks, coordination of deliverables, and reviews of biannual reports) throughout the project.

Meetings: For all work packages there are regular meetings in a two or four week period in order to ensure that the technical development of the project as well as its public appearance meets the grant agreement and the expectations of all partners.

Task efforts: Task leaders were assigned who are responsible for the execution of the work in a single task and realizes a detailed coordination of the involved partners.

Deliverables: In order to ensure a high quality, deliverables follow three steps before submission to the participant portal. A first version is created by responsible partners (due three weeks before the official deadline). This version is reviewed by someone who was not involved in writing the document (as defined in D1.1). After iteration and a final approval by the coordinator, it is submitted to one or both of the external reviewers as assigned by the PO (due one week before the official deadline).

Risk management: Biannual reports are assessed in order to initiate any required corrective action, aiming at safeguarding the project objectives and plans.

1.2.1.2 Summary of achievements

The main achievements within WP1 are:

- Organization of the kick-off meeting held remotely via GoTo Meeting platform (09.12.2021)
- Availability of a signed consortium agreement
- Setup of the ESRIUM cloud for document management
- Setup of Confluence Space (done by NNG) for all types of communication.
- Definition of a project quality plan
- Realization of regular WP meetings and consortium meetings
- Collection and approval of biannual progress reports (technological and financial)
- Continuous monitoring of the overall progress, financial administration and maintenance of legal documents

1.2.2 *Work Package 2*

WP number	WP 2	Lead beneficiary	7 – NNG	Start month	1	End month	17
WP title	Use Cases and Requirements Analysis						

1.2.2.1 Description of performed activities

The tasks of WP2 were built upon each other. The purpose and the result of each one of them was a well defined specification document that serves as basis of the upcoming documents besides providing fundamental and essential information for the tasks of WP3, WP4, WP5 and WP6 (see Figure 3).

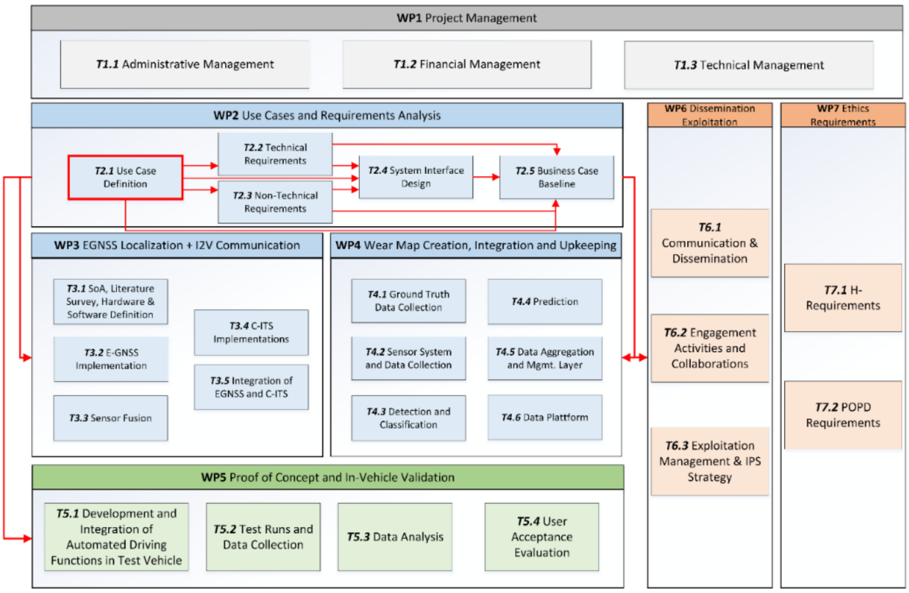


Figure 3: WP2 Tasks relations to other tasks and WPs.

<u>Task 2.1 - Use case definition</u>

As part of WP2, Task 2.1 began the process of defining needs and requirements by considering the full range of service offerings of the ESRIUM project. For this purpose, four use cases of ESRIUM services, including their benefits and potential audiences as well as their respective realization prerequisites and challenges were defined by collaborative input and contribution of all project partners.

From a methodological approach, the use case description is based on the ESRIUM project proposal and business plan. A step-by-step approach for the development of the use cases and their validation from different points of view was applied.

- Based on the GA, a use case analysis to develop a detailed description of the services that can be offered by ESRIUM was performed. Within this analysis, four application scenarios of ESRIUM services including their potential target groups and application requirements, as well as the respective challenges were defined and developed.
- This internal view has been validated first with the key customer (road operator) ASFINAG in a bilateral workshop.
- After the integration of related feedback in an advanced version of the use cases, another internal validation process with all project partners took place to develop a consolidated consensus within the diverse and multidisciplinary team of ESRIUM. The main advantage of the ESRIUM team is the coverage of the different parts of the necessary value chain.

- Lastly, external feedback was obtained from ASECAP, confirming the relevance of the developed use cases.
- Furthermore, use case 1 (EUC-001) “AI-based road damage prediction to support enhanced road maintenance planning” and use case 2 (EUC-002) “Routing Recommendations within and between lanes based on the road wear map, provided via C-ITS messages” were also subjected to external expert validation by means of an online questionnaire (see Task 2.3)[1].

During the formulation process of the use cases, legal rules (GDPR) have been discussed regarding the developed use cases with project partners.

The use cases were not only developed in textual form, but there were also special illustrations and icons created to show the functionality of the individual use cases in a simple and clear way. For example, *Figure 4* shows the functionality of use case 2 (EUC-002) “Routing Recommendations within and between lanes based on the road wear map, provided via C-ITS messages”.

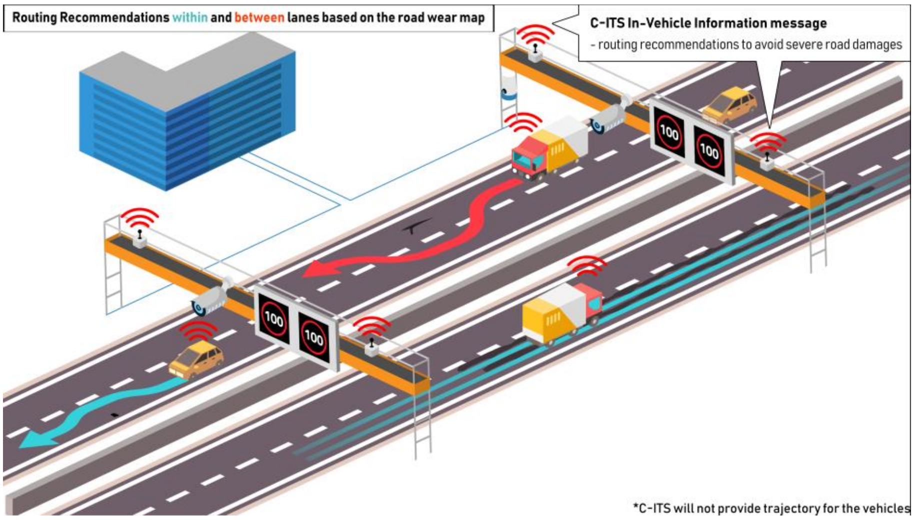


Figure 4: Use Case 2 (EUC-002) - Routing Recommendations within and between lanes based on the road wear map, provided via C-ITS messages.

In addition to the formulation and illustration of the individual use cases, an analysis of their mutual dependencies and their relations to the stakeholders was also carried out. As a result, the individual dependencies of the use cases as well as their connection with the stakeholders and their respective roles (e.g. provider, user) in connection with the ESRIUM services could be identified (see *Figure 5*). All results of Task 2.1 are collected in the deliverable “*D2.1 Use Case Definition*”.

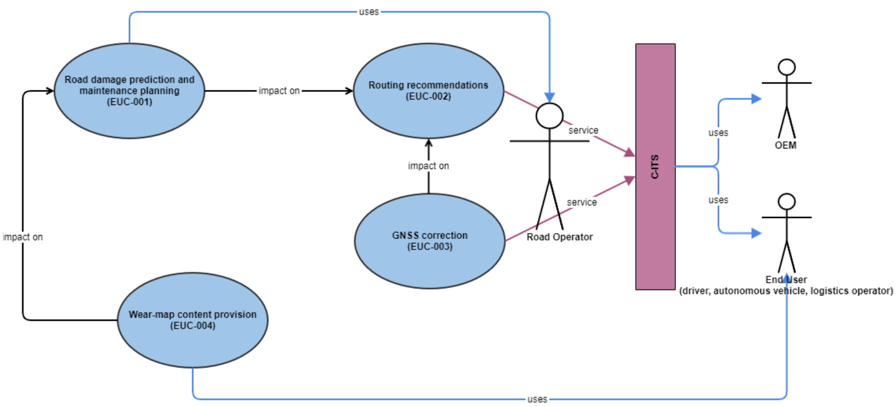


Figure 5: Use Case interrelations.

[1] UC3 and UC4 are not suitable for validation by a broad expert group, thus, not mentioned here.

Task 2.2 - Technical requirements

Technical requirements (TR) were collected after the identification of three different sources from the system and its components: end-users, use cases, component interfaces. A requirement setting process was also developed (see *Figure 6*).

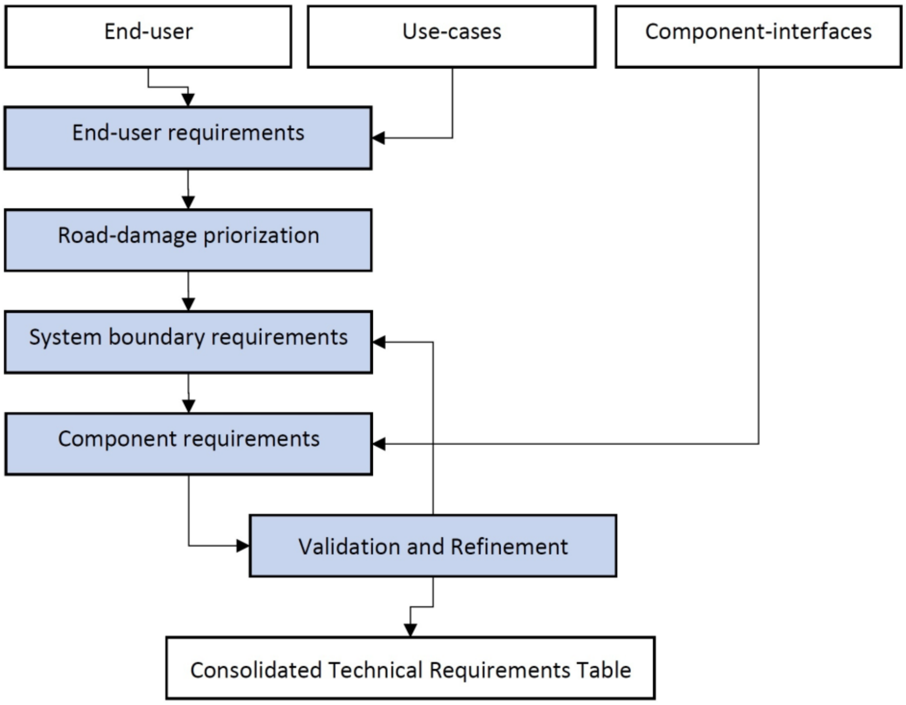


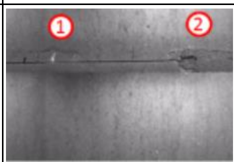
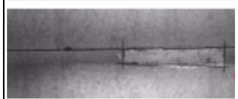
Figure 6: Methodology development for technical requirements.

In a first step, requirements imposed on the system through end-users were considered. Therefore, the project partners ASFINAG and VIF established a connection to their company departments which have a thorough overview on the needs of road maintenance and (semi-)autonomous driving. In a series of workshops their requirements on system performance were collected. With these first workshops the project consortium also received a catalogue of road damages, as they are assessed now, either manually or with precision measurement equipment.

In a second step, these classes of road damages were analysed and it was classified, which types of road damage can and should be captured by the lower-cost ESRIUM system. Because the catalogue was very textual/technical, an additional web research was conducted to obtain a more general view on the road damages, and also get example images for better understanding. The result was *Table 2*. Further, since the catalogue was only available in German, the most relevant sections were translated to English language and disseminated in the project consortium. The relevant categories of road damages served as input for the third step: technical requirements on the overall system in order to deliver the road damages. In this step, the sensing accuracies, recognition capabilities, localization capabilities and timing constraints of the overall system were assessed and translated to technical requirements. Once the technical requirements on the system boundary have been established, we concentrated on propagating these to individual components. We did this along the data path in the system, where each receiver of data or information imposes constraints on the sender. Thereby, the interfaces between components were associated with technical requirements. In a final step, the requirements were consolidated and refined to form a feasible overall solution, where the technical risk is manageable. This step again involved propagating relaxed or firmed requirements though the system components and assess the consequences at each component interface and at the system borders.

Key	Type	Description	Image[2]	Parameter			
				Area	Length	Severity Class	Width Class
DMG-01	DMG - Lack of mortar in asphalt	Flat pothole caused by gradual loss of binder, which further causes the loss of gravel.	 	✓		✓	
DMG-02	DMG - Grain breakout in asphalt	Frost-induced breakout of material from the asphalt surface.	 	✓		✓	
DMG-03	DMG - Flake breakout in asphalt	Breakout of material flakes caused by low quality construction.	 	✓		✓	

[2] Images are only for orientation. The goal of the images is to provide a visual impression of the damage type, for a better overview. Since there is no exhaustive image catalogue of damages available, similar damages have been assigned similar images. This does not imply, which damages will be discriminable by the sensor system.

DMG-04	DMG - Pothole	Frost-induced hole in the subsurface layer of the road surface.	 	✓		✓	
DMG-05	DMG - Mend area in asphalt	Area on which old material was replaces by new material and glued with binder.		✓		✓	
DMG-06	DMG - Binder emission in asphalt	Binder enrichment on the road surface due to excessive stress cause by traffic.		✓		✓	
DMG-07	DMG - Grain breakout in concrete	Breakout of material flakes caused by low quality construction.		✓		✓	
DMG-08	DMG - Chip Breakout in concrete	Breakout of material flakes caused by low quality construction.		✓		✓	
DMG-09	DMG - Detachment	Breakout of material flakes caused by low quality construction.		✓		✓	
DMG-10	DMG - Edge defects in concrete	Breakouts of material especially at the edges of concrete plates. Mostly caused by over-stressing the edge.	 	✓		✓	
DMG-11	DMG - Single cracks in asphalt	Cracks are typically caused by ageing of the binder material.			✓		✓

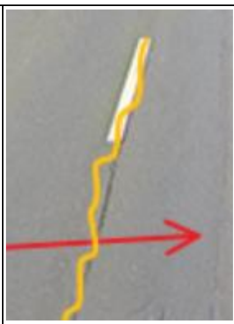
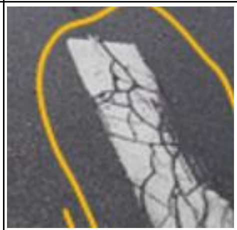
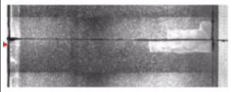
DMG-12	DMG - Seam cracks in asphalt	Cracks occurring between neighbouring layers of asphalt.			✓		✓
DMG-13	DMG - Network cracks in asphalt[3]	Cracks spreading as a network or web, in contrast to elongated, linear cracks.		✓		✓	
DMG-14	DMG - Cracks and corner defects in concrete	Cracks in concrete are caused by excessive stress or deformation of the subsurface layer. Corner defects are caused by excessive stress.			✓	✓	
DMG-15	DMG - Mending area in concrete, mended by asphalt	Defects on concrete layers, which are filled/repaired with asphalt.		✓		✓	
DMG-16	DMG - Mending area in concrete, mended by concrete	Defects on concrete layers, which are filled/repaired with concrete.		✓		✓	

Table 2: Identified damage types.

The technical requirements were also developed based on the different interfaces and components of the system:

- Geodetic Requirements: 2 requirements
- EGNSS System: 2 requirements
- C-ITS EGNSS: 1 requirement
- Ground Truth Data System: 2 requirements
- Road Wear Sensor System: 5 requirements
- Data Management Platform: 6 requirements
- Road Wear Data Interface: 2 requirements
- Prediction System: 1 requirement
- Road Wear Prediction Interface: 2 requirements
- HD Map Interface: 2 requirements
- Road Condition Interface: 2 requirements
- Data Service Platform: 1 requirement
- Road Maintenance Interface: 2 requirements

[3] Network crack in asphalt: This is a crack in the asphalt, which spreads like a network.

- Routing Interface: 4 requirements
- Map Service Interface: 1 requirement
- C-ITS IVI: 1 requirement
- End User: 8 requirements

Task 2.3 - Non-technical requirements

As part of WP2, Task 2.3 builds on the previously defined use-cases from Task 2.1. It establishes the requirements for both user experience and user acceptance of ESRIUM services. Therefore, non-technical requirements (NTRs) are derived for the involved stakeholders (road operator, map provider, OEM, fleet operator, truck drivers). Those requirements include e.g. user acceptance, traffic safety and efficiency, organizational and legal aspects or environmental drivers and barriers.

The methodological approach for the development of the NTRs was carried out in a stepwise approach. The *Figure 7* gives a good overview of the steps performed.

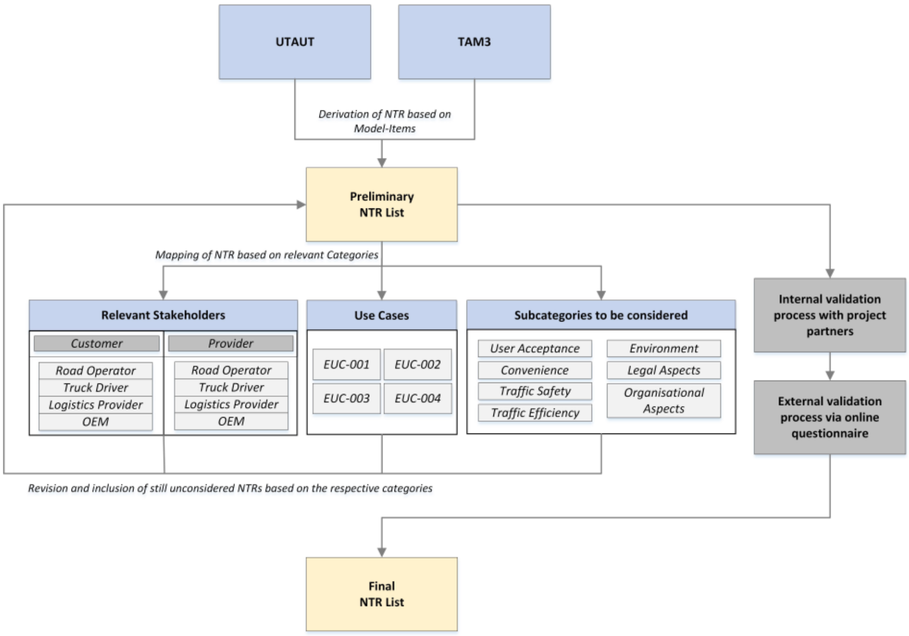


Figure 7: Methodology development for non-technical requirements.

In a first step, items and constructs from the technology acceptance models UTAUT [VEN2003] and TAM3 [VEN2008] were examined and a preliminary list of non-technical requirements for ESRIUM services was derived.

In addition, the NTRs were associated with the use cases defined in Task 2.1, the relevant stakeholders identified during the use case definition and ESRIUM-related subcategories considered in the project proposal (User Acceptance, Convenience, Traffic Safety, Traffic Efficiency, Environment, Legal Aspects, and Organisational Aspects).

The resulting NTR list was then revised in an internal validation process during a workshop with all project partners (e.g. road operators, technical experts) to ensure a multidisciplinary view from different perspectives. Any NTRs discovered during the revision that had not yet been taken into account were added to the list in this step.

Finally, the NTRs were subjected to external expert validation by means of an online questionnaire asking for the perceived importance of the individual requirements based on the stakeholder groups.

In total, 23 NTRs were defined. The online-survey results show that the NTRs are generally all perceived as important by the respective stakeholder groups, although the results for the individual

NTRs can vary somewhat. The NTR-List serves as a basis for future measurements of user acceptance of ESRIUM services and helps to optimize human-system interaction and thus increase user and technology acceptance.

All outcomes of tasks T2.2 and T2.3 have been published in the deliverable "*D2.2 Technical and non-technical user requirements document*".

Task 2.4 - System interface design

Task 2.4 has specified the internal and external interfaces of the ESRIUM system in the deliverable *"D2.3 System interface design document",* to use it as a base of the development tasks in WP4. The specification has been developed according to the results of Task 2.1, Task 2.2 and Task 2.3.

The document has a generic description part of the whole system, including components relations describing and data flow diagrams. The main part contains the specification and explanation of each and every interface supplemented with some examples given in the appendix.

Task 2.5 - Business case baseline

Task 2.5 defines the business case baseline for the project and the four use cases that are developed under T2.1 namely, *"EUC-001: AI-based road damage prediction to support enhanced road maintenance planning"*, *"EUC-002*: *Routing Recommendations based on the road-wear map, provided via C-ITS messages"*, *"EUC-003: C-ITS Message 'GNSS-correction data' provision"*, and *"EUC-004: Wear map content provision"*.

Lean approaches combined with other tools as mind-mapping, and brainstorming were used to develop an ESRIUM business case and four business use cases. The main objectives were to:

- Identify the potential end-users´ and customers´ problems and demands
- Align the solution with the customer needs
- Assess the business potential of each use case
- Develop an initial business model for the ESRIUM business case and each one of the business use cases
- Identify alternative solutions, channels, key metrics, unique value proposition, cost structure, revenue stream, among other important pillars

In *"D2.4 First Business Case Baseline"* the value proposition canvas has been used to visualize the customer tasks, pains and gain as well as the products and services ESRIUM offers to meet the market needs. Then, the lean canvas approach has been utilized to visualize the business model and illustrate the value generated and the options to capture it. The initial ESRIUM business case and four business use cases were validated internally by partners.

"D2.5 Second Business case baseline" updated the initial market findings and validated the ESRIUM business case and business use cases by acquiring external feedback though an online survey and some interviews with potential clients and other stakeholders. In addition, the ESRIUM business case was further developed by including the cost structure, pricing strategies, and the life cycle cost estimation of the system.

1.2.2.2 Summary of achievements

The main achievements within WP2 are:

- Establishment and documentation of four use cases
- Validation of the overall system concept (together with W5)
- Definition of 16 different road damage types, 47 technical requirements and 23 non-technical requirements

- Creation of an online questionnaire for stakeholders
- Specification and design of 9 interfaces between ESRIUM system components and end users
- Finalization of the structure of ESRIUM system components
- Determination of the logical components of the ESRIUM concept and their relationship
- Preparation of optional implementation of DATEX II standard
- Definition of the ESRIUM business case and four business use cases
- Organisation of workshop for stakeholder identification
- Conduction of interviews with road operators, road associations, universities and research centres, and representatives of public road users such as AUTOPISTA in Spain, BAST in Germany, VEGVESEN in Norway, AIPSS in Italy, SESMAD in Czech Republic

1.2.3 Work Package 3

WP number	WP 3	Lead beneficiary	4 – FGI	Start month	2	End month	30
WP title	EGNSS Localization + I2V Communication						

WP3 is dedicated to tasks related to the position estimation of both, the end-user and the sensor vehicles. These tasks include all aspects related to the design, purchase and assembly of the necessary HW, as well as the decision about what algorithms to use, the production of the necessary SW and the integration of the resulting systems. There are two important distinctive features that drive the design of the positioning systems: a) the aim of cm level accuracy, and b) the delivery of authenticated positions, both leveraging on Galileo's services. These features entail challenges that are to be considered since the conception of the overall solutions. The following sections explain in more detail the activities carried out in the different tasks in order to design, assemble and test a fully working and integrated solution.

1.2.3.1 Description of performed activities

<u>Task 3.1 State-of-the-art, literature survey and definition of the hardware and software tools</u>

Task 3.1 was dedicated to the selection of the most appropriate positioning methods to be used in ESRIUM as well as to the preliminary design and definition of the HW and accompanying SW and infrastructure necessary for the positioning systems to work, including their integration in the end-user vehicle. The result of these activities has been documented and reported in Deliverable D3.1. We now proceed to present a summary.

One of the most important key performance parameters that characterize a positioning system is the accuracy. Having high enough accuracy is a key enabler of many applications, and as a result, the requirements on accuracy are ever increasing. In ESRIUM, we are aiming at cm-level, which is at a level that has been only available in geodetic applications. However, advances in the GNSS technology have made it possible to start reaching this level also with receivers targeting the upper range mass-market sector, and nowadays we can see manufacturers advertising receivers for the automotive industry and promising such accuracy. However, the accuracy that one can obtain from a receiver strongly depends on the signals and positioning method that it uses.

Year	Data Set	Const.	Freq.	GNSS Aug.	Environment	Accuracy (95% horiz.)	Availability	Outage Time	Source
2010	186 hrs (13,000 km)	GPS	L1	None	Urban, Suburban, Rural, Highway	-	85%, Code Phase Position (HDOP > 3)	28 sec, 95%, Code Phase Position (HDOP > 3)	[PIL2010]
2016	5.71 hrs (613 km)	GPS, GLO	L1	SBAS	Highway	2.6m	100% with inertial		[STE2018]
2018	355 hrs (30,000 km)	GPS, GLO	L1, L2	NRTK	Mostly Highway	1.05m	50% Integer Ambiguity Fixed	10 sec, 50%, 40 sec, 80% fixed	[REI2019]
2018	10 km	GPS	L1, L2, L5	PPP (float)	Arctic	0.18m (~0.5 m)	avg. age = 0.5 s		[THO2020]
		GPS, GLO, Gal, BDS		NRTK		0.04 m	> 99.9%		
	196 km	GPS		PPP		0.26 m			
		GPS,GLO,		NRTK		0.07m	47%-73%		
2019	2 hrs	GPS, Gal	L1, L2	NRTK	Urban	0.14m	87% Integer Ambiguity Fixed	2 sec, 99% fixed	[HUM2019]
2020	18 h 56 min (1604 km)	GPS, GLO, BDS, Gal	L1, L5	NRTK	Urban, Suburban, Highway, Arctic	0.23 m – 0.31 m	0.1 m accuracy availability was between 43% to 83% depending on the environment		[PET2020]

Table 3: Results on GNSS based positioning performance in road applications.

Task 3.1 started with a literature survey aiming at identifying the most appropriate GNSS-based positioning methods for the needs of ESRIUM. In this survey, techniques such as RTK, PPP, PPP-RTK and their variants were considered. *Table 3* shows some reported results on GNSS based positioning performance in road applications, emphasizing the evolution in time.

One design parameter that influenced the decision is the proximity of reference stations in the places where the tests are placed, both in Austria and in Finland. Indeed, these places have a reference station within less than 10 km. In this condition, classic single station RTK was deemed as the most appropriate for ESRIUM, at least during the project execution. RTK based positioning requires the real-time delivery of information to the GNSS receiver. This information is exploited by the receiver to eliminate or mitigate the effects of different sources of error. The information is originated in the reference station network, and can be delivered in many different ways. Nowadays it is most common to use Internet, and a protocol called RTCM has been specifically devised to transmit the necessary information in compact messages. In the GNSS jargon, it is typical to hear or read about "RTCM corrections" when referring to these messages. These are delivered by dedicated servers, called NTRIP casters, which receive the information from the reference network and relay it to multiple (NTRIP) clients.

In ESRIUM, it was decided that the RTCM messages are to be delivered in two different ways. In the Austrian testing site, located in Graz, the tests are going to take place in a highway equipped with Cooperative Intelligent Transportation Systems (C-ITS) infrastructure. This infrastructure consists of so-called roadside units (RSU) that communicate with the vehicles. One of the goals within ESRIUM is the testing of the RTCM messages delivery using this C-ITS. *Figure 8* shows a schematic representation of the main systems involved in the delivery of RTCM messages to the end-user localization module as envisioned in ESRIUM.

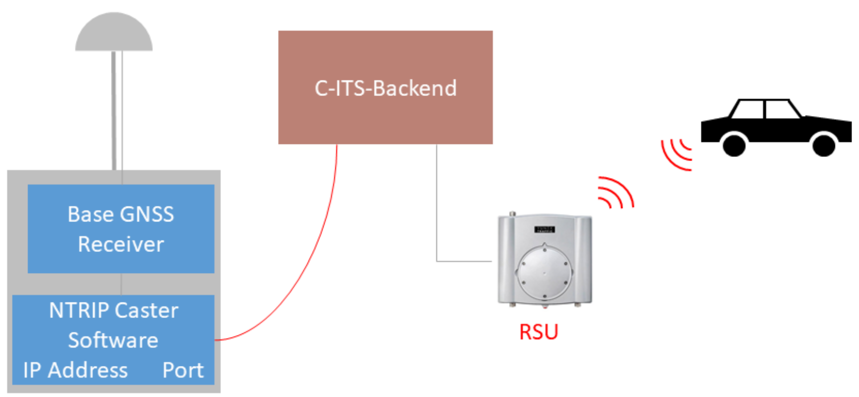


Figure 8: RTCM messages delivery to the end-user vehicle via C-ITS.

The GNSS receiver of the base station receives the satellite signals, and the reference network processing SW calculates some additional parameters (of the bias model). All this information is packed into RTCM messages and made available to external clients via an NTRIP caster. This caster is connected to and reacheable via Internet. In the ITS backend, an NTRIP client connects to the NTRIP caster. For each RSU, this client sends the RSU's position to the NTRIP caster and retrieves RTCM messages corresponding to a virtual base station (VBS) located at the involved RSU. It then adds the C-ITS specific headers to provide a RTCM C-ITS message (also known as RTCMEM message), which is then forwarded to the RSU. The RSU then distributes the message to the cars in its vicinity via ITS-G5 link. Once in the car, the C-ITS header is stripped from the RTCMEM header and the message is passed to the end-user localization module, which then uses them for RTK positioning. In the Finnish testing site, there is no C-ITS infrastructure installed, and therefore it was decided that 4G is to be used to connect the NTRIP client of the end-user localization system to an appropriate NTRIP server.

Regarding the selection of the GNSS receiver, a number of specifications had to be taken into account, namely:

- It has to have multi-constellation (at least GPS and Galileo) and multi-frequency capability,
- It can provide raw observables and navigation messages,
- It had to be relevant to automotive applications, leverage RTK positioning and be capable of reaching cm-level accuracy in real time, and
- It has to be available in a development board in order to ease the integration with other HW in the project.

After the review and test of different receivers, the Septentrio Mosaic X5 was selected. This receiver is notable by its high performance, flexibility and ease of use.

Finally, in Task 3.1 a survey was done, aiming at the selection of the appropriate HW to conform the sensor vehicle positioning system. This system has to include a GNSS receiver and an IMU, all at a cost of less than 20 k€.

Task 3.2 - EGNSS implementation

Task 3.2 is dedicated to the assembly and testing of the end-user vehicle localization system, including the implementation of OSNMA in order to deliver authenticated positions, and the overall testing of the whole system. This is still an ongoing task. The result of the activities carried out so far pertaining the OSNMA implementation have been reported in Deliverable D3.2, including explanations of the adopted solution architecture of the solution and the outcomes of some preliminary tests. The following paragraphs explain the work done so far and necessary next steps.

One important part of the task is the development of a solution to use Galileo's OSNMA service for position authentication in both, the end-user and sensor vehicles. For this matter, a partial implementation of OSNMA in the receiver side has been carried out within ESRIUM following the interface control document (ICD) published after the start of the public testing phase. In the architectural design, an extra effort has been dedicated to account for the need to use it with different receivers, in real time and off-line. A series of preliminary tests have been conducted, although more development and testing effort is still required. In the meanwhile, Septentrio has implemented native support for OSNMA in the Mosaic X5 receiver. Using this "native" implementation enormously simplifies the design of the end-user vehicle localization module, and will then be one used there. There is still need for a solution for the sensor vehicle that shall work off-line.

One potential limitation of authenticated positions as of now (leveraging OSNMA) is that pursuing strict authentication decreases accuracy. The reason is that, at the moment, OSNMA only provides authentication of Galileo navigation messages, and thus, a strict authenticated position as per OSNMA would require using only Galileo satellites. This exclusion of other constellations in the position computation, most notably GPS, has the consequence of a deterioration of the achieved performance. In principle, one could consider more intelligent strategies to allow the use of GPS. A simple one would be to closely monitor the overall positioning performance: should a spoofing attack affect GPS, the receiver would clearly see a precision decrease, since the GPS-only solution would diverge with respect to the Galileo-only solution. However, this type of development is outside the scope of ESRIUM. Besides, it is only a question of time that OSNMA supports GPS navigation messages authentication. Native GPS authentication (by GPS satellites themselves) is also expected to eventually arrive. Therefore, accuracy has been given more weight than authenticity in ESRIUM and the aim is to maximize accuracy (by using GPS) and maintain authenticity as much as possible (by using Galileo satellites with authenticated navigation messages).

In addition to the GNSS inherent sources of error in RTK positioning, and while pursuing high accuracy, in dynamic applications involving mobile devices one has to also consider the latency of the measurements, especially when the device moves at relatively large speeds. As an example, a car moving at 120km/h will traverse 33,3m each second, or equivalently 3,3cm each millisecond. The time that it takes for a GNSS receiver to compute a position estimate from the received signals (the processing time) can easily be in the order of tens of milliseconds. In addition, the communications also take a non-negligible time. Overall, the impact of latencies is an issue that is to be considered in dynamic applications aiming at cm-level accuracy. For this purpose, in ESRIUM we have measured the receiver processing time and the communication latency when using different positioning methods and update rates. *Figure 9* shows the latency statistics for a test with an X5 receiver configured to use dual frequency RTK (GPS L1/L2), to produce position estimates with varying rates from 1 to 100 Hz, and to deliver the position estimates via serial port (null modem at 921600 bps).

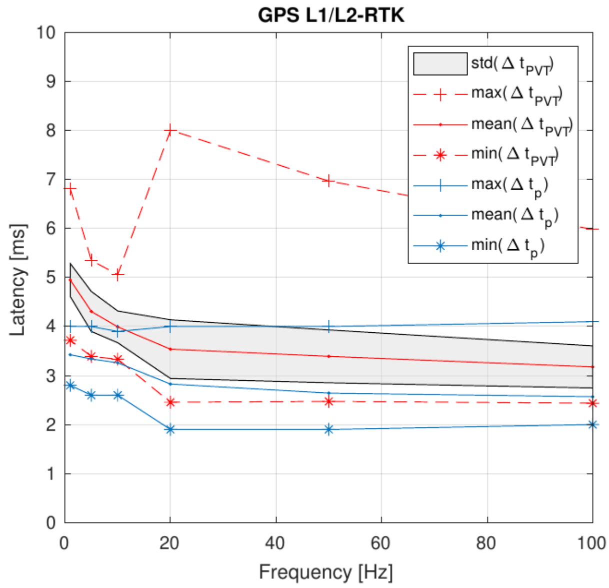


Figure 9: PVT processing time and effective latencies as a function of the measurement update rate for the selected GNSS receiver.

The blue curves represent the statistics of the processing time as reported by the receiver, and the red ones of the total delay or latency measured as received by a program running in a small card-sized computer (a raspberry pi). *Figure 9* clearly shows that both latencies are relevant and worth consideration.

Finally, and as part of Task 3.2, the end-user vehicle localization module is being tested in static, laboratory-controlled conditions as well as using a car traversing real scenarios with different types of obstructions (from open sky to urban scenarios). These tests will continue in RP2, and their associated results will be reported in forthcoming deliverables.

<u>Task 3.3 - Sensors fusion for enhancing post-processing PVA accuracy in sensor system</u>

Task 3.3 encompasses all required steps to extend the road wear sensor platform with an EGNSS/IMU system to provide georeferencing for the image and LiDAR data. The goal is to achieve a continuous and reliable highly accurate position, velocity and attitude (PVA) information with a medium-priced MEMS-based EGNSS/IMU system (~ 20 k€). The position and attitude information from the EGNSS/IMU system is required to estimate the orientation of the camera and LiDAR sensors on the sensor platform and to correctly map the road wear.

Besides the purchase and assembly of the MEMS-based EGNSS/IMU system, T3.3 involves other sub-tasks. First, the achievable position accuracy under realistic conditions shall be compared with the specifications from the manufacturer using either more accurate FOG-based GNSS/IMU systems or using accurately known ground control points which are identified in the captured image data of the sensor car. These ground control points already exist along the Austrian test region. Second, depending on the achieved results, the need for an additional odometer or a dual-antenna GNSS/IMU system may also be evaluated, and its potential benefits estimated. This potential heavily depends on the defined system requirements. Third, the OS-NMA algorithm implemented in T3.2 is to be included to identify potential manipulated GNSS data. And fourth, the most appropriate approaches in terms of sensor setup and processing configurations for the sensor fusion for the automotive application including precise EGNSS will be analysed and evaluated. The planned output of the task is an enhanced medium-priced position solution for the road wear sensor system.

In RP1, the main parts of the MEMS-based EGNSS/IMU system for the sensor vehicle have been ordered. In addition, and together with WP2, the technical requirements including the specifications for the EGNSS/IMU system or the road wear sensor system were defined within multiple workshops. Within these workshops, accuracy requirements, required sensor update rates, interfaces, data types and coordinate frames were discussed and defined. It was also defined that the EGNSS/IMU system shall support dual-antenna but should not include a wheel odometer due to simplified vehicle installation.

The requirements engineering was an important step, which took longer than expected (until the end of 2021). The outcome was a mandatory input for the selection of a proper MEMS-based EGNSS/IMU system. Intense research and talks with manufactures, resellers, and people from the community followed to look for adequate EGNSS/IMU systems for the road wear sensor system. The system specifications including GNSS, gyroscope and accelerometer performance of existing systems were analysed in detail. Price information was collected and based on the cost requirements (~ 20 k EUR) a decision was made with the Novatel PwrPak 7 PW7720E2-FDD.

During the first test drives in Finland, where the requirements engineering was not yet finished, a temporary MEMS-based EGNSS/IMU system was installed. For these test drives, the ground truth for the position and attitude information was generated to enable the evaluation of the EGNSS end-user localization module and the EGNSS performance in general. *Figure 10* indicates the achieved EGNSS/IMU accuracy of the ground truth derived with the iMAR iNAT FSLG 01 system with fibre-optical gyroscopes.

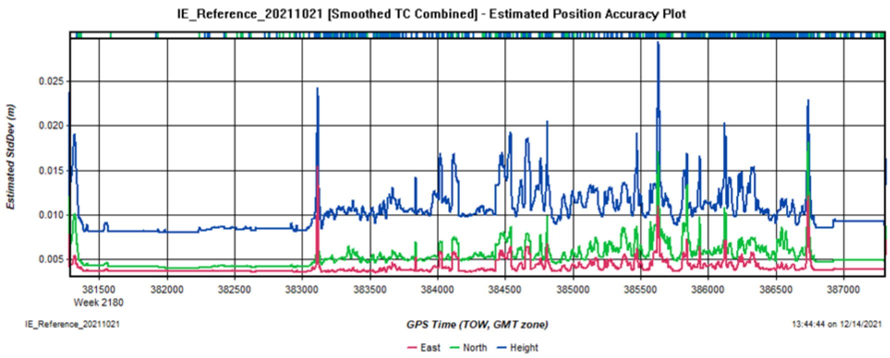


Figure 10: Estimated position accuracy in east (red), north (green), and vertical (height, blue) direction as derived from test data from the test drives in Finland via combined processing of EGNSS and IMU data.

Together with FGI and the results from Task 3.2, an OSNMA approach to authenticate the results of the road wear sensor system was designed. The goal of the chosen approach is to authenticate the georeferencing data (mainly the trajectory) as good as it is currently possible.

As soon as the EGNSS/IMU system will be available, it will replace the temporary solution and the open tasks will be addressed.

Task 3.4 - C-ITS implementations

Within Task 3.4 all C-ITS messages needed for the ESRIUM Use Cases were defined in line with the C-ROADS C-ITS Specification.

General: Messages will be broadcasted with a default of 2 Hz rate (but can be made faster if necessary). The transmission range from minimum 400 meters but up to 2000 meters was measured (depending on the site). Messages will be signed according to TS 103 097 and the European Certificate Policy. The ECTL level will be level 0.

RCTMEM: RTCMEM will be broadcasted according to TS 103 301 V2.1.1 and EN 320 890-2 V2.1.1. (Clause 7.2.2 Table 5)[4].

IVIM: IVIM will be broadcast according to TS 103 301 V2.1.1 and ISO 19321: 2020[5].

Lane Change use case: The lane change recommendation will be broadcast using the pictograms shown in *Table 4* identified by their GDD ISO 14823 code.

ISO 14823 code	Meaning (lane recommendation)	Pictogram
13 660	Lane Free	
13 661	Clear lane to left	
13 662	Clear lane to right (optional, not sure if needed)	
13 659	(Lane closed, optional not sure if needed)	

Table 4: Pictograms for lane change recommendations.

The pictograms code will be broadcast in the following automated vehicle container: *IviStructure.optional.avc.AvcPart.automatedVehicleRules.roadSignCodes.code. iso14823*

The IVIM will contain four zones in its *GeographicLocationContainer*: one detection zone and three consecutive relevance zones as depicted in *Figure 11*. Note that the relevance zones 1 and 2 also serve as the detection zone for relevance zones 2 and 3 respectively.

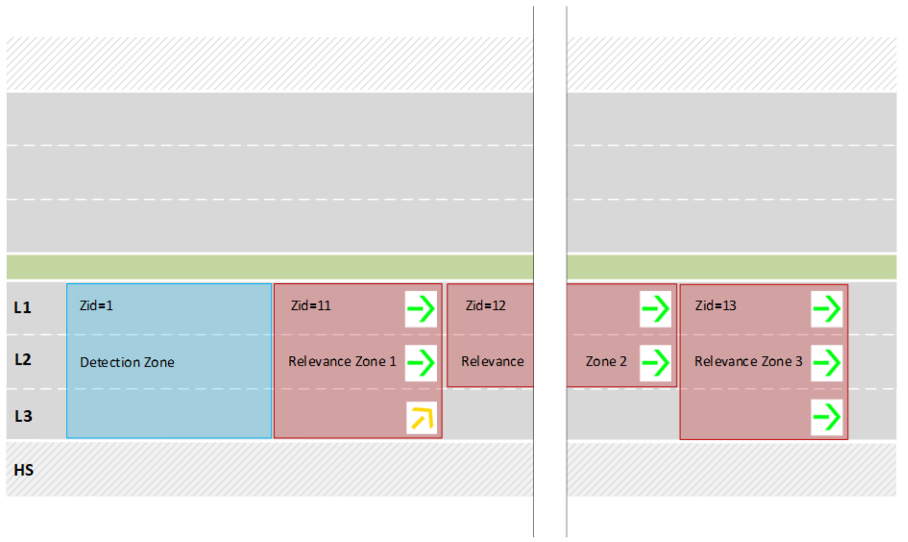


Figure 11: Message transmission zones for lane change. Arrows indicate traffic direction.

[4] https://www.etsi.org/deliver/etsi_en/302800_302899/30289002/02.01.01_60/en_30289002v020101p.pdf
[5] The ASN.1 module is available here: https://standards.iso.org/iso/ts/19321/ed-2/en/ISO19321IVIv2.asn

Each lane recommendation will be coded as one *AvcPart* as presented in *Table 5*

AvcPart	detectionZoneIds	relevanceZoneIds	applicableLanes	Code
1	1	11	1, 2,	13 660
2	1	11	3	13 661
3	11	12	1, 2,	13 660
4	12	13	1, 2, 3	13 660

Table 5: Lane recommendation coding for lane change.

Lane offset use case

The lane-offset recommendation will be broadcast using the free text option in the automated vehicle container: *IviStructure.optional.avc.AvcPart.automatedVehicleRules.extraText*

The free text will contain the "+" or "-"symbol followed by the offset in centimetres.

"+" indicates an offset to the right of the lane centre

"-"indicates an offset to the left of the lane centre

The IVIM will contain one detection zone and one relevance zone as depicted in *Figure 12*:

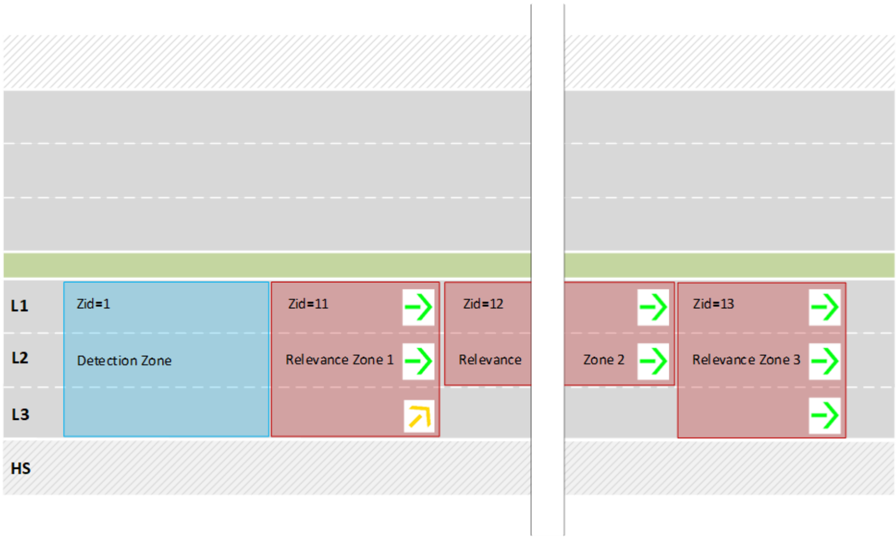


Figure 12: Message transmission zones for lane offset. Arrows indicate traffic direction.

The lane-offset recommendation will be coded as one *AvcPart* per lane as shown in *Table 6*; the default is only one part for one lane:

AvcPart	detectionZoneIds	relevanceZoneIds	applicableLanes	Offset
1	1	11	1	± offset in cm
2	1	11	2	± offset in cm
3	1	11	3	± offset in cm

Table 6: Lane recommendation coding for lane offset.

<u>Task 3.5 - Integration of the EGNSS system and the C-ITS link to the user vehicle</u>

Throughout the first period of the project, this task has officially been in the planning phase. However, in conjunction with the WP5 the activities for development of the demonstrator have started, as summarized below.

First, the system architecture for the end-user vehicle has been made to ensure the provision of EGNSS based localization solution based on the requirements and specification of the automated driving demonstrator vehicle. This required a C-ITS based RTK correction delivery solution to ensure high-accuracy positioning, both for proper functioning of the driving functions as well as the accurate evaluation of the corresponding KPIs. The intended solution also involves an integration of ITS-G5 OBU, which is based on an in-house development solution at VIF.

OBU System Solution:

The OBU system (internally called "Vehicle Captain") comes in two specific implementations, one being a desktop development version and the other for the vehicle-integrated version. The desktop development version is shown in *Figure 13*, and is mainly used for lab development of the parsing software for the RTCM and IVIM messages.

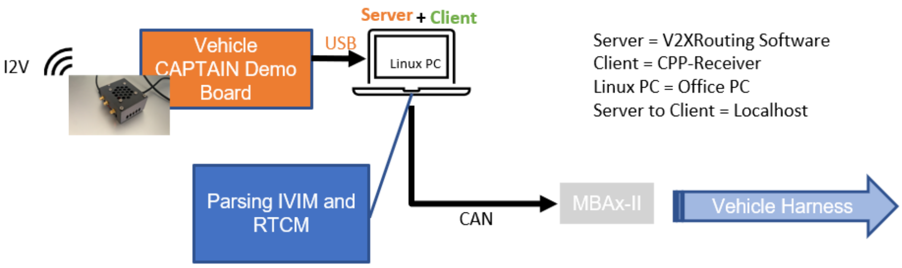


Figure 13: OBU (Vehicle Captain) desktop development architecture.

The vehicle version of the OBU can be seen in *Figure 14*, and is a more advanced version of the development board based on the Raspberry Pi4 mini PC. In this configuration, the OBU runs in a server mode and provides the received messages from the C-ITS infrastructure to an on-board client PC, which parses the IVIM and RTCM(EM) messages for further interpretation by the driving functions running on the DSpace MicroAutobox II (MBAx-II) real-time ECU.

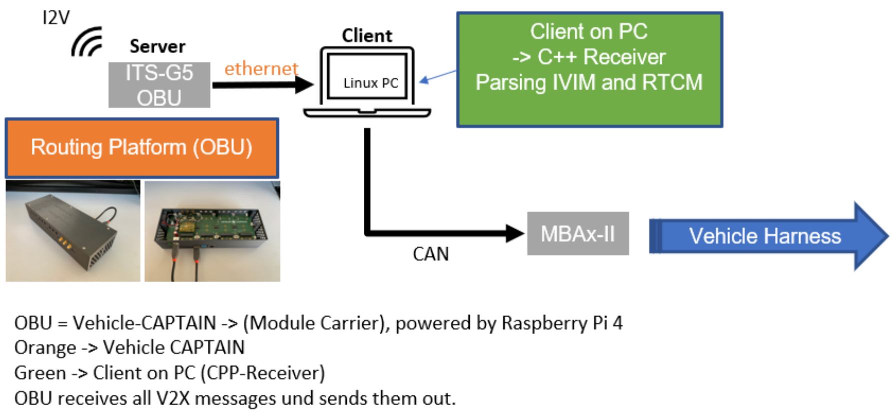


Figure 14: OBU (Vehicle Captain) vehicle architecture.

EGNSS System Selection:

In collaboration with FGI and JRD, the EGNSS receiver development kit fitting to the requirements of the project was selected. For preliminary tests, the *Septentrio mosaic-H GNSS heading module development kit with 2 GNSS antennae*[6] (shown in *Figure 15*) will be used.

[6] https://shop.septentrio.com/en/shop/mosaic-h-gnss-heading-module-development-kit-2-gnss-antennae

Figure 15: Septentrio mosaic-H EGNSS Development Kit to be used during preliminary tests for the localization of the automated driving demonstrator vehicle.

The integration of the EGNSS board will be completed early in the second period of the project, and validation and performance tests will follow in collaboration with FGI and JRD, which are planned for fall 2022.

1.2.3.2 Summary of achievements

The main achievements within WP3 are:

- Selection of the positioning method to be used in the end-user localization module
- Decision and consolidation of the GNSS module to be used in the end-user vehicle
- Determination of the overall HW design
- Performance assessment of the end-user vehicle localization module via preliminary tests
- Partial implementation of OSNMA and conduction of preliminary tests
- Engineering of the requirements (joint task with WP2).
- Selection of the final EGNSS/IMU system for the sensor vehicle
- Data processing of the first measurement campaigns
- Definition of all required C-ITS messages in the form of ITS-G5 based message standard (IVIM) for routing recommendations
- Implementation and adoption of the use of RTK correction message for EGNSS, based on the RTCM (EM) utilising ITS-G5
- Selection of the OBU and EGNSS hardware for the end-user vehicle and acquisition of all necessary components

1.2.4 Work Package 4

WP number	WP 4	Lead beneficiary	1 – JRD	Start month	1	End month	36
WP title	Wear Map Creation, Integration and Upkeeping						

1.2.4.1 Description of performed activities

<u>Task 4.1 - Road Wear Ground Truth Data Collection</u>

Within this task, a selection of test areas for road wear data, the data collection in Austria and Finland and the generation of labelled ground truth data for such road wear features (to be used further in WP4 tasks) has been done. Results have been described in the deliverable "*D4.1 Road Wear Ground Truth Data*" that also includes a specification for labelled road wear features and links to demo data.

The selection of suitable test sites is crucial for getting a valuable database of road wear features (RWF). It is important to cover a wide range of different RWF, which can be found on different road/surface types (asphalt, concrete). On the other hand, selected road sections should be limited to 5-10km and should be easily accessible in order to limit the effort for (repeated) data collection. Within ESRIUM, we are able to use test sites in Austria as well as in Finland, which makes it possible to cover different road (wear) types, weather and traffic conditions.

Selected test areas in Austria

Test sites in Austria have been identified by evaluation of existing road wear data provided by the project partner ASF. Near Graz, several highway sections have been identified which show good samples of road damages on both asphalt and concrete surface types (*Figure 16* and *Table 7*). Collection of mobile mapping data has been performed using the PEGASUS system from Leica Geosystems equipped with two pavement cameras mounted at the back looking downwards (*Figure 17*). PEGASUS has also two survey-grade LIDAR profilers mounted which provide 3D point data at 2 M points/s at an accuracy of 1-3mm.

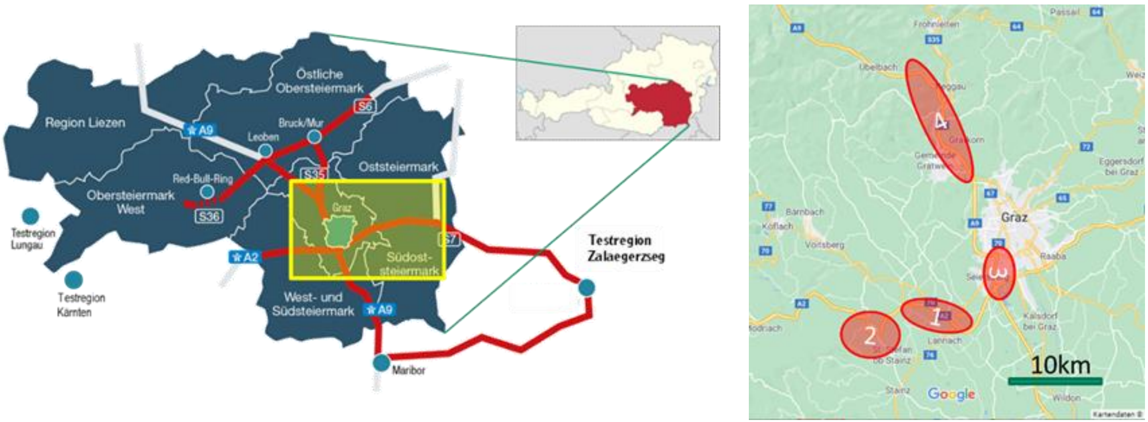


Figure 16: Selected test sites on highways A2 and A9 near Graz/Austria.

Figure 17: PEGASUS Mobile Mapper used by JRD in Austria.

Test area	Surface type	Highway	Section
#1	Concrete	A02	Km 195,4-199,2
#2	Asphalt	A02	km 205,0-202,1
#3	Concrete	A09	km 190,4-185,3
#4	Asphalt/Concrete	A09	km 157,0-172,3

Table 7: Surface material, highway name and service provider range identification of each test site.

Selected test areas in Finland

In Finland, also four test sites have been defined (*Figure 18* and *Table 7*); data has been collected using an in-house developed system called ROAMER equipped with a Riegl VMX scanner and a ladybug panoramic camera (*Figure 19*). All road damages are on asphalt (*Table 8*).

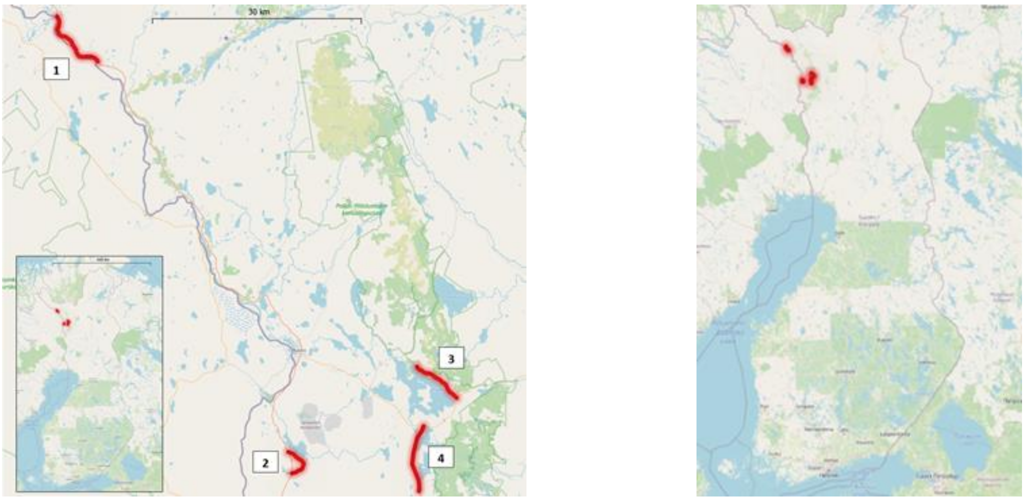


Figure 18: Selected test sites in Finland.

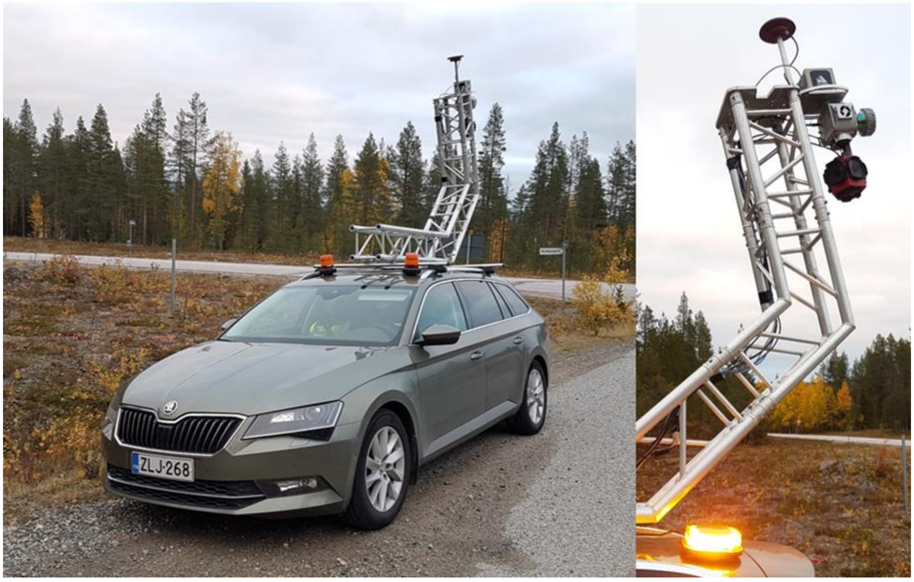


Figure 19: ROAMER system used by FGI in Finland.

Test area	Surface type	Highway	Section
#1	Asphalt	E21	10 km south from Kuttanen
#2	Asphalt	19872	5,3 km
#3	Asphalt	9572	7,6 km starting from road 79
#4	Asphalt	940	10 km starting from road 79

Table 8: Overview of Finland test site tracks, only asphalt is used.

In contrast to the Austrian test sites, there is quite low traffic in the Finish test sites, all of them having vehicle counts below 1000 per day, for test areas 2, 3 & 4 even below 150 vehicles per day (numbers taken from an online-map by Finnish Transport Infrastructure Agency).

Ground Truth Data Labelling Guideline

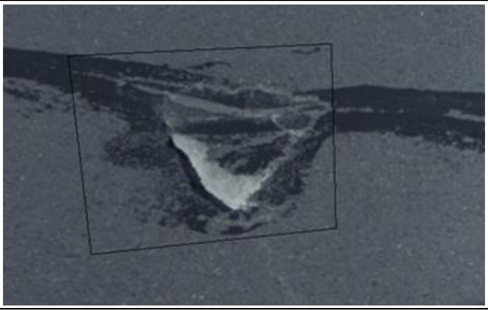
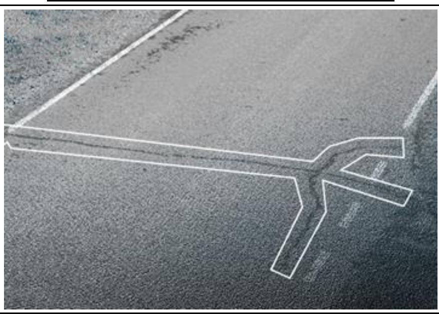
Following a damage classification guideline from Austria's motorway operator ASF, a list of surface damages was annotated semi-automatically within the acquired mobile mapping data in the test areas. The process was done by first assigning annotation polygons around damaged areas on the ground manually and subsequently calculating properties (surface area, lateral and longitudinal length, section id) automatically. The damage types can be categorized into (1) surface damages on asphalt, (2) surface damages on concrete, (3) cracks on asphalt and (4) cracks on concrete. Every damage type has assigned an additional severity class, which serves as a weight factor in calculating the current state value.

Table 9 gives an overview of all damage classes with respective severity. The last column “manually classified” denotes the classes, which were selected for the classificator training. The remaining classes are not considered in the scope of project.

Damage ID	Parent Category	Damage Type	Severity class	Manually classified
01	(1)	Lack of mortar in asphalt	1	
02	(1)	Grain breakout in asphalt	1	
03	(1)	Chip breakout in asphalt	2	
04	(1)	Pothole in asphalt	2	x
05	(1)	Mending area in asphalt	1	x
06	(1)	Binder emission in asphalt	1	
07	(2)	Grain breakout in concrete	2	x
08	(2)	Chip breakout in concrete	2	
09	(2)	Detachment in concrete	2	
10	(2)	Edge defects in concrete	2	x
11	(3)	Single cracks < 2 mm and mended cracks in asphalt	1	x
	(3)	Open cracks > 2mm and < 10 mm	2	
	(3)	Open cracks > 10 mm or parallel cracks	3	
12	(3)	Seam cracks < 2 mm and mended cracks in asphalt	1	
	(3)	Seam cracks > 2mm	2	
13	(3)	Unmended network cracks in asphalt	2	
	(3)	Unmended network cracks with polygon breakouts	3	
14	(4)	Unmended cracks and corner defects in concrete	3	x
15	(2)	Mending area in concrete, mended by asphalt	2	x
16	(2)	Damaged mending area in concrete, mended by concrete	2	x

Table 9: Road service provider road damage classification overview: This table represents the maximum possible level of detail, automated classification and detection approaches can only approximate this definition.

An illustration of damage classes used is given in *Table 10*:

Damage ID	Damage Type	Sample Image
04	Pothole	
05	Mend area in asphalt	
07	Grain breakout in concrete (Austria only)	
10	Edge defects in concrete (Austria only)	
11	Single cracks in asphalt	

14	Cracks and corner defects in concrete (Austria only)	
15	Mending area in concrete, mended by asphalt (Austria only)	
16	Mending area in concrete, mended by concrete (Austria only)	

Table 10: Visual examples of the most important road damage classes. This is already a subset of the reference table but still contains a high level of detail, like distinguishing for surface types. Information about surface types like concrete and asphalt are implicitly available through the location and have not to be covered by automated recognition algorithms.

Figure 20 shows a sample of two manually annotated road wear features (RWFs). For mapping RWFs, JRD uses a digitization software capable of projecting equirectangular and planar measurement images into a 3D point cloud. For that task, Orbit 3DM Feature Extractor is suited. The test areas have been recorded through one or more mobile mapping missions. The point cloud's LAS Files and the panoramic pictures, as well as the two pavement camera photo series have to be imported. For manually classifying an RWF, a polygon has to be defined around the damage and the correct damage class has to be selected. The severity value is set implicitly, except for damage types 11, 12 and 13, where it has to be set explicitly. Mapping of the RWF features should be done according to *Table 10* with Polygon Z as geofeature type in *Table 11*.

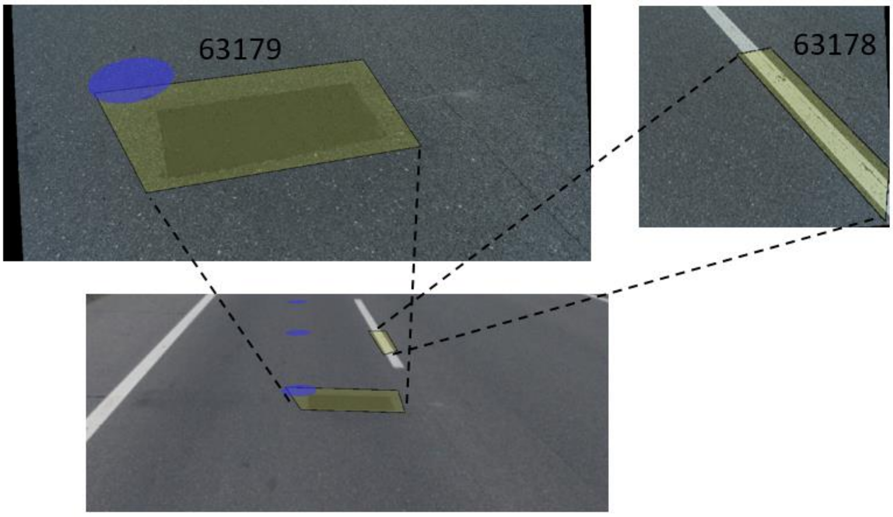


Figure 20: Sample view of damage types in the low-resolution panoramic camera (bottom) and the high res pavement cameras (top).

Parameter	Value
ID	Unique Mapping ID
Editor	Name of the Mapper / Author
Damage Type	Damage Type of the feature
Severity Class	Severity class value from 1 - 3
Geometric Extent	Enclosing Polygon of the mapped feature
Mapping Timestamp	The time, the feature was identified

Table 10: Parameters and attributes of the ground truth database.

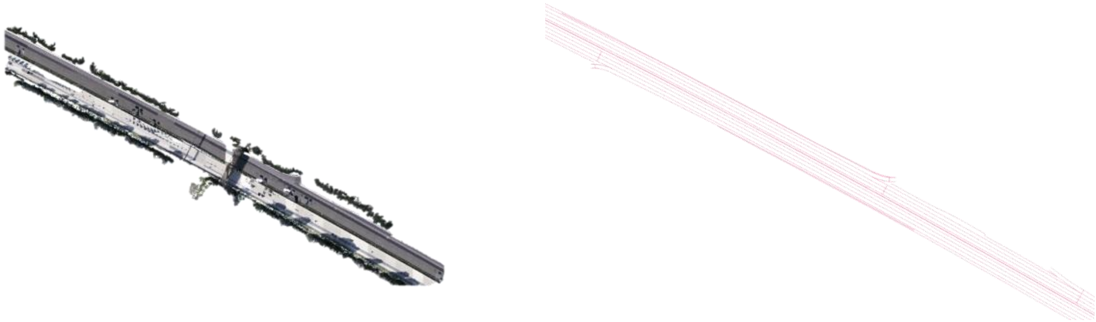
Id	Type	Severity	Extent	Editor	Timestamp
63179	5 (mending area in Asphalt)	1	POLYGON Z(…)	hal	2021-08-24T09:42:26+0000
63178	11 (single cracks in Asphalt)	2	POLYGON Z(…)	las	2021-08-24T09:46:26+0000

Table 11: Example for meta data for mapped features.

The collection of RWFs is saved in the Data Management Platform (T4.5) and made available as Ground Truth Training Data to the Detection System (4.3). In addition, the Prediction System (4.4) utilizes both manually annotated and automatically recognized RWFs for providing deterioration estimates.

UHD Map

The Ground Truth Data collection task also covered generating an Ultra High Definition Map (UHDmap). The point cloud scanning data provided the basis for deducing lanes, road markings, topology and driveable areas. This map allows for accurately providing navigation suggestions and localizing road wear features with centimetre-level accuracy. An illustration of the UHD map in vector format is given in *Figure 21*.



(a) (b)

Figure 21: (a) Point cloud scan in Test Area #1 and (b) deduced UHD map features on point cloud.

The map is saved in the Data Management Platform (D4.5) in a suitable exchange format (OpenDrive) and made available through a dedicated interface to D4.6.

Task 4.2 - Road Wear Sensor System and Data Collection

Road wear Sensor System

The sensor platform (details are given in the deliverable "*D4.2 Road Wear Sensor System*") was developed for experimental testing of different sensors in different combinations and therefore provides different possibilities of mounting. Information from GNSS/IMU (Global Navigation Satellite System / Inertial Measurement Unit), laser scanner and cameras of high quality are recorded synchronized and geo-referenced building the data source for the ESRIUM road wear sensor development. A standard roof box serves as the basic framework for the sensor platform (*Figure 22* and *Figure 23*). The box's ceiling load capacity provides sufficient clearance for all the necessary sensor technology. In addition, it is easily transferable to other vehicles and heaving a simple and certified vehicle mount using the car's roof racks. In order to simplify the mounting and dismounting, four anchor points were included to allow the use of a ceiling crane to ensure safe mounting. One of the benefits of this construction is that the roof box offers certain resistance to environmental influences such as rain or snowfall. In addition to the hardware inside the box, there are two cameras mounted into an IP67 camera housing with active heating elements and a LiDAR sensor directing on the backside of the vehicle onto the streets surface.

List of included Sensors:

- 1x LiDAR Sensor Velodyne VLP32C
- 2x XIMEA xiC MC124CG-SY-UB cameras
- MEMS (Microelectromechanical Systems) based GNSS/IMU System (Novatel Propak6 und Novatel IMU-IGM-S1)
- GNSS/IMU System for reference localization (iMAR iNAT FSLG01)

Figure 22: Detailed view inside the roof box with the reference GNSS/IMU system for evaluation in the centre and the GNSS unit. The actual optical road wear sensor components for ESRIUM (cameras and LiDAR) are mounted on the back.

Figure 23: The road wear sensor system in Finland with the actual ESRIUM sensors (mainly the two high-resolution cameras).

An important aspect of the development has been the hardware-based synchronization of the individual sensors. This synchronicity is essential for later evaluations but also for the calibration of the multi-sensor system itself. In the constructed platform special attention had to be paid to the interaction between LiDAR and camera. All sensor data receive a hardware-based time stamp based on the GNSS PPS signal (pulse per second). The GNSS signal serves as the general time base of the platform. The challenges here are that this time base must be valid on several computers at the same time and not all sensor components can be controlled via a physical trigger line. The selected Ximea cameras have a hardware trigger, but the LiDAR sensors do not. The cameras can be read using the global shutter, therefore, can be triggered precisely and consequently be synchronized with the localization unit. The LiDAR sensors, however, have a temporal inertia due to the mechanical rotation of the sensor and can be set to a pulse per second signal over time. All Velodyne LiDAR sensors have the ability to synchronize their data with an external GNSS using a PPS signal and an NMEA message. The LiDAR also synchronizes its rotation so that its position is always known to the PPS pulse.

The recording software (*Figure 24*) was developed using the software component RTMaps[7] and runs on the two computing units of the mobile computing platform, that are connected by a Gigabit

[7] https://intempora.com/products/rtmaps/

Ethernet network. RTMaps provides all necessary requirements to synchronously store different sensor information – platform-independent and on distributed systems. To ensure time synchronization between the camera data and the GNSS clock times, a custom synchronization initialization was developed by using an external trigger. The recording software additionally provides a GUI to monitor the data acquisitions.

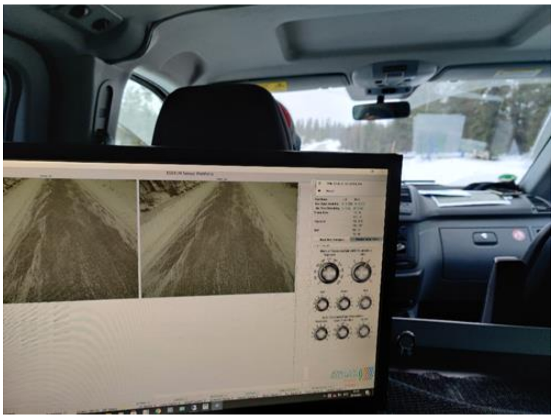


Figure 24: Recording software GUI monitoring and controlling the sensor platform during data acquisition in Finland.

Data Collection

Data collection with the road wear sensor system took place in the areas of Graz and Muonio (Finland). The areas are covered by our ground truth database and correspond to that area. On both data sites, the same road wear sensor system was used.

The tracks in Austria/Graz are shown in *Figure 25* and cover two highway segments of 18 km and 17 km length in two directions. In total approximately 40000 stereo pairs, resulting in 80000 images have been recorded:

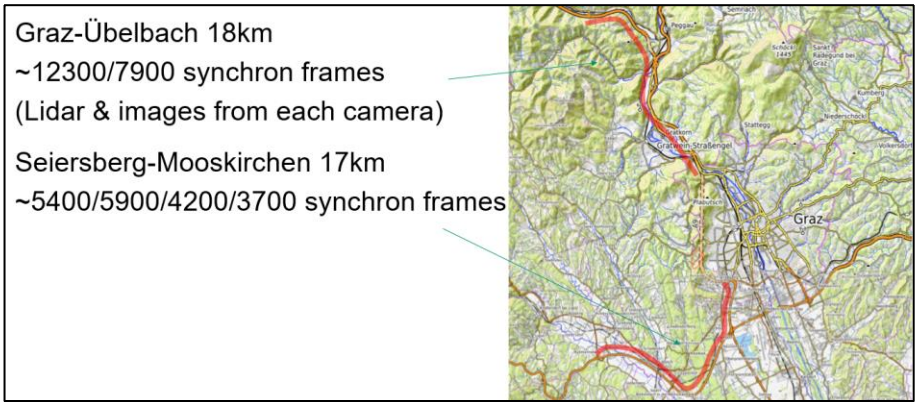


Figure 25: The test tracks in the Austria/Graz area, highlighted by the red lines.

The tracks in Finland are shorter but there were three segments covered, with a total length of 28 km (*Figure 26*). Again, both directions are covered and about 36000 stereo pairs have been recorded, leading to 72000 individual images.

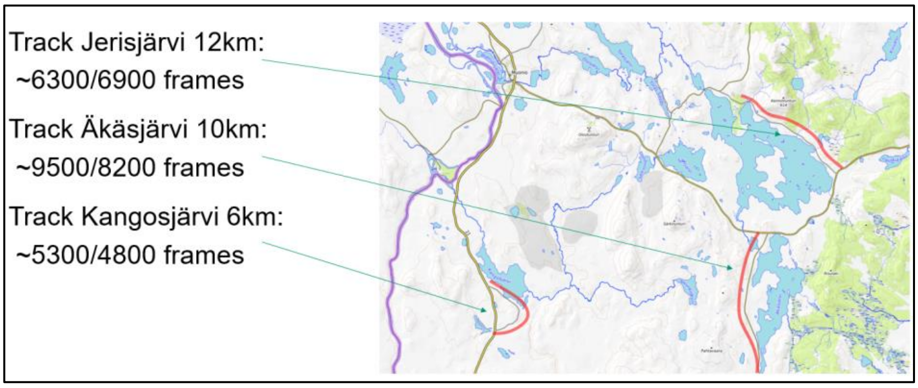


Figure 26: The test tracks in the Finland area, highlighted by the red lines.

Task 4.3 - Road Wear Detection and Classification

For the road wear detection task two different classes of approaches are developed. A geometry based detection or measurement of lane grooves and object based detection and classification of different types of road wear damage.

Object detection and classification

The major activities in task 4.3 were carried out to create a road damage object detection framework and data set.

The activities carried out in Task 4.3 were:

- Pretraining object detector for road wear damage on public data
- Creating the ESRIUM training data set
- Training and data set iteration using the detector on new data

The ESRIUM object detection started by training a YoloV4 [BOC2020] model with data from public data set. There are two reasons for this pretraining: Deep learning based approaches benefit from more domain specific data and it is possible to compare our selected method to published results on this public data set. Therefore, results on the ESRIUM data were improved and the method is validated to be state of the art.

Pretraining on GRDDC_2020 [ARY2021] data set

The main difference of this data (*Figure 27*) set to the ESRIUM data is that images are of low resolution and of course, the classes are slightly differently defined. The data set consists of the following images:

- Number of all images: 21041
- Number of images without defect: 6472

Figure 27: Example image from GRDDC_2020 data set.

In this example, a modified YOLOv4 Tiny model on GRDDC was trained and achieved a performance as expected on the data set (*Figure 28*). As the ESRIUM data set grows, also, models that are more complex will be employed, that are more prone to overfitting and need more data, but can achieve a better performance on more complex tasks.

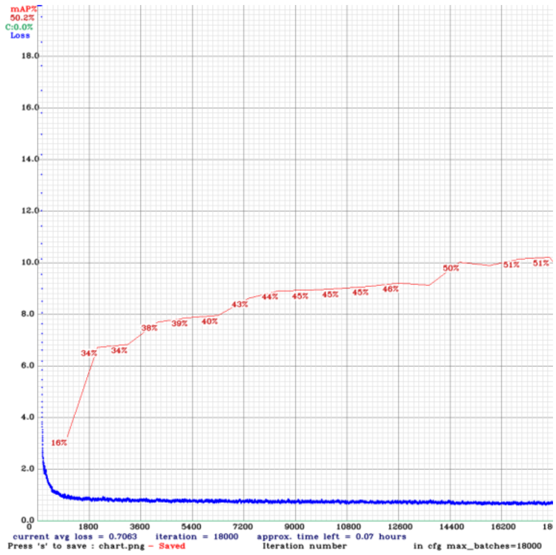


Figure 28: Training a model of our detector with low complexity on GRDDC_2020.

Creating the ESRIUM training data sets

The current ESRIUM data set (V3) consists of the following number of images:

- Number of all images: 5948
- Number of images without defects: 2174

The data set is not yet finished but progressing. Images are added and class definitions will be adapted slightly. The training of a YOLOv4 Tiny model has currently a mAP of 39% (*Figure 29*), this will be improved further. The reason for the lower mAP as compared to the GRDDC_2020 data is currently mainly caused by some classes that have too few examples. This will be resolved in the future. Furthermore, different models will be evaluated on the ESRIUM data set. Also validated was the assumption that pretraining on GRDDC data improves result on the ESRIUM data. Training on the

ESRIUM data set with and without GRDDC domain specific initialization clearly showed the benefits of this approach.

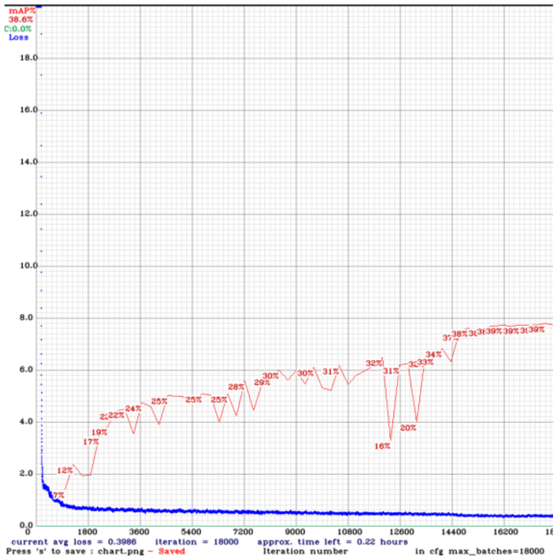


Figure 29: Training a model of the detector with low complexity on the ESRIUM data set.

Improving the ESRIUM training data set

Training on the ESRIUM data set already provides a detector that achieves reasonable results on the collected data and can be used to improve the data set itself. The trained detector was already used to create an iteration of the data set. The inference was used on new image data and the results were checked and corrected by human supervision, leading to an extended training data set. Detection examples can be seen in *Figure 30*.

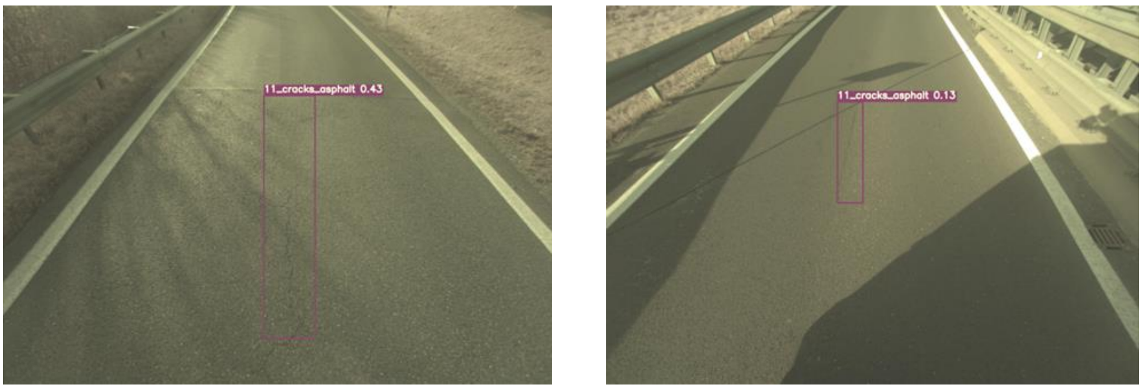
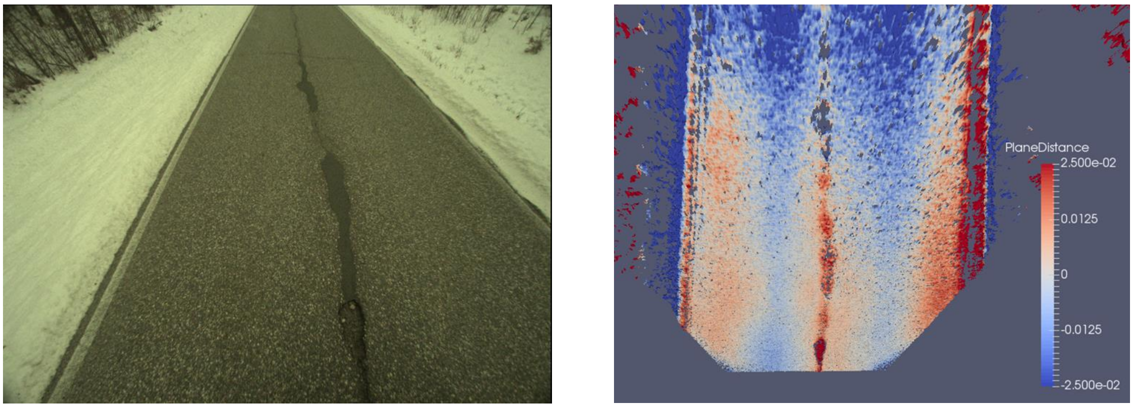


Figure 30: Detection results with YOLOv4 detector trained on ESRIUM data on new unseen data.

Lane groove measurement

The lane groove geometry cannot be observed well by one camera. Experiments were carried out if it is possible to measure the geometric details of the road surface by using 3D information. The road wear sensor is equipped with a low cost LiDAR sensor and stereo cameras. The LiDAR resolution and point density is not sufficient for detecting the necessary geometric details. A high accuracy semi-global stereo matching algorithm [HIR2007] with subpixel matching was applied to the geometrically calibrated stereo system and the plane fit distance in the stereo frame was evaluated. In *Figure 31* the geometric details of the lanes are visualized.



(a) (b)

Figure 31: (a) Left camera image and (b) visualization of plane fit distance. The geometry of lane grooves is visible.

The distance to the plane fit is colour coded, the blue stripes show the lane grooves in the road surface. It was demonstrated that it is possible to measure these fine details using stereo images.

Task 4.4 - Road Wear Prediction

First, existing data and classification options were analysed. It was possible to identify missing data and requirements regarding the level of granularity of certain data (mostly temperature). In the end, specification and enhancement of the following data sets was done:

- Ground truth data
- Weather data
- Traffic data

Those data sets are provided by Task 4.5 and serve Task 4.4 as input data for the prediction algorithms.

Furthermore, the specification of the output/prediction data was finalized. Consequently, Task 4.5 will receive the following details for each road wear allowing for several developments of a single road wear over time with a certain probability:

- Timestamp of prediction
- Timespan
- Wear type
- Probability

First approaches were analysed and surveyed how to process the data. Therefore, two machine learning algorithms were defined that will be used for the first predictions. Each of them has its advantages and disadvantages and once there are first results and more historical data included it can be deduced what works best.

Description and approach of machine learning algorithms

Decision Tree/Random forest

A decision tree is built on the basis of existing ones, which then covers the various variables as well as possible and then spits out an approximate result value at the end. If several decision trees in parallel are trained and then used, it is called a random forest. In that case, also probabilities are available.

This method has some clear advantages:

- It is explainable/interpretable, i.e. it can be said why the particular decision was made
- It can be trained (and retrained) very quickly
- Little data is required

But also some disadvantages:

- The more possible result values there are, the more data is required. The best that could be done with that would be about as much as, we can predict the next category will be in 1, 2, 3, 4, ... 12 months
- More complex connections are not recognized

Unsupervised learning

The other variant, that is expected to be the direction for ESRIUM, is that unsupervised learning will be used.

In that case predefined clustering algorithms can be used, or a small neural network will be trained that tries to place the existing pairs of defects in a multidimensional space, such that the defects that behaved similarly (i.e. not in a certain period of time, or have deteriorated a lot), will be close to each other. Then, when a new defect comes, the variables are also transformed back into these spatial coordinates (by the trained network), and it is then looked at what the results were for the closest, known defects.

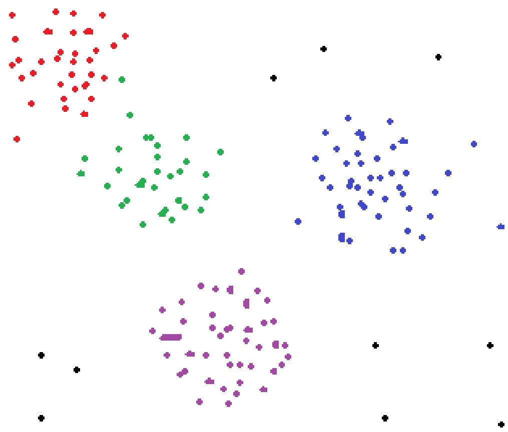


Figure 32: Clustering of similar road defects by neural network in a 2D space.

Each point corresponds to a known defect. Of course, during the training it must be known, for each of these individual points, what the progress of the wear was like: it hardly got worse, slowly, quickly, and very quickly. For example, the defects in the red cluster in *Figure 32* have hardly deteriorated, those in the green one slowly but surely, and the other two much faster. These clusters also have a centre. The closer a defect is to the centre; the more typical it is of the (deterioration) class. Of course, there can always be outliers (black) that cannot really be assigned to a group.

When a query is placed, it is calculated where this defect is located on the map above, what is the distance from the various cluster centres, and then it can be determined to which degradation category the defect belongs. Ideally, one can then also determine the probabilities or the rate of deterioration more precisely. The good thing is that this clustering can always be refined later.

Next Development steps

The setting up of the development environment was finished and the developing the decision tree stated in Q2/2022. The first prediction results are expected to be available in July2022 and then the development of the second algorithm will be continued. Throughout the development and after having the first results, the evaluation of the prediction data will be continued and all algorithms will be continuously improved.

Task 4.5 - Road Wear Data Aggregation and Management Layer

The activities carried out in Task 4.5 were:

- Implement and provide interfaces for importing road survey data, traffic and weather data, wear deterioration predictions and ultra-high-definition map (UHD map) data
- Design and implement a geographic database capable of storing road wear features and predictions as well as underlying UHD map data
- Design and implement a 3D web based visualization capable of displaying survey data (point clouds and images), vector data (UHD map) and detected road wear features.

In the following sections, those activities are described in more detail.

For ESRIUM, it was essential to implement a Data Management Platform capable of receiving and providing survey, traffic and weather data, road wear feature recognition results as well as deterioration predictions and UHD map data. In the first project-reporting period, the interfaces and data management modules for these types of data have been finalized. An illustration of the data flow with the road wear data aggregation layer in the centre is illustrated in *Figure 33*.

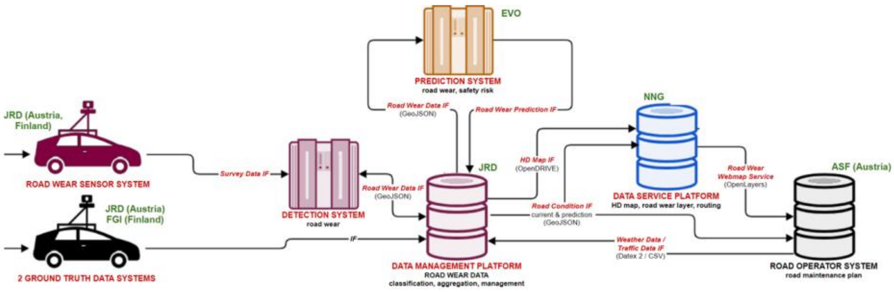


Figure 33: Data flow diagram with Road Wear Data Aggregation and Management Layer in the centre.

Survey data is passed to the Data Management Platform twofold: The ground truth data system (T4.1) is provided by mobile mapping vehicles with high accuracy laser scanning systems and measurement cameras. *Figure 34* shows a detailed view of the collected data. On top of these measurement results, an initial ground truth training data set for road wear features (RWFs) was created. Utilizing these training data, automatic RWF recognition was developed operating within the detection system component. This component will receive new survey data regularly by the road wear sensor system fleet described in T4.2. Building up on newly identified RWFs, the prediction component developed in T4.4 estimates deterioration over certain time periods and reports them back to the data management. This is done by incorporating historic damage development data and environmental factors such as weather and traffic conditions. This kind of data is provided by the road operator and fed into the Data Management Platform via a dedicated interface. The result provided to the Data Service Platform is (1) an UHD map and (2) road condition information, which denotes the current and future state of the identified road damage classes. The interfaces implement REST and Datex 2 as communication layer and their payloads follow GIS standard formats (GeoJSON) In addition to the interface implementation, the underlying database has to be able to combine and manage the incoming road condition and environmental data. For that, a relational PostgreSQL database with spatial extensions (Postgis) has been employed.

In addition to storing and communicating data, a module to efficiently visualize the current database contents has been developed. This viewing system is based on the open source project Potree and has been extended to interface with the database and to support vector overlays. It is possible to navigate through the point cloud data gathered by the ground truth data systems. Measurement pictures are available through viewing windows and can be loaded by click. Detected damages are annotated with red overlays and can be viewed in detail with corresponding meta data, see *Figure 35*.

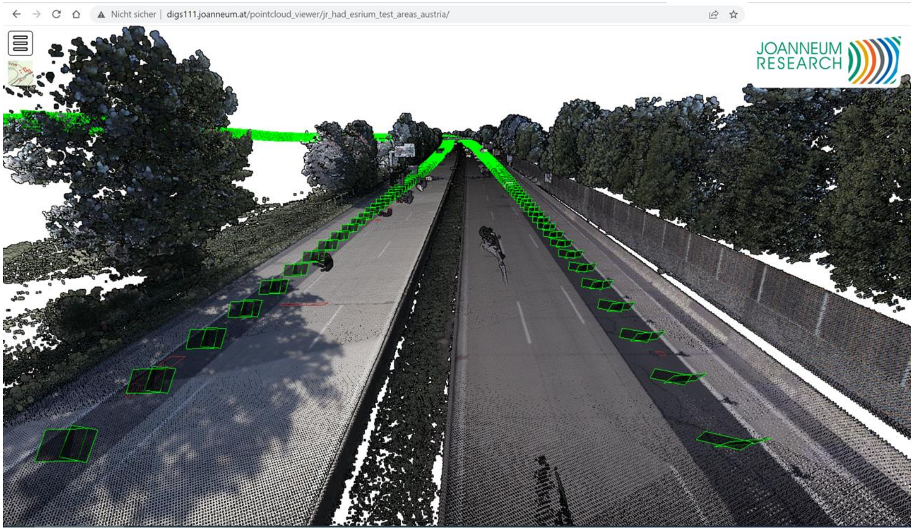


Figure 34: ESRIUM point cloud scan on a motorway test area on an Austrian highway. Measurement images can be obtained by clicking on the window views with green borders.

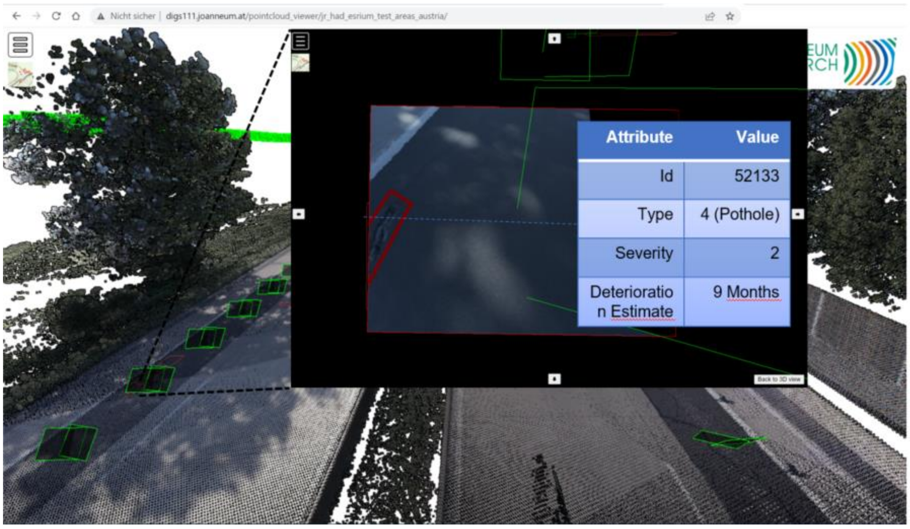


Figure 35: Detailed view of a damage overlay (red) with meta data.

<u>Task 4.6 - Road Wear Data Platform</u>

Task 4.6 has not been started yet.

1.2.4.2 Summary of achievements

The main achievements within WP4 are:

- Execution of mobile mapping campaigns in AT and FI (also under harsh winter conditions)
- Creation of high accuracy measurement and survey data

- Selection of road sections for measurements
- Labelling and human classification of road wear features
- Creation of high definition maps from measurement data
- Development of a novel sensor system
- Calibration and synchronisation of sensors and the whole system
- Development of a high performance data recording system
- First training of object detector and performance comparison
- Demonstration of additional geometric methods for the detection of lane grooves
- Definition of the architecture for machine learning algorithms for first predictions
- Implementation of the first decision tree algorithm
- Implementation of interfaces for import and export of all kind of ESRIUM data
- Implementation of a geographic database
- Development of an efficient and scalable 3D WebGL based visualization

1.2.5 Work Package 5

WP number	WP 5	Lead beneficiary	3 – VIF	Start month	1	End month	36
WP title	Proof of Concept and In-Vehicle Validation						

1.2.5.1 Description of performed activities

<u>Task 5.1: Development and integration of automated driving functions in the test vehicle</u>

The goal of Task 5.1 is to develop the dedicated and specialized ADAS functions and supporting information pipeline for realizing the automated driving demonstrator vehicle such that the strategic lane-change and lane-offset recommendations can be implemented. The recommendations are C-ITS messages in the form of IVIM, and the corresponding recommendations along with the vehicle's environmental sensor information needs to work together to achieve the expected end result.

During the first half of the project duration specialized versions of the ADAS functions including a lateral tracking (LKA), a longitudinal tracking (ACC) and a trajectory planner (TP) algorithms were developed utilizing a simulation framework. In the meantime, the vehicle localization solution for high-accuracy (cm-level) was chosen to be based on EGNSS, and hardware selection, sourcing and integration has been initiated and completed.

The two specific test scenarios that will be implemented in the scope of the EUC-002 are shown in Figure 36 and Figure 37.

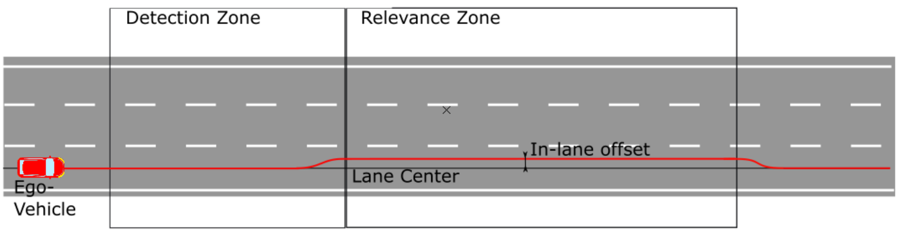


Figure 36: In-lane offset recommendation.

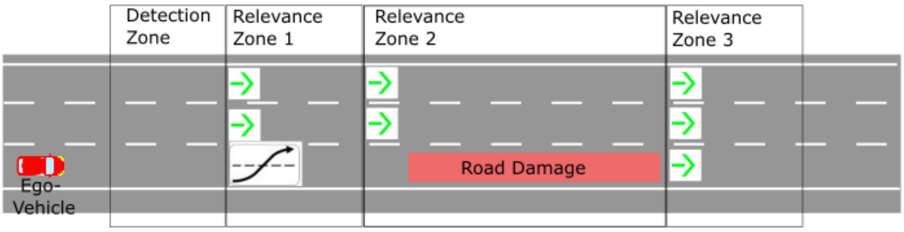


Figure 37: Lane change recommendation.

For the development of the driving functions, a co-simulation environment based on Matlab/Simulink and the vehicle dynamics software IPG Carmaker was utilized as seen in *Figure 38*. This simulation environment was preferred since it is well suited for rapid-prototyping purposes. All driving functions in terms of trajectory planner, as well as longitudinal and lateral tracking controllers were developed and implemented in Matlab/Simulink. The environment and vehicle dynamics simulator IPG Carmaker provides the vehicle state, an object list and lane marking information to Matlab/Simulink for processing of the information by the respective driving functions. The vehicle state includes actuation signals (steering angle, brake and gas pedal), velocities and accelerations. For the object list, no sensor dynamics were assumed considering only occlusion effects. Taking into account limitations of a prospective real world demonstration of the presented implementations, lateral vehicle guidance was based on lane marking information only. For that purpose, a polynomial lane marking model was recreated in simulation, which describes lane boundaries as third order polynomials and related polynomial domains.

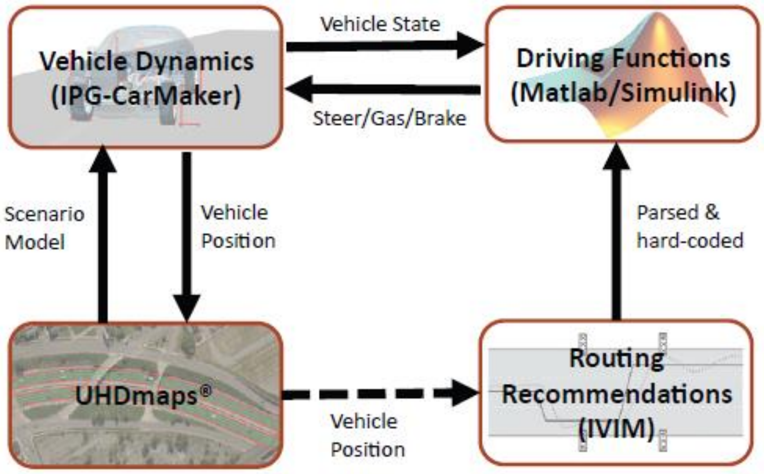
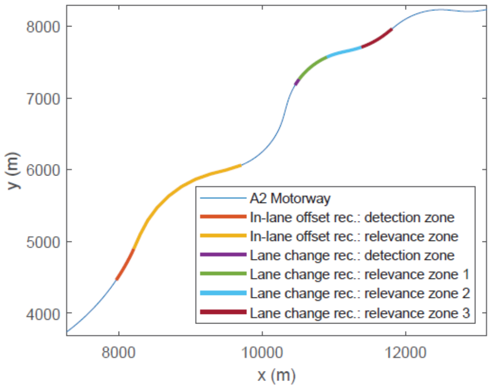


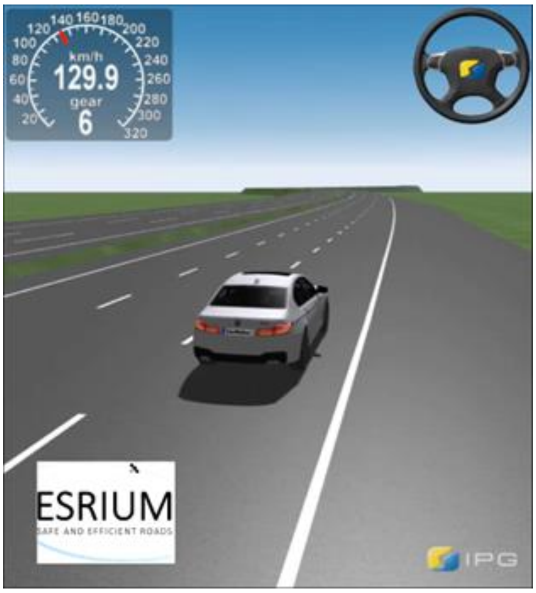
Figure 38: Co-simulation architecture utilizing Matlab/Simulink and IPG Carmaker 10.

The routing recommendations based on IVIM messages were implemented as pre-set messages, without taking into account specific details about communication models in the simulation framework.



(a)

(b)



(c)

Figure 39: UHDmap® of the Austrian A2 Motorway section near Graz. (a) Overlay of detection and relevance zones and corresponding recommendations as used in the test scenario, (b) Google maps image showing the location (c) Carmaker implementation.

For development and initial verification purposes a straight two-lane road stretch was used. Later this simple road was replaced by a UHD Map of the A2-motorway with three lanes (*Figure 39*). This model represents the part of the A2 were the on-road test will take place in the use case demonstrations in the final year of the project.

The simulated vehicle starts in the southeastern corner and drives to northwestern corner. During this test scenario, the automated vehicle receives two different IVIMs. The first IVIM contains an in-lane offset recommendation of 40 cm to the left and the second a lane change recommendation. This setup was used for the conference paper, and differs a little from the defined setup for the road tests.

AD Functions Development:

The AD functions developed follow the well-known sense–plan–act scheme. The sensing task is delegated to IPG CarMaker simulator, which provides all the required ego vehicle states, as well as obstacle and road information to the driving functions. The sensors are therefore modelled as low-fidelity ideal sensors providing object lists within specified cones representing their respective field of view. The planning task is accomplished by a rule-based trajectory planner adapted to utilize C-ITS messages.

Planning: Rule-Based Trajectory Planner based on Bézier Curves

The planning task is accomplished by a rule-based trajectory planner (TP) that was developed for structured environments like highways with well-defined lane boundaries. It uses a finite state machine and a set of discrete decisions to trigger lane changes or to keep the vehicle on its current lane. By default, the ego vehicle (the automated vehicle utilized with the developed ADAS-function) drives in the middle of the rightmost lane. If a slower vehicle prevents the ego vehicle from reaching its desired cruising speed, and the target lane is not occupied, a Bézier curve is planned to perform a lane change to available lanes on the left side of the vehicle.

The value of the Bézier curve at a tuneable look-ahead distance is then used as the desired lateral offset for the underlying lateral controller. As can be seen from *Figure 40*, this offset is defined with respect to the centre of the current lane. Therefore, the TP needs to handle a change of reference during the lane change manoeuvre. This allows future deployment of the proposed algorithm to a demonstrator vehicle, which utilizes only a vision sensor for lane marking based in-lane localization.

Together with emulations blocks for parsing the IVIM, the TP is able to generate the input signals for the lateral and longitudinal controllers to accomplish the described scenarios in the scope of EUC-002.

Path planning relies on a Bézier curve approach that was enhanced to handle specific limitations that are common in real world applications. While the ideal lane information is obtained using UHD maps in simulation, currently available vehicle sensors lack the ability of providing trustworthy lane information, specifically the lane width, besides the current lane. To overcome this issue, the planned path consists of two quadratic Bézier curves connected via a straight segment (also shown in *Figure 40*).

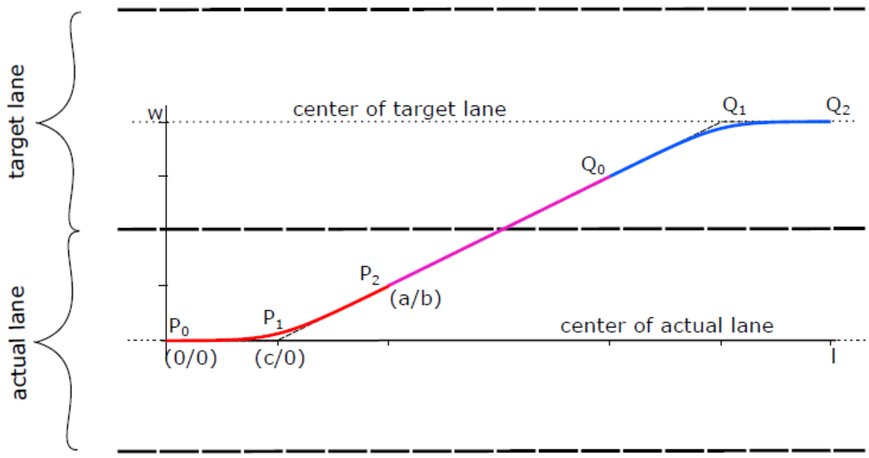


Figure 40: Lane change with two quadratic Bézier curves and a linear segment.

The Bézier curves provide a smooth transition to initiate and finish the lane change, while the straight segment can be shortened or extended during the lane change manoeuvre according to the width of the target lane. To achieve a comfortable lane change, the length "*l*" of the lane change is chosen according to the current vehicle speed, while the lane change offset "*w*" is pre-defined by the widths of the current and target lanes.

Beside the Bézier curves, solutions with a polynomial of fifth order and a construct of two fourth order polynomials and a connecting straight were intensively tested, and the results were published in a series of two papers. The journal paper [RUD2021] focuses on the Trajectory Planning (TP) algorithm development and its implementation in the respective ESRIUM use case EUC-002. The conference paper [RUD2022] focuses on the comparison of different lane change curves for the TP and simulation on the UHD map of the A2 as well as the KPIs analysis of the driving functions according to functional requirements. In the end, the Bézier curves proved the best results in terms of specific KPIs.

Actuation: Lateral and Longitudinal Control

For tracking the lateral and longitudinal references from the trajectory planner, two proven controller implementations were used. The lateral controller implements a state-feedback control law based on LQR as motivated from the demonstrator vehicle application. It makes use of the reference path from the trajectory planner up to the second geometric continuity, i.e., lateral error, heading error, and path curvature. The actuated signal is the steering wheel angle. Although, the dynamics of a steer-by-wire actuator are considered.

The longitudinal controller is implemented as a time-discrete PI (proportional-integral) controller with an anti-wind-up measure providing the control signal p_k at time step k according to:

$$p_k = k_{\mathrm{P}} e_k + \alpha_k$$
$$\alpha_k = k_{\mathrm{I}} e_k + \max(-100, \min(\alpha_{k-1}, 100)).$$

Here, e_k is the acceleration error, k_P and k_I are the proportional and integral gain and p_k is the commanded brake pedal position for $p_k < 0$ and the throttle position for $p_k > 0$. The anti-wind-up measure is implemented via max() and min() functions ensuring $p_k \in [-100, 100]$. To ensure bumpless activation of the longitudinal controller, α_0 is initialized according to the current pedal positions. Both controllers execute with a sample time of 20ms.

<u>Task 5.2: Test runs data collection</u>

In this task, pre-defined use-case demonstrations will be performed on the test sites and the corresponding data will be saved on a data server. In doing so, all the hardware and software components including UHD-Map, automated driving demonstrator vehicle, infrastructure-assisted EGNSS localization, ITS-G5 capable road infrastructure and a wear-map based POI information will be fused in specific use-case demonstrations. Tests will be first performed on proving ground (*ÖAMTC Lang/Lebring Fahrtechnikzentrum*) and consequently phase to developments runs on the Austrian A2 motorway.

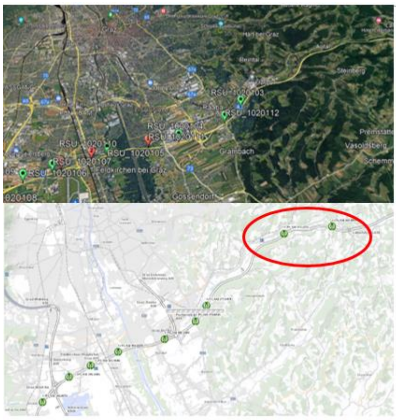
In the first period of the project, the test scenario specifications as well as the KPIs to be analysed were defined as part of the first WP5 deliverable "*D5.2 Test Scenarios & Performance Criteria Specifications"* in month M12. Some of these KPIs are analysed as part of the simulation framework used in the development as described below. We have also defined the C-ITS communications standard and the corresponding IVIM message structure based on the test cases in collaboration with ASF.

IVIM preparation:

The storyboard for the tests was reviewed and agreed upon and finally technically implemented by ASF. It now only has to be rolled out on the four RSUs on the test track. The refinement of test scenario descriptions for internal use is still in progress and will be finalized in the second project period.

The scenario preparation on A2-Motorway is depicted in *Figure 41*. For the development, the following boundary conditions were assumed:

- 4 RSUs but only 2 are capable of RTCM(EM)
- Graz-Laßnitzhöhe: 3 in-lane offset (20cm, 30cm, 40cm) and 1 lane change recommendations
- Laßnitzhöhe-Graz without current correction data, again three in-lane and 1 lane change recommendations.



R-ITS-S	Message type	indicative Message content	Approximate Size
RSU_1020112	RTCMEM	As provided by NTRIP caster + RTCMEM header	RTCM size + some bytes
RSU_1020112	IVIM – lane Offset 1	See separate file. Offset = + 20 cm	236
RSU_1020112	IVIM – lane Offset 2	See separate file. Offset = + 30 cm	236
RSU_1020112	IVIM – lane Offset 3	See separate file Offset = + 40 cm	236
RSU_1020112	IVIM – lane Change: Road Damage on the rightmost lane (L3).	See separate file: recommended speed is 80 km/h	573
RSU_1020103	RTCMEM	As provided by NTRIP caster + RTCMEM header	RTCM size + some bytes
C-ITS-A02 172,275G	No message		
C-ITS-A02 169,897G	IVIM – lane Change: Road Damage on the rightmost lane (L3). (optionally to be used only if needed)	See separate file: recommended speed is 80 km/h.	573
C-ITS-A02 169,897G	IVIM – lane Offset 3 (optionally to be used only if needed)	See separate file Offset = + 40 cm	236
C-ITS-A02 169,897G	IVIM – lane Offset 2 (optionally to be used only if needed)	See separate file. Offset = + 30 cm	236
C-ITS-A02 169,897G	IVIM – lane Offset 1 (optionally to be used only if needed)	See separate file. Offset = + 20 cm	236

Figure 41: The storyboard and test scenario structure for the demonstrations on the Austrian A2 Motorway.

Analysis of the KPIs using Simulation Implementation of the Test Scenario:

The scenarios were simulated on a straight section without other traffic elements at first. The vehicle speed was set to 130km/h for the longitudinal tracking controller. *Figure 42* shows the results of the in-lane offset recommendation scenario. For this simulation, a detection zone with a length of 200m was chosen and a relevance zone with a length of 1000m and the in-lane offset recommendation is only valid for the rightmost lane. In *Figure 42*a, the steering wheel angle during the manoeuvre is depicted. Moreover, the lateral acceleration in *Figure 42*b, the yaw rate in *Figure 42*c, and the desired and driven offsets in *Figure 42*d are shown, respectively. According to the simulated scenario, at approximately 2.5 s the ego vehicle starts the transition to the desired in-lane offset. In this example, the vehicle reaches its desired steady-state offset value of -0.2m at approximately 7s. The total time it took to reach the set offset value is, therefore, about 4.5s, which matches the in the controller defined value. According to the designed scenario, the ego vehicle drives through the relevance zone (RZ) with the desired offset and leaves it at about second 35 returning back to zero offset value. As seen from the results in *Figure 42*, the developed enhanced driving functions are quite effective in achieving the desired offset value. The difference between the desired and achieved offset values are quite small except a small overshoot. The overshoot in the lateral position was smaller than 2cm in this case. The small oscillation in the middle point of the manoeuvre (which should not be existing at all, at about 21s) was caused by the CarMaker itself and is believed to be a modelling bug, as it varied when the vehicle model was changed, but could not be avoided completely.

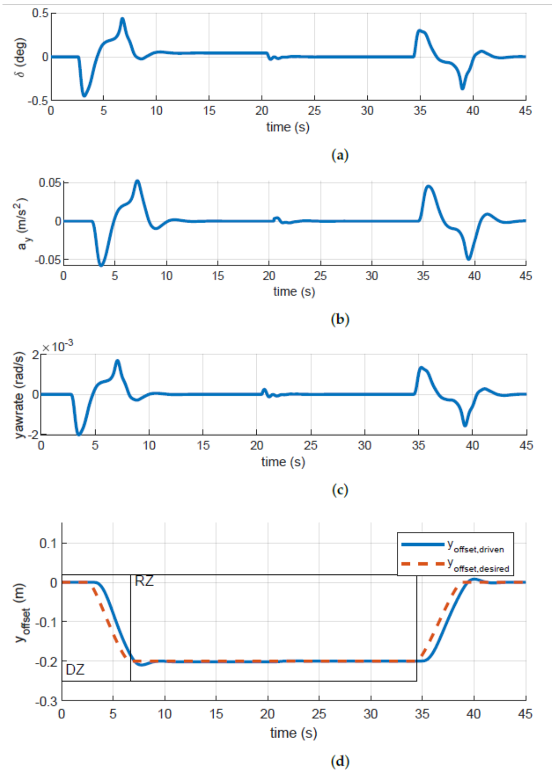


Figure 42: In-lane offset recommendation on a straight road. (a) Steering angle, (b) lateral acceleration, (c) yaw rate and (d) lateral offset

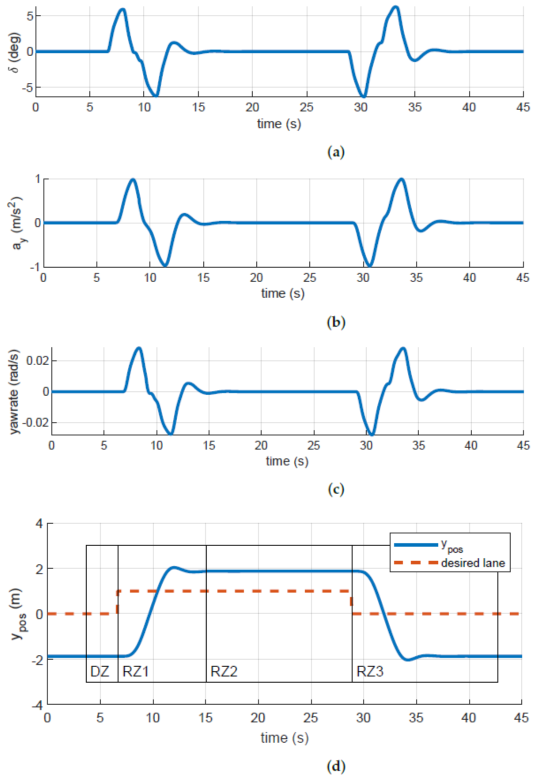


Figure 43: Lane change recommendation on a straight road. (a) Steering angle, (b) lateral acceleration, (c) yaw rate and (d) lateral offset and desired lane

Figure 43 and *Figure 44* show the use case scenario simulation results for the strategic lane change and lane utilization recommendation for CAVs. *Figure 43* corresponds to a lane-offset manoeuvre whereas *Figure 44* to the lane change one. In both examples the steering wheel angle variation during the manoeuvre are indicated in (a). Furthermore, the lateral acceleration (b), yaw rate (c), and vehicle lateral position relative to the desired lane (d) are shown. According to this example scenario for the lane change manoeuvre (*Figure 44*), the ego vehicle enters the relevance zone 1 (RZ1) at about 6.6s and the desired lane, therefore, switches from 0 to 1. Note that in the TP the rightmost lane is indexed with 0 and the index is increased while going towards the left side, which is different to the numbering convention in the IVIM. Since there is no hindering traffic in the scenario, the TP initiates immediately a lane change manoeuvre to lane 1, where it stays while passing the relevance zones 1 and 2 (RZ1 and RZ2). In relevance zone 3 (RZ3) the TP computes a lane change manoeuvre back to the original starting lane (i.e., lane 0). In this use case as well, the recommended manoeuvres were conducted effectively with little overshoot. It can be observed that the total lane change manoeuvre was achieved with less than 5s transition times between steady state driving positions.

As a further simulation use case example, we implemented also a combined in-lane off-set and lane change recommendations, as seen in *Figure 44* In this scenario, the ego vehicle starts in the right lane and first receives an in-lane off-set recommendation and then consecutively a lane change to the left lane followed by reverse manoeuvres to return to the right lane lateral 0-off-set position. In this case, the in-lane off-set values were varied with specific values {-1m, -0.5m, -0.2m, -0.1m, 0m, 0.1m, 0.2m, 0.5m, 1m} and the resulting trajectories were displayed. The results indicate that complex manoeuvres combining the two specific recommendations can also be achieved with efficacy.

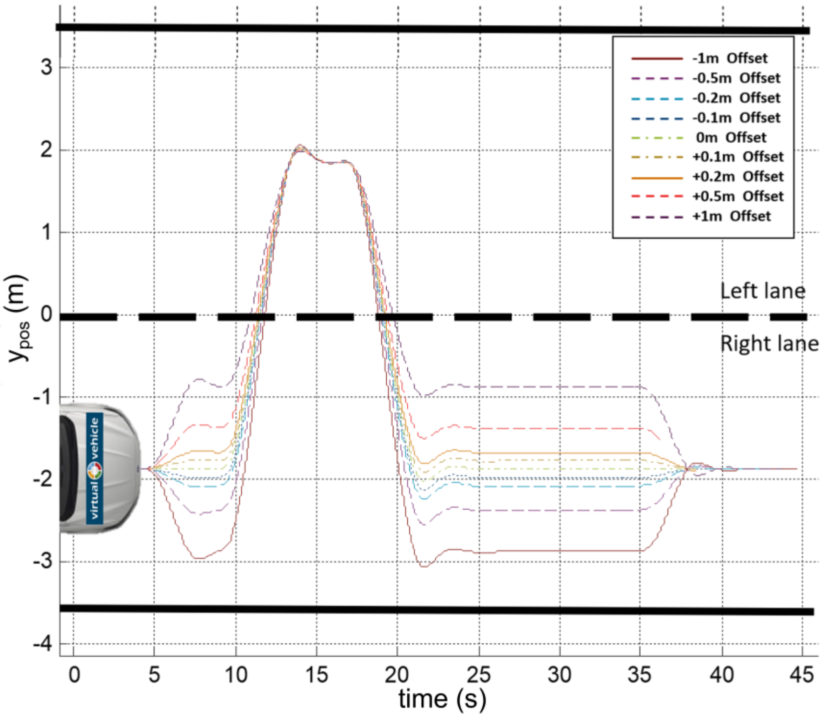


Figure 44: Combined lane change and in-lane offset recommendations.

Here we define the basic performance indicators that were used to compare the three types of transition curves. These KPIs are selected taking into account the specific use case scenarios. The specific KPIs are given in *Table 12*, which stem from the functional requirements of the driving functions.

KPI Designation	Performance specification		
	Definition	**Performance**	**Unit**
KPI-1	Maximum longitudinal velocity tracing error from set-point	5	km/h
KPI-2	Maximum lateral position overshoot from set-point	20	cm
KPI-3	Minimum safety distance from road lane border	20	cm
KPI-4	Maximum allowed longitudinal acceleration/deceleration*	2/3.5	m/s²
KPI-5	Maximum allowed lateral acceleration**	4	m/s²

** According to ISO 15622:2018 standard (for 130km/h).*
*** according to ISO21202:2020 standard (for light-duty vehicles)*

Table 12: Key performance indicators for the comparison of the rule-based trajectory planners.

In literature, a wide variety of lateral path tracking error definitions is used, which can be categorized by vehicle reference (e.g. centre of gravity), look-ahead direction and distance and error orientation (e.g. perpendicular to the vehicle heading). For KPI-2, the lateral error was defined with respect to the vehicle centre of gravity, at zero look-ahead distance and perpendicular to the vehicle heading. (*Figure 45*) Considering the safety aspect of KPI-3, the lateral error was defined as the perpendicular distance from the lane border to the vehicle corner closest to the lane border (*Figure 45*).

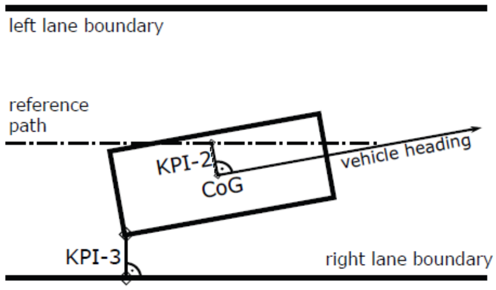


Figure 45: Lateral position overshoot and safety distance from road lane border.

For KPI-4, the maximum allowed longitudinal acceleration/ deceleration was defined according to ISO 15622:2018 norm. In this standard, the maximum allowed longitudinal acceleration and deceleration are defined as a function the ego-vehicle velocity. The values given in above table are valid for 130km/h, which corresponds to the maximum velocity allowed in the examined scenario. KPI-5 was defined following ISO 21202:2020, which deals with partially automated lane change systems PALS). For light duty vehicles, a maximal allowed lateral acceleration of $4m/s^2$ is defined in this standard.

A test scenario on a section of the Austrian A2 motorway was defined, which combines the two routing recommendations of lane offset and lane change as described in the scenario storyboard. Here the corresponding simulation results are given for the three different transition curves along with their comparison and evaluation according to the KPIs defined in section IV. In the simulation, the ego vehicle drives along the chosen stretch of the A2 motorway. The driving function normally keeps the vehicle in the centreline of the rightmost lane, except when an ITS-message tells the ego vehicle to use another driving strategy. According to the setup of the scenario, first, a lane offset recommendation, and then consequently a lane change recommendation was simulated. In *Figure 46* the simulation results for the offset from the centreline of the rightmost lane is shown. Initially the offset is zero, between 30s and 90s the ego vehicle receives a recommendation to drive with an in-lane offset of 40cm and between 130s and 160s, the vehicle is instructed to use the second lane. *Table 13* gives an overview of the results of the KPI evaluation for the three different transition curve options. The main observations from this analysis and comparison will be summarised. The maximum longitudinal velocity tracking error from set-point (KPI-1) is very small due the fact that we use constant velocity set-point and the only disturbances in the longitudinal dynamics are caused by steering manoeuvres. Yet there is a small difference in favour of the Bezier construct. The maximum lateral position overshoot from set-point (KPI-2) arise during the lane change manoeuvre, as would be expected. The comparison of KPI-2 yields 11cm overshoot for the Bezier curve construct, whereas 14cm for the 5th order polynomial, and 12cm for the 4th order polynomial construct. The results of all three solutions are well below the threshold of 20cm, yet Bezier construct had the smallest overshoot among all three. We note here that the overshoot in the manoeuvres indicates that there are modelling errors in the lateral tracking controller. A linear lane-keeping model is utilized for the LQR-control design, which is clearly an over-simplification of the actual dynamics of the vehicle. However, the controller is tuned such that the overshoot is within tolerable limits. The minimum safety distance form road lane border (KPI-3) cannot be evaluated during a lane change, since the vehicle crosses the lane border during the manoeuvre. Therefore, KPI-3 was evaluated only for the in-lane offset recommendation situation. This corresponds to the first part of the test scenario between 30s to 90s (see *Figure 46*a). Since there is no lane change in this period, the result for the

KPI-3 is the same for all the three transition curve options, therefore was not a distinguishing factor. In-lane offset must be determined as function of lane width, vehicle width and the minimum allowed safety distance from the road lane border. Minimum safety distance must also take the transient tracking errors from the lateral controller into account. To show the effect of the in-lane offset recommendation on the KPI-3, a series of simulations with varying in-lane offsets were performed. The results are given in *Table 14*, where it can be observed that in-lane offset of up to 57cm leads to fulfilment of KPI-3, given the lane width of 3.5m.

The maximum allowed longitudinal acceleration (KPI-4) is by far not reached. The simulation with constant velocity without traffic means the only significant disturbance is due to steering manoeuvres, which led in all three simulations to the KPI-4 value of 0.13m/s2. The maximum allowed lateral acceleration (KPI-5) is also not reached by any of the three planners. The lateral acceleration is shown in *Figure 47*. It can be seen that maximum acceleration is reached during lane change manoeuvres. The ego vehicle travels at the rightmost lane. At about 130s, a lane change to the left lane is initiated and at about 157s, a lane change back to the rightmost lane is performed. The results of the evaluation of KPI-5 are 2.3m/s2 for the Bezier curve, 2.52m/s2 for the polynomial of 5th order and 2.6m/s2 for the construct with polynomials of 4th order. The smallest lateral acceleration occurred in the planner using the Bezier curves.

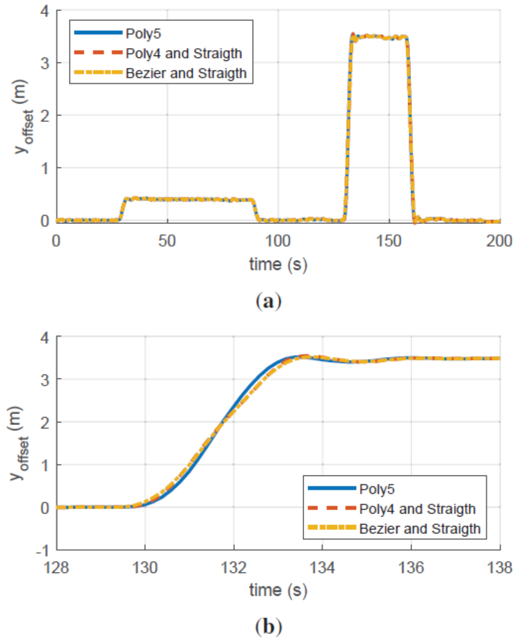


Figure 46: The lateral offset from the centreline of the rightmost lane for (a) the whole simulation and (b) the section of the lane change manoeuvre.

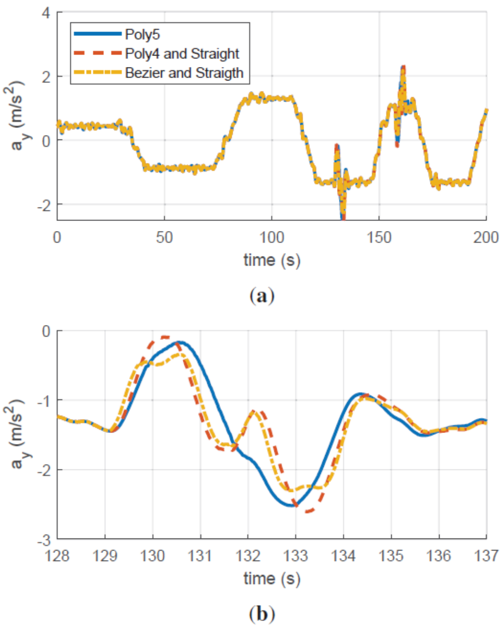


Figure 47: Lateral acceleration of the ego vehicle for (a) the whole simulation run and (b) the section of the first lane change manoeuvre.

KPI	Unit	Bezier curve	Polynomial 5th order	Polynomial 4th order
KPI-1	km/h	0.09	0.10	0.10
KPI-2	cm	11	14	12
KPI-3	cm	37.8	37.8	37.8
KPI-4	m/s²	0.13	0.13	0.13
KPI-5	m/s²	2.30	2.52	2.60

Table 13: Evaluation of the KPIs for the three different transition curves.

In-lane offset	cm	20	40	60
KPI-3	cm	57.9	37.8	17.9

Table 14: KPI-3 for different in-lane offsets.

Task 5.3: Data Analysis

The task has not started during the reporting period.

Task 5.4: User Acceptance Evaluation

The task has not started during the reporting period. However, the corresponding test scenario specifications were reported in deliverable D5.2.

1.2.5.2 Summary of achievements

The main achievements within WP5 are:

- Completion of ADAS function development for in-lane-offset and lane change functions
- Implementation of demonstration scenario in simulation using UHD-map and CarMaker 10
- Completion of preliminary evaluation and verification of ADAS functions in simulation
- Publication of two papers that describe and analyse the developed driving functions
- Specification and selection of the OBU and EGNSS hardware and acquisition of necessary components
- Definition of ITS-G5 based message standard (IVIM) for routing recommendations
- Definition of RTK correction message for EGNSS based on the RTCM(EM) utilizing ITS-G5
- Execution of first localisation tests were in Finland
- Definition of the relevant use case EUC-002 demonstration test scenarios

1.2.6 Work Package 6

WP number	WP 6	Lead beneficiary	8 – ENI	Start month	1	End month	36
WP title	Dissemination, Exploitation						

1.2.6.1 Description of performed activities

Task 6.1 Communication & dissemination activities

This task is divided into three subtasks:

ST6.1.1- Definition of communication strategy and plan:

As part of this subtask, during the first reporting period, ENI developed a strategic and planning document ("*D6.1 Dissemination and communication strategy and plan*") identifying which types of interventions are necessary to promote and enhance the overall communication strategy and plan to be followed, to achieve maximum impact, knowledge continuity and wide market penetration of ESRIUM. The communication strategy and plan presents the various target groups, a detailed timeline of the C&D of the foreseen activities and KPIs. The plan enables the accomplishments of the C&D objectives by exploiting specific C&D channels to strategically reach relevant stakeholders within a feasible timeline. In addition, the ESRIUM project corporate image was part of this strategy and it is applied on every information and communication material, coherently with Horizon 2020 communication guidance, detailed in *Table 15*.

Type of information	Main audience	Channels	Goals
CDE Year 1 ***Objective: Create awareness and get feedback***			
• Presentation of ESRIUM • Objectives and expected results of ESRIUM • Demonstration of alpha prototype	• Industry • Scientific and academic institutions • Press and general public	• Website • Social media channels • Communication kit • Participation in external events • Organisation WS 1	• General visibility • Attract potential customers, investors and collaborators • Get constructive feedback for further technical developments
CDE Year 2 ***Objective: Evaluation and preliminary exploitation of ESRIUM results***			
• Demonstrations of ESRIUM mature solutions	• Industry • Public authorities and policymakers • Standardization bodies and associations • Scientific and academic institutions	• Website • Social media channels • Participation in external events • Scientific publications • Organisation WS 2	• Evaluation of ESRIUM results • Boost the exploitation potential of ESRIUM results • Improve ESRIUM position in their scientific and industrial fields • Create an early network of possible customers of the system • Informing EC authorities
CDE Year 3 ***Objective: Consolidate results***			
• Demonstration of ESRIUM mature solutions	• Industry • Public authorities and policymakers • Standardization bodies and associations • Scientific and academic institutions • Press and general public	• Website • Social media channels • Participation in external events • Scientific publications • Organisation WS 3 • Special sessions in major congresses / exhibitions	• Finding the opportunities for additional investments, technological transfer and future exploitation of ESRIUM. • Informing the EC Authorities

Table 15: ESRIUM CDE timeline.

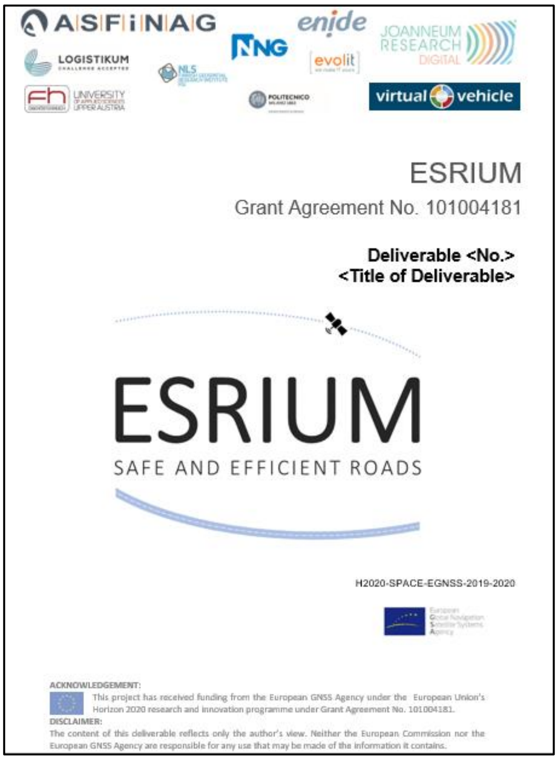
ST6.1.2- ESRIUM communication tools and activities:

This subtask developed the deliverable "*D6.2 Communication kit - Initial version*" as a set of communication materials specifically designed for ESRIUM, including the logo (*Figure 48*), the project background, a roll-up (*Figure 50*a), a leaflet (*Figure 49*, copies were distributed to all partners in M6), a template presentation (*Figure 50*b), and a template press release. Additionally, this subtask created the website (*Figure 51*) and the social media channels (Twitter, LinkedIn and YouTube), that are continuously curated and populated with new content. More updates are also being shared though the biannual newsletter. The activities under this subtask guarantee coherent, wide and timely communication of HARMONY concepts, objectives and solutions to multiple audiences and to the public.

Figure 48: ESRIUM Logo.

Figure 49: ESRIUM Leaflet thumbnail.

(a)



(b)

Figure 50: (a) ESRIUM roll-up thumbnail and (b) ESRIUM Word Template.

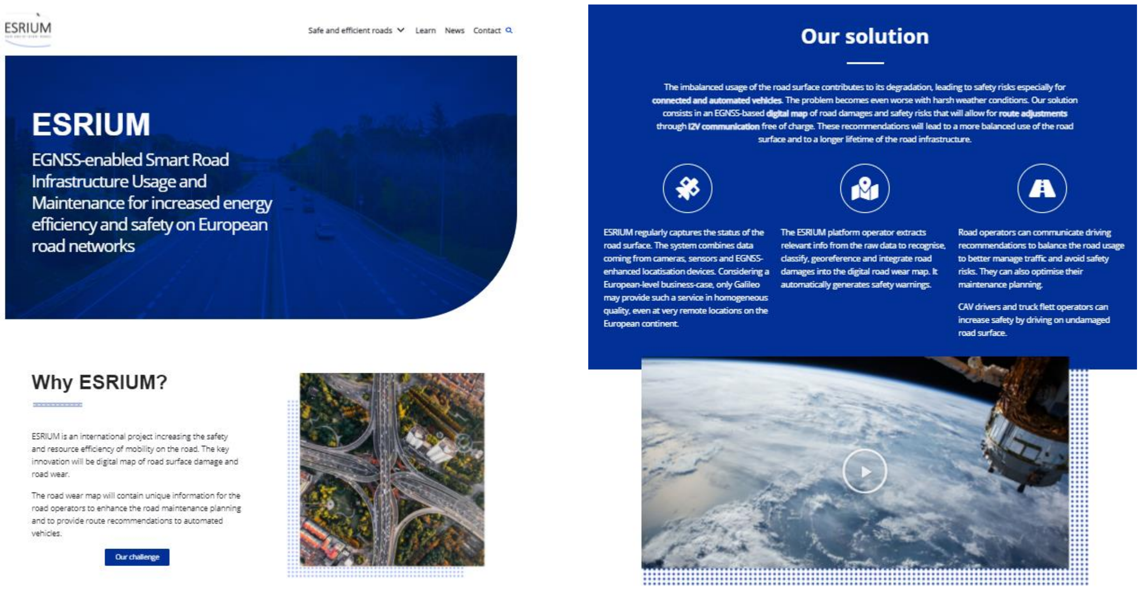


Figure 51: ESRIUM website screenshots.

ST6.1.3- Use of foreground and dissemination activities:

The project technical results and findings will be primarily disseminated through presentations and demonstrations in conferences and other events. To this end, related conferences and congresses are targeted for raising project awareness, presenting technical project advances. A major effort is ongoing towards publishing results in peer-reviewed scientific journals and popular industrial magazines. Open access of publications are secured to all interested users through the project website and respective open access repositories.

This subtask includes the promotion of ESRIUM activities and results through presentations in physical and virtual conferences and events. A number of ESRIUM dedicated special sessions (e.g. at the ITS World Congress, *Figure 52*) and other events have been organised as described in D6.2. Some scientific publications have been submitted to several conferences. With this regard, T6.1.3 created some dedicated spaces for Open Access to future publication, namely the website (https://esrium.eu/index.php/publications/).

Figure 52: ESRIUM at ITS World Congress - Hamburg (2021).

Task 6.2 Engagement activities, standards and collaborations

This task focuses on organizing the collaboration activities of ESRIUM.

There were several liaison activities with related H2020 projects. Following an excessive web search, twelve other projects were contacted. These efforts resulted in one workshop with Stefan Nord from "RISE Measurement Science and Technology", the coordinator from PRoPART (http://propart-project.eu/) and three workshops with OMICRON (https://omicronproject.eu/). In addition there was a joint session at the ITS in Toulouse with GAMMS (https://gamms.eu/). A follow up workshop with OMICRON is already planned in the second reporting period. Another immediate action will be the CEDR SAFEPATH Highway Capacity & Road Safety Workshop (https://www.cedr.eu) in June2022.

In September 2021 the first ESRIUM workshop (*Figure 53*) embedded in the "13th International Conference on Computer Vision Systems - ICVS2021" (https://esrium.eu/index.php/workshop-1/) was organized. Around thirty participants were informed about the ESRIUM goals and the state of the developments. This was a perfect opportunity to collect the first external feedback about the ESRIUM solution.

Figure 53: 1st ESRIUM workshop.

Regarding standards, especially the partner NNG was quite active. At a TISA (Traveller Information Services Association, https://www.iso.org/organization/624840.html) meeting slides regarding road damage standardisation with the title "UCP21004 - Road Wear Information" were presented and vividly discussed.

Task 6.3 Exploitation management & IPR strategy

During the first reporting period, the activities in T6.3 focused on the first steps of the ESRIUM's exploitation plans. As part of this task, a shared IP inventory template was generated to collect inputs from partners regarding the background IP used in the project and the foreground IP generated. The assets and knowledge generated in the project was classified and the technology readiness level of the assets was assessed. Based on this classification, different assets were grouped to define the products and services offered by ESRIUM. This task bases itself on the results of Task "T2.5 Business Case Baseline". During the first periodic report this task...

- planned and organized exploitation workshops at the beginning of the cyclical periods in which the partners carried out their periodic exploitation planning. In addition, ENIDE organized a workshop to coach partners on the exploitation approach and methodology.
- provided the necessary methodology, metrics, and templates for preparation of homogeneous and effective exploitation plans for ESRIUM results. This activity's main result is the Exploitation Handbook ("*D6.6 Preliminary exploitation plans*") which outlines specific business metrics to analyse the exploitation potential of the partners' exploitation ideas, as well as define legal rights and obligations in the exploitation process. Further, it will set the precise procedure to be followed in order to define and agree upon Intellectual Property Rights of the single partners. It will also include templates and procedures to be followed to elaborate the individual exploitation plans, which are prepared by each partner on a regular yearly basis.

- supported partners to establish their first individual exploitation plans and proposed some strategies for the joint exploitation of outcomes. The initial exploitation plans are reported in D6.6.
- reviewed, assessed and benchmarked current approaches and solutions offered to the market. The market size was quantified estimating the current demand for products and services of ESRIUM and the potential additional demand that could be generated through expansion on EU level of the project's outcomes. Deliverable "*D6.4 Market & business ecosystem analysis*" provides an analysis of the market for ESRIUM assets and knowledge, aimed at supporting a sound exploitation plan for the different involved stakeholders.

In total, eight exploitable results are identified so far in the project as listed in *Table 16*.

ID	Org.	ASSETS	Description
ESR_ER_01	JRD	Road Wear Reference Data (Ground Truth Data)	Collection of ground truth data using the road wear sensor system.
ESR_ER_02	JRD	Road Wear Sensor System	The road wear sensor system will collect Road Wear Data (Images, Lidar, GNSS, etc.,) during measurement drives and upload the data to the detection and classification software.
ESR_ER_03	JRD	Road Wear Feature Detection and Classification Software	Algorithm developed based on the ground truth data
ESR_ER_04	JRD	Road Wear Map Generation and Management Software	Identified Road Wear Features will be aggregated into an up-to-date Road Wear Map, which will be managed and made available by the management software.
ESR_ER_05	VIF	Infrastructure assisted ADAS/AD functions	The novel driving functions receive the information on the danger zones on the motorway along with recommended manoeuvre. The ADAS function then implements the recommended action, which in turn implies higher safety and comfort.
ESR_ER_06	EVO	AI software algorithm generates data to optimize maintenance schedules and estimate costs.	EVO creates an AI algorithm to calculate a predictive maintenance cycle and cost forecast. The AI algorithm calculates an extrapolation based on probabilities and provides recommendations for action.
ESR_ER_07	ASFINAG	Maintenance concept of recording road wear data by combining state-of -the -art technologies	A maintenance concept was created for combining the existing road wear data acquisition harness with a novel video-based harness and integrating these procedures into existing road operator procedures.
ESR_ER_08	NNG	Map-as-a-Service	NNG develops a software to provide a map streaming service containing static and dynamic data elements following industry standards.

Table 16: ESRIUM list of exploitable assets.

These exploitable results are grouped in commercial products and services as depicted in *Figure 54*.

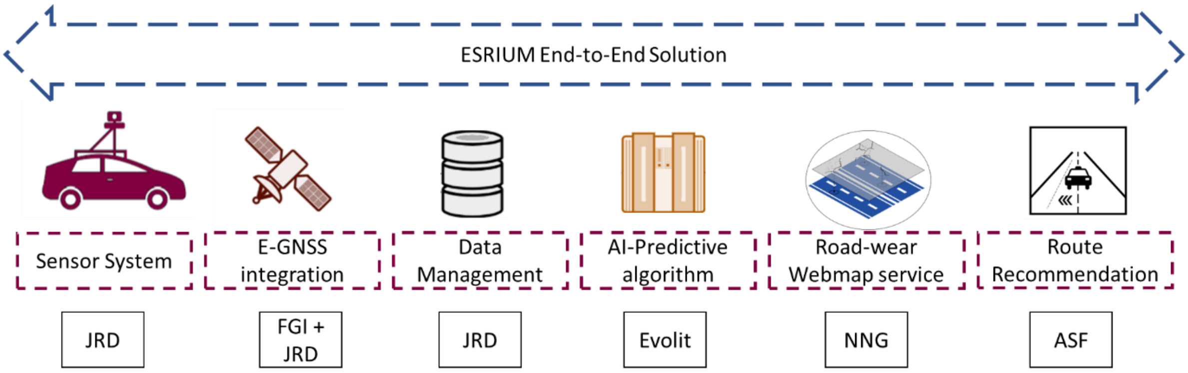


Figure 54: ESRIUM commercial products and services.

As part of this task, also a detail market analysis was performed for the main exploitable results of the project and reported in D6.4.

1.2.6.2 Summary of achievements

The main achievements within WP6 are:

- Realization of WP monthly meetings to monitor the progress of the tasks within the WP
- Definition of the project target groups and development of the dissemination and communication strategy and plan
- Set up of ESRIUM communication tool kit
- Launch of ESRIUM website and social media accounts
- Development and upload of project overview video on project YouTube channel
- Presentation of project results and participation in 14 conferences
- Liaisons with other EU funded projects and organization of 10 liaison activities.
- Organization of ESRIUM's first workshop on 24th Sep 2021
- Set up of the exploitation/innovation committee
- Set of IP inventory and listing of exploitable results
- Definition of exploitation strategy and plan and provision of exploitation guidelines
- Organization of innovation management workshop
- Realization of the initial market and business ecosystem analysis
- Development of initial individual/partner level exploitation plans
- Proposal of strategies for joint exploitable results
- Participation and demonstration of ESRIUM solutions in various exhibitions and trade fairs.

1.2.7 Work Package 7

WP number	WP 7	Lead beneficiary	1 – JRD	Start month	1	End month	36
WP title	Ethics Requirements						

1.2.7.1 Description of performed activities

WP7 was not anticipated in the proposal but during the ethics review two topics arose that had to be handled by creating two corresponding deliverables. Regulations defined there build the basis for the tests that will be conducted in the second period of the project.

Task 7.1 H-Requirement No.1

The deliverable *"D7.1 H - Requirement No. 1"* describes the ethical issues regarding "Humans" in ESRIUM as raised in the EthSR. Overall, three topics were listed by the reviewers. The main points were the handling of recruitments and the implementation of sophisticated informed consent procedures as well as the presentation of corresponding informed consent templates.

The document treats all stated concerns individually, presenting the outcome of discussions within the consortium about how participants in different research studies and activities will be handled in an ethically correct manner.

1. *Recruiting procedure:* Procedures to identify and recruit research participants were developed. Both, for user acceptance tests and drivers of vehicles.
2. *Informed consent procedures:* Three informed consent procedures for the participation of humans were implemented. For participation of humans in workshops, for participation of humans as test drivers and for participation of humans in the acceptance tests following the uses cases as drafted in D2.1.
3. *Informed consent forms:* Four templates of informed consent/assent forms and information sheets were designed. For workshop participants, for drivers, for acceptance studies in the context of personal interviews and for acceptance studies in the context of test-drives.

Task 7.2 POPD-Requirement No.2

The deliverable *"D7.2 POPD - Requirement No. 2"* describes the ethical issues regarding "Protection of personal data" in ESRIUM as raised in the EthSR. Overall, eight topics were handled as listed by the reviewers.

The document treats these issues individually, presenting the outcome of discussions within the consortium about how the data collected during different research studies and activities will be handled in an ethically correct manner.

1. *DPO:* A data protection officer in organisations where participants exchange or capture non-anonymized data was appointed.
2. *Relevance of data:* The relevance of the data to be collected was explained. The primary focus in ESRIUM is the acquisition of geometric and radiometric data of the road surface. This is conducted via LiDAR scans and camera images from a driving vehicle. The data is acquired at two levels of resolution: (1) high-resolution data as ground truth and (2) low-resolution data for research purposes. For both kinds of data collection a detailed explanation of the limitations and relevance of the data to the research project was provided. In addition, details on training data and ground truth data were given.
3. *Safeguards:* Measurements to safeguard the rights and freedoms of participants were provided. Collected image data may contain sensitive company information and personal information, thus, data access will be restricted to the research team (under defined rules). The safeguards also include measures about rights concerning rectification, erasure, objections, restrictions and data portability were described.
4. *Security measures:* Security measures are put in place concerning user management, access rights and storage location. To prevent unauthorised access to personal data the procedures as established at the coordinator JRD were listed and build the basis for all partners working with acquired data.
5. *Informed consent procedures:* During the project, personal information is collected as a by-product in form of image data, or deliberately in form of results from a user-acceptance study (for the user-study, all participants are informed about the data collection and processing procedure). Image data is only exchanged in anonymized form. After product development, the final sensor system will perform on-board anonymization, and the sensor range will be strictly limited to the road surface, so no personal information is created by design.

6. *Previously collected personal data:* No previously collected personal data is brought into the project. There are potential applications for previously collected HD map information within the project, but this data is brought in at the level of vector data. Raw sensor data is not required.
7. *Privacy measures:* Privacy by design is a development goal of ESRIUM. After the project finishes, it will be a key requirement from road infrastructure operators, in order to be compliant to general legislation. No personal information will leave the data acquisition device.
8. *Tracking individuals:* In ESRIUM, end-User vehicles will receive two types of ITS-G5 data: EGNSS correction signals and routing recommendations. These messages are only received and processed on-board the vehicle. At this stage, no tracking possibilities are generated, which go beyond the pure usage of ITS-G5 as a communication service.

1.2.7.2 Summary of achievements

- Definition of rules for the protection of personal data
- Availability of Templates, procedures, consent sheets and safeguards
- Designation of DPOs for all partners where GDPR relevant data is received or captured
- Definition of easy to follow ethical rules for the data collection, data handling as well as acceptance tests and test-drives

1.3 Deliverables

No.	Deliverable Name	WP	Type	Diss.	Submission	Lead
D1.1	Project handbook and project quality plan	WP1	R	P	02.03.2021	JRD
D1.2	First financial information required by EC	WP1	R	C	Interim	JRD
D1.4	First periodic project report	WP1	R	P	Interim	JRD
D2.1	Use case definition	WP2	R	P	13.07.2021	NNG
D2.2	Technical and non-technical user requirements document	WP2	R	C	13.04.2022	JRD/FHO
D2.3	System interface design document	WP2	R	C	08.06.2022	NNG
D2.4	First business case baseline	WP2	R	C	22.09.2021	ENI
D2.5	Second business case baseline	WP2	R	C	09.06.2022	ENI
D3.1	Report on EGNSS-based Precise Localization for Autonomous Cars	WP3	R	C	29.06.2021	FGI
D3.2	Galileo OS-NMA implementation	WP3	O	C	24.05.2022	FGI
D4.1	Road wear ground truth data	WP4	O	C	15.12.2021	JRD
D4.2	Road wear sensor system	WP4	O	C	09.06.2022	JRD
D5.2	Test scenarios and performance criteria specifications	WP5	O	P	20.12.2021	NNG
D6.1	Dissemination and communication strategy and plan	WP6	R	C	02.03.2021	ENI
D6.2	Communication kit - Initial version (including website)	WP6	O	P	02.03.2021	ENI
D6.4	Market & business ecosystem analysis	WP6	R	P	23.06.2022	ENI
D6.6	Preliminary exploitation plans	WP6	R	P	13.07.2022	ENI
D7.1	H - Requirement No. 1	WP7	E	C	06.07.2021	JRD
D7.2	POPD - Requirement No. 2	WP7	E	C	06.07.2021	JRD

Table 17: Achieved deliverables in months 1-18. Types: R = report, O = Other, E = Ethics. Dissemination Level: P = Public, C = Confidential.

1.4 Milestones

MS No.	Milestone Name	WP	Lead	Due date	Means of verification
1	Project management documents ready in version 1	WP1	JRD	M3	First version of D1.1 delivered. Continuous adaptions during full project lifetime according to occurring needs.
2	Communication strategy established and initial communication kit available	WP6	ENI	M3	D6.1, D6.2 available
3	Use case definition	WP2	NNG	M6	Use Case Definition Deliverable ready (D2.1)
4	Results of the state-of-the art and literature survey about EGNSS location	WP3	FGI	M6	D3.1 delivered, EGNSS receiver identified
5	Technical, non-technical user requirements and system interface design ready for handed over to WP3	WP2	ENI	M12	Documentation of user requirements and system interface ready (D2.2, D2.3)
6	Sensor system operational	WP2, WP4	JRD	M12	Measurement data of at least one test run available.
7	KPIs and scenarios defined	WP5	NNG	M12	Test scenarios and KPI definitions for the real-vehicle experiments are ready
8	Sensing vehicles ready	WP2, WP3, WP4, WP5	JRD	M12	The following deliverables are ready: D1.1, D2.1, D2.2, D2.4-1, D3.1, D4.1, D5.2, D6.1, D6.2
9	EGNSS authentication implementation	WP3	FGI	M15	Galileo OS-NMA software released and validated
10	Successful mid-term review	WP1	JRD	M18	Mid-term reporting documents and financial statements accepted by EC
11	Intermediate business and exploitation approach defined	WP6	NNG	M18	D6.4, D6.6 available

Table 18: Achieved milestones in months 1-18.
Note that M10 was set inappropriately (see Section 5.1.2).

1.5 Global status of the project

As can be seen in the ESRIUM dashboard (Figure 55) the project is quite on track. All deliverables and milestones of the first reporting period were reached mostly without delays. The project is minimally behind in terms of person months and costs but this is due to the fact that the development effort is not linear and will be slightly higher in the second reporting period (see Figure 56).

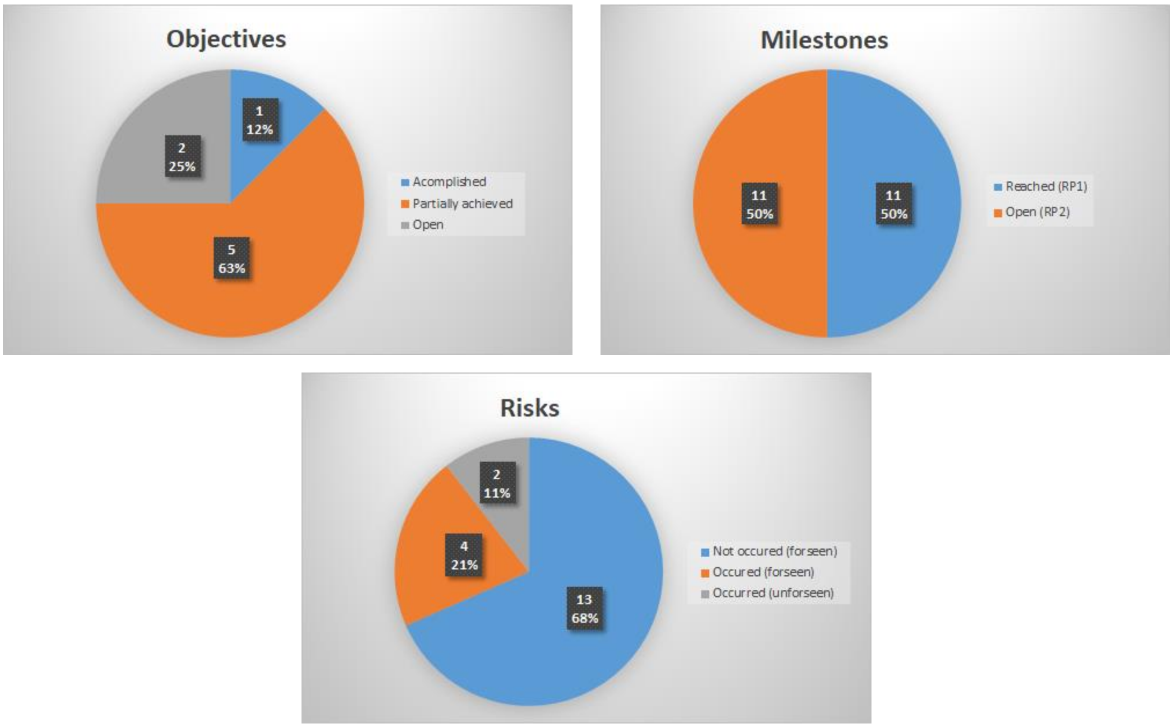


Figure 55: ESRIUM dashboard.

Figure 56 represents the expected product maturity versus the project timeline and the effort required for commercialization. As it can be seen, throughout the project timeline the effort towards the maturity of the product increases exponentially. Since ESRIUM targets a TRL level of 7-8, it is crucial to take into account the high effort needed to achieve the expected product maturity level building the essential basis to commercialize the product and achieve full deployment. In order to ensure this, the whole project consortium is focused on the timely delivery of the main results and that the project reaches all its objectives as planned.

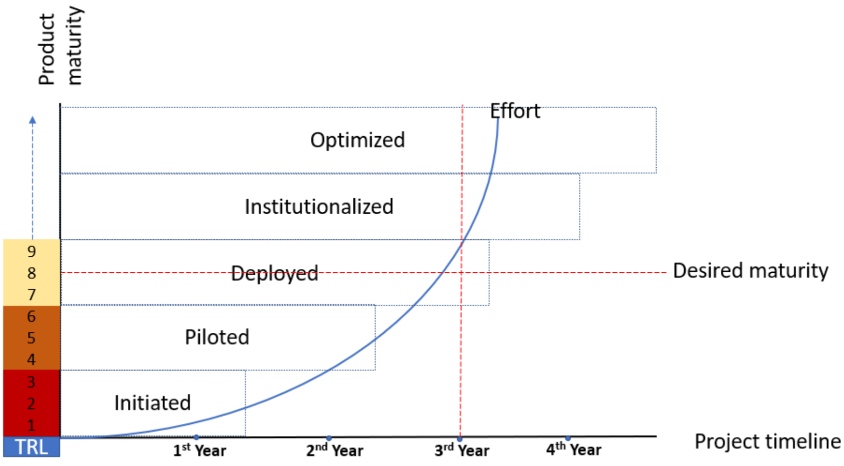


Figure 56: Expected product maturity vs. project timeline.

The second reporting period consists of six main next steps, namely, (1) the software development for the selected EGNSS Hardware, (2) the realization of the road wear detection (including classification and prediction), (3) the implementation of the C-ITS communication, (4) the creation of the data management platform, (5) the execution of performance and user tests, and (6) the determination of a final exploitation plan.

The expected main risks and their mitigation actions for the second reporting period are shown in Table 19.

Description	WP	Risk Mitigation Measures	Prob	Dmg
Project plans abandoned under pressure, resulting in inefficient development	1	WP leaders and the Coordinator will be following the project activities very closely to ensure that project plans are precisely followed by the relevant partners in WP level.	L	H
Public/private sector companies low willingness to provide factual data for business case development	2	Non-disclosure agreements in place, restricted access deliverables, other legal measures to keep confidentiality	M	H
Unavailability of OSNMA service at the signal level during the development and test phases	3	Reschedule of the test or performance evaluation through simulation	M	H
Possible delays related to integration and interfacing of the C-ITS and EGNSS equipment to the test vehicles.	5	Creation of mock-ups for either system: messages stored in-vehicle, localization via COTS GNSS/IMU system.	L	M
Failure to properly disseminate the results of the project among the decision making stakeholders.	6	Several partners are in a good position to approach relevant European actors, while others have a wide technical dissemination background. ASF as a road operator is part of the consortium and will disseminate ESRIUM to key stakeholders through their contacts and related associations (e.g. ASECAP, CEDR, etc.).	L	M

Table 19: Major risks for second reporting period (Dmg = Damage, Prob = Probability).

1.6 Impact

1.6.1 Expected impacts listed in the work program

- Foster the EGNSS market uptake in transport. It should build on specific features and differentiators of Galileo and EGNOS, demonstrating the advantage of their use in smart and green mobility.
  ➔ Still valid
- Contribute to the resource efficient, climate and environmental friendly transport that will be also safe and seamless for the benefit of all citizens, the economy and society.
  ➔ Still valid
- Road safety
  ➔ Still valid
- Encourage market take-up, taking into account infrastructure and regulatory requirements, coordination of multiple actors and projects.
  ➔ Still valid
- Commercialize the products and services developed.
  ➔ Still valid

1.6.2 Impacts not mentioned in the work program

- Enhance innovation capacity; create new market opportunities, strengthen competitiveness and growth of companies
  ➔ Still valid
- Address issues related to climate change or the environment
  ➔ Still valid
- Bring other important benefits for society
  ➔ Still valid

SECTION 2: UPDATE OF THE PLAN FOR EXPLOITATION AND DISSEMINATION OF RESULT (IF APPLICABLE)

Not applicable.

SECTION 3: UPDATE OF THE DATA MANAGEMENT PLAN (IF APPLICABLE)

Not applicable.

SECTION 4: FOLLOW-UP OF RECOMMENDATIONS AND COMMENTS FROM PREVIOUS REVIEW(S) (IF APPLICABLE)

Not applicable.

SECTION 5: DEVIATIONS FROM ANNEX 1 AND ANNEX 2 (IF APPLICABLE)

Significant progress has been made towards achieving critical objectives (see Section 1.1) and most of the deliverables were submitted to the external reviewers on time. Iterations sometimes took a while, thus, the submission to the participant portal was not the anticipated submission date from the GA. There were some changes regarding deliverables (Section 5.1.1) and milestones (Section 5.1.2), shifts in duration of tasks (Section 5.1.3) and minor shifts in efforts and costs (Section 5.2).

5.1 Tasks

WP	Change request	Comment PO
1	Do we need to create explicit documents for “D1.2 First Financial information required by EC” and “D1.4 First Periodic project report”, or is it sufficient to fill all the required information in the participant portal?	These 2 documents are the ones you will generate in the participant portal after the midterm review. In order to avoid the “system alarm”, you will have to submit them to the deliverables platform too. You always have 2 months after the midterm review to organise the submission. Please share them with the experts once they are ready.
4	It is planned to change the timeline of Task 4.6 from M25-M36 to M19-M30, since other tasks depend on the availability of the platform.	Obviously, no problem to anticipate D4.6.

	Thus, having it at the end of the project would be a bit late.	
4	It is expected that the timeline of T4.3 and T4.4 needs to be elongated to M30. The deliverable "D4.3 Road Wear Data Collection" in M24 is a major a prerequisite for the tasks T4.3 and T4.4. Following the GA, they also end with M24 but the consortium needs additional time to work with the data from D4.3. This extension does not influence the other work packages (T4.5 provides data to other WPs and is also due in M30). Data is ongoing and already available and the interfaces of the use cases will be available earlier.	In relation to D4.3 and D4.4, the proposed 6-month extension is within the overall duration of the project. Besides, this change seems necessary in order to take advantage of the data generated by the platform and in order to successfully achieve the overall project objectives.
6	There is an issue with the dissemination level of "D6.6 Preliminary exploitation plan" and "D6.7 Final exploitation plan". In the GA, they are marked as PU but they should be CO. Especially, D6.7 where we will include the business plan of ESRIUM with financial estimations.	Therefore I accept your proposal of having two versions of D6.6 and D6.7: • an extended version (confidential, will not be distributed) you will submit for review and approval; • a summary version (public) you will produce + publish on the website after the formal approval of the confidential version

Table 20: Change requests – General.

5.1.1 *Changes in deliverables*

5.1.1.1 Postponed deliverables

Two deliverables (D3.2 and D6.4) were submitted later than originally planned. In the second reporting period, there will also be two delays, namely D4.4 and D4.5. The argumentation can be found in Section 5.1 and *Table 21*. The PO accepted all delays.

No.	Deliverable Name	WP	GA due date	New due date	Reason
D3.2	Galileo OS-NMA implementation	WP3	M15 28.02.2022	M16 31.03.2022	This was due to the late release of the new ICD protocol. That is, the reasons were outside the consortiums perimeter and are connected with the Galileo programme implementation delay.
D4.4	Road Wear Detection and Classification	WP4	M24 30.11.2022	M30 31.05.2023	Task 4.3 will benefit from an elongation to M30.
D4.5	Road Wear Prediction	WP4	M24 30.11.2022	M30 31.05.2023	Task 4.4 will benefit from an elongation to M30.
D6.4	Market & business ecosystem analysis	WP6	M15 28.02.2022	M17 30.04.2022	The leader of "Task 6.3 Exploitation management & IPR strategy" changed from NNG to ENI. It took some time to shift efforts and reassign the new responsibilities.

Table 21: Postponed deliverables.

5.1.1.2 Earlier deliverables

Due to the interaction of tasks, it is essential that one deliverable is ready earlier than planned (also see Section 5.1.3). This change relates to the second reporting period.

No.	Deliverable Name	WP	GA due date	New due date	Reason
D4.7	Road Wear Data Platform	WP4	M36 31.11.2023	M30 31.05.2023	Other tasks can only be tackeled if the platform is already available.

Table 22: Earlier deliverables.

5.1.1.3 *Lead of deliverables*

There were some minor inconsistencies between the proposal and the GA and some issues with Task leaders/members and deliverable responsibilities. In addition, there was a change of responsibility in Task 6.3 (see Section 5.2) from NNG to ENI. This also influenced the connected deliverables (D6.4 and D6.6). The resulting changes can be seen in *Table 23*.

No.	Deliverable Name	WP	Lead GA	Final Lead
D2.2	Technical and non-technical user requirements document	WP2	ENI	JRD/FHO
D2.3	System interface design document	WP2	JRD	NNG
D2.4	First business case baseline	WP2	FHO	ENI
D2.5	Second business case baseline	WP2	FHO	ENI
D4.1	Road wear ground truth data	WP4	FGI	JRD
D6.4	Market & business ecosystem analysis	WP6	NNG	ENI
D6.6	Preliminary exploitation plans	WP6	NNG	ENI

Table 23: Lead changes of deliverables.

5.1.1.4 *Changes dissemination level of deliverables*

In the GA the deliverables "D6.6 Preliminary exploitation plan" and "D6.7 Final exploitation plan" are marked as PU but they should be CO. Especially, D6.7 where the business plan of ESRIUM with financial estimations will be included.

The following procedure was arranged with the PO:

- An extended version (confidential, will not be distributed) have to be submitted for review and approval.
- A summary version (public) will be produced and published on the website after the formal approval of the confidential version.

5.1.2 *Changes of milestones*

Since the milestones are directly connected to deliverables most of them seem to be late having a look at the submission date in the participant portal. It is to mention that the submission of the first version of the documents to the external reviewers were always on time. One milestone was late, but this is directly correlated to the postponed deliverable D3.2. Two milestones were set at an improper date, one not correlating to the connected deliverables and the other being set at the start of the reporting period and not at the end. Details are given in *Table 24*.

MS No.	Milestone Name	GA Due date	Date PP	Date Internal	Comment
1	Project management documents ready in version 1	31.02.2021	02.03.2021	26.02.2021	D1.1: Submission to PO: 26.02.2021
2	Communication strategy established and initial communication kit available	31.02.2021	02.03.2021	26.02.2021	D6.1: Submission to PO: 26.02.2021 D6.2: Submission to PO: 26.02.2021
3	Use case definition	31.05.2021	13.07.2021	12.05.2021	D2.1: First submission to external reviewer: 12.05.2021
4	Results of the state-of-the art and literature survey about EGNSS location	31.05.2021	29.06.2021	21.05.2021	D3.1: First submission to external reviewer: 21.05.2021
5	Technical, non-technical user requirements and system interface design ready for handed over to WP3	30.11.2021	waiting	22.02.2022	D2.2: First submission to external reviewer: 24.11.2021 D2.3: First submission to external reviewer: 22.02.2022 D2.3 was due 28.02.2022, thus the milestone was not set correctly from the beginning
6	Sensor system operational	30.11.2021	15.12.2021	19.11.2021	D4.1: First submission to external reviewer: 19.11.2021
7	KPIs and scenarios defined	30.11.2021	24.11.2021	24.11.2021	D5.2 (Szenarios and KPIs): First submission to external reviewer: 19.11.2021 D2.2 (KPIs): First submission to external reviewer: 24.11.2021
8	Sensing vehicles ready	30.11.2021	13.04.2022	24.11.2021	D1.1: Submission 02.03.2021 D2.1: First submission to external reviewer: 12.05.2021 D2.2: First submission to external reviewer: 24.11.2021 D2.4: First submission to external reviewer: 27.07.2021 D3.1: First submission to external reviewer: 21.05.2021 D4.1: First submission to external reviewer: 19.11.2021 D5.2: First submission to external reviewer: 19.11.2021 D6.1: Submission 02.03.2021 D6.2: Submission 02.03.2021
9	EGNSS authentication implementation	28.02.2022	20.05.2022	08.04.2022	D3.2: First submission to external reviewer: 08.04.2022 The submission of D3.2 was delayed to 31.03.2022 (approved by the PO)
10	Successful mid-term review	31.05.2021	open	open	Milestone not set correctly, since the reporting period starts with this date.
11	Intermediate business and exploitation approach defined	31.05.2021	13.07.2022	18.05.2021	D6.4: First submission to external reviewer: 03.05.2022 D6.6: First submission to external reviewer: 18.05.2022 The submission of D6.4 was delayed to 31.05.2022 (approved by the PO)

Table 24: Comparison of submissions for achievement of milestones.

5.1.3 *Changes of timelines*

WP No.	Task No.	Task Name	Lead	Original Period	New Period	Connected Deliverable	Reason
4	4.3	Road Wear Detection and Classification	JRD	M7 - M24	M7 - M30	D4.4	Deliverable D4.3 Road Wear Data Collection (M24) is a major a prerequisite for this task. In order to be able to work with this data, we would like to extend this task until M30.
4	4.4	Road Wear Prediction	EVO	M7 - M24	M7 - M30	D4.5	Deliverable D4.3 Road Wear Data Collection (M24) is a major a prerequisite for this task. In order to be able to work with this data, we would like to extend this task until M30.
4	4.6	Road Wear Data Platform	JRD	M25 - M36	M19 - M30	D4.7	This taks has to be finalized earlier than planned. Other tasks can only be tackeled if the platform is already available.

Table 25: Changes in the timeline of tasks.

5.2 Use of resources

WP	Change request	Comment PO
6	NNG will move 5 PMs from WP 6 to other direct costs (dissemination costs) in WP 6.	As far the (minor) change proposed below does not compromise the quality and the scope of the technical activities, I think it is acceptable and justified. Besides, it is coherent/balanced with the importance of awareness activities in H2020 projects.
6	JRD will also claim some costs for dissemination material (0,5-1 PM).	
4	The costs for the transportation of equipment from Austria to Finland are around 12.000€ instead of the anticipated 1.000€. Costs will be shifted from “Travel” to “Other goods and Services”.	I see the cost changes proposed does not imply reshuffling of the budget among partners; they are due to justified external circumstances and are operationally necessary in order to fulfil the project objectives. In my opinion, I do not see the need for a legal amendment of the GA.
4	The following costs were put in the wrong subcategory in the proposal (“Other goods and services” instead of “Internally invoiced goods and services”):	

	• DIG Mobile Mapping & DIG Messfahrzeug • DIG Trägheits-navgationssystem • DIG Sensorplattform But they were foreseen in the GA (p.171): • 10h Mobile Mapping System • 10h IMU for Ground Truth • 85h sensor platform	
6	Due to internal experts leaving NNG, they are no longer able to lead Task T6.3. We as consortium agreed that ENI will take over the responsibility and will be supported by EVO. This results in a shift of PMs from WP6: • 6,5 PM from NNG to ~6 PM for ENI → 35.100€ direct personal costs • 1,5 PM from NNG to ~1 PM for EVO → 8.100€ direct personal costs NNG has left some PM in WP2, which they will use in WP6 in order to compensate for the rather large reduction.	Following analysis from our legal department, the conclusion is that there is <u>no need for an amendment</u> because there is no change to Annex 1 and the changes in budget and staff effort are minor. Therefore, the changes are OK with me as PO and can be approved as part of the mid-term reporting through 'simplified procedure'.
2/5/6	FHO planned 16 person months in total with average cost/month of 8,300 Euro for the whole project. Until M18, FHO used about 43% of the total planned budget. However, the person months reported for WP2, WP5 and WP6 were about 16 person months. FHO planned in the proposal phase to carry out all dedicated tasks with senior researchers. That was the basis for the planned average costs. After the project started we had the chance to involve junior researchers instead of one senior researcher. This changing caused some new plannings for the project because the junior researchers had not that much experience and needed more time to come up with project results compared to senior researchers. Junior researchers were coached by FHO senior researchers during the project period so far. All in all, FHO reported more man months than planned with a lower cost rate. However, this mixed team approach will not cause any lower quality of the outcome compared to a team of only senior researchers. In total FHO will need more person months as stated in the proposal. However, this does not lead to an overspending of FHO. FHO confirms herewith	No comment yet.

	to cover all open tasks with the remaining budget.	
2	JRD spent 5,79 PM on WP2 instead of the planned 9,1 PM. That is -3,31 PMs remain despite the fact that WP2 is finalized. These PMs will be used in WP6 to compensate for the shift of costs from PMs to dissemination material and to strengthen the liaison and networking efforts.	No comment yet.

Table 26: Change requests – Use of resources.

5.2.1 Unforeseen subcontracting (if applicable)

Not applicable.

5.2.2 Unforeseen use of in kind contribution from third party against payment or free of charges (if applicable)

Not applicable.

SECTION 6: REFERENCES

[ARY2021] Arya, Deeksha, et al. "RDD2020: An annotated image dataset for automatic road damage detection using deep learning." Data in brief 36 (2021): 107133.

[BOC2020] Bochkovskiy, Alexey, Chien-Yao Wang, and Hong-Yuan Mark Liao. "Yolov4: Optimal speed and accuracy of object detection." arXiv preprint arXiv:2004.10934 (2020).

[HIR2007] Hirschmuller, Heiko. "Stereo processing by semiglobal matching and mutual information." IEEE Transactions on pattern analysis and machine intelligence 30.2 (2007): 328-341.

[HUM2019] Humphreys, T. E., Murrian, M. J., & Narula, L. (2019). Deep urban unaided precise GNSS vehicle positioning. jun 2019. http://arxiv.org/abs/1906.09539

[PIL2010] Pilutti, T., & Wallis, T. (2010). Onroad GPS Availability Analysis. SAE 2010 World Congress & Exhibition. SAE International, apr 2010. https://doi.org/10.4271/2010-01-0742

[PRT2020] PETAL (2020). Deliverable TN 1.2.2. GNSS and SBAS Performance at High Latitudes v2 (Field Data Analysis). PETAL project (Position, Navigation and Time Traffic Light).

[REI2019] Reid, T. G. R., Pervez, N., Ibrahim, U., Houts, S. E., Pandey, G., Alla, N. K. R., & Hsia, A. (2019). Standalone and RTK GNSS on 30,000 km of North American Highways. 32nd International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2019), Miami, FL, sep 2019. http://arxiv.org/abs/1906.08180

[RUD2021] Rudigier, M.; Nestlinger, G.; Tong, K.; Solmaz, S. Development and Verification of Infrastructure-Assisted Automated Driving Functions. *Electronics* 2021, *10*, 2161. https://doi.org/10.3390/electronics10172161

[RUD2022] M. Rudigier, S. Solmaz, G. Nestlinger and K. Tong, "Development, Verification and KPI Analysis of Infrastructure-Assisted Trajectory Planners," *2022 International Conference on Connected Vehicle and Expo (ICCVE)*, 2022, pp. 1-6, doi: 10.1109/ICCVE52871.2022.9742783.

[STE2018] Stern, A. & Kos, A. (2018). Positioning performance assessment of geodetic, automotive, and smartphone gnss receivers in standardized road scenarios. IEEE Access, vol. 6, pp. 41 410–41 428.

[THO2020] Thombre, S. (2020). Role of GNSS in Enabling Autonomous Driving at the Aurora Snowbox Ecosystem. Finnish Satellite Workshop 2020. https://fgisnowbox.files.wordpress.com/2020/01/thombre_arctic-pnt_fsw_presentation_fgi.pdf

[VEN2003] Venkatesh, Viswanath & Morris, Michael & Davis, Gordon & Davis, Fred. (2003). User Acceptance of Information Technology: Toward a Unified View. MIS Quarterly. 27. 425-478. 10.2307/30036540.

[VEN2008] Venkatesh, Viswanath & Bala, Hillol. (2008). Technology Acceptance Model 3 and a Research Agenda on Interventions. Decision Sciences - DECISION SCI. 39. 273-315. 10.1111/j.1540-5915.2008.00192.x.

SECTION 7: GLOSSARY

Acronym	Definition
ACC	Adaptive Cruise Control
ACEA	European Automobile Manufacturers' Association
ADAS	Advance Driver Assistance System
AI	Artificial Intelligence
AIT	Austrian Institute of Technology
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
ALP.Lab	Austrian light vehicle proving region for automated driving
AltBOC	Alternate Binary Offset Carrier
AOIs	Areas of Interests
API	Application Programming Interface
APOS	Austrian Positioning Service
ARCADE	Aligning Research & Innovation for Connected and Automated Driving in Europe
ASAM	Association for Standardization of Automation and Measuring Systems
ASECAP	Conference of European Directors of Roads (Association Européenne des Concessionnaires d'Autoroutes et d'Ouvrages à Péage)
ASF	Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft
ASFINAG	Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft
ASPRS	American Society for Photogrammetry and Remote Sensing
AV	Automated Vehicle
BMVIT	Austrian Federal Ministry of Transportation
C-ITS	Cooperative Intelligent Transport Systems
C-ROADS	Platform of harmonised C-IST deployment in Europe
CA	Consortium Agreement
CAD	Cooperative and Automated Driving
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CAV	Cooperative Automated Vehicle
CCAM	Cooperative Connected Automated Mobility
CEDR	Conférence Européenne des Directeurs des Routes
CEF	Connecting Europe Facility (Förderprogramm)
CEN	European committee for standardisation
CO	Confidential
CORS	Continuously Operating Reference Station
COTS	Commercial Off-The-Shelf
CPM	Collective Perception Message
CPU	Central Processing Unit
CRG	Curved Regular Grid
DARS	Družba za avtoceste v Republiki Sloveniji (Motorway Company in the Republic of Slovenia)
DENM	Decentralized Environmental Notification Message
DGPS	Differential GPS
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAB	Expert Advisory Board
EC	European Commission (EU-Projekte)
ECU	Electronic / Engine Control Unit
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System

ENI	ENIDE SOLUTIONS .S.L
ENR	ESRIUM Non-technical Requirement
EPN	EUREF Permanent GNSS Network
EPOSA	Echtzeit Positionierung Austria
ERF	European Union Road Federation
ESRIUM	EGNSS-Enabled Smart Road Infrastructure Usage and Maintenance for Increased Energy Efficiency and Safety on European Road Networks
ETPC	European Truck Platooning Community
ETRS89	European Terrestrial Reference System 1989
ETSI	European Telecommunication Standards Institute
ETSI TS	European Telecommunication Standards Institute
EUC	ESRIUM Use Case
EUREF	Regional Reference Frame Sub-Commission for Europe
EUREF-FIN	Regional Reference Frame Sub-Commission for Europe - Finland
EVO	Evolit Consulting GmbH
FAIR	Findable, Accessible, Interoperable and Reusable
FEM	Finite Element Modeling and Analysis
FFG	Forschungsförderungsgesellschaft
FGI	Finnish Geospatial research Institute
FHO	FH OÖ - Logistikum
FOG	Fiber Optic Gyroscope
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GIS	Geographic Information System
GLO	GLONASS, Russian, Globalnaja Nawigazionnaja Sputnikowaja Sistema
GNSS	Global Navigation Satellite System
GPC	GNSS Positioning Correction
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GPU	Graphics Processing Unit
GRF	Geo-Referenced Feature
GSA	European GNSS Agency
H2020	Horizon 2020
HAS	High Accuracy Service
HGV	Hochgeschwindigkeitsverkehr (High Speed Traffic)
HIC	High Income Countries
HMI	Human-Machine Interface
I2V	Infrastructure to Vehicle
IBTTA	International Bridge, Tunnel and Turnpike Association
IGS	International GNSS Service
IMU	Inertial Measurement Unit
INSPIRE	Infrastructure for spatial information in Europe
IP	Intellectual Property
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
IVIM	In-Vehicle Information Message
JRD	JOANNEUM RESEARCH Forschungsgesellschaft mbH – Institute DIGITAL

LAS	Laser File Specification
LEVITATE	Societal Level Impacts of Connected and Automated Vehicles
LiDAR	Light Detection and Ranging
LKA	Lane Keeping Assistant
LoI	Letter of Intent
LQR	Linear Quadratic Regulator
MaaS	Mobility as a Service
MEC	Multi Access Edge
MMS	Mobile Mapping System
MS	Milestone
MVA	Machine-Vision and Applications
MWC	Motorway Chauffeur
NLS	National Land Survey
NMA	Navigation Message Authentication
NNG	NNG Software Developing and Commercial LLC
NTR	Non-Technical Requirement
OBU	On-Board Unit
ODR 2020	OpenDrive
OEM	Original Equipment Manufacturer
OGC	Open Geospatial Consortium
OpenCRG	Curved Regular Grid
OS	Open Service
OS NMA	Open Service Navigation Message Authentication
OTH	Other
PCD	Point Cloud Data (File Format)
PDAL	Point Data Abstraction Library
PESTLE	Political, Economic, Social, Technological, Environmental and Legal factors
PI	Proportional-Integral
PIARC	World Road Association
PMB	Project Management Board
PMS	Pavement Management System
PMT	Project Management Team
POI	Point of Interest
POL	Politecnico di Milano
PPP	Precise Point Positioning
PUB	Public
PVA	Position, Velocity, Attitude
PVT	Position, Velocity, and Time
QoS	Quality of Service
RGB	Red Green Blue (color values)
RSI	Road Safety Inspections
RSU	Road Side Unit
RTCM	Radio technical Commission for Maritime Services
RTCMEM	RTCM Extended Message
RTD	European Commission's Directorate-General for Research and Innovation
RTK	Real-Time Kinematic
SAE	Society of automotive engineers, USA
SAR	Synthetic Aperture Radar

SMEs	Small and medium-sized enterprises
SOA	Service-oriented architecture
SV	Subject Vehicle. This refers to the demonstration vehicle equipped with automated driving functions and a C-ITS OBU. The SV receives and reacts to the C-ITS messages.
SWOT	Strengths, Weaknesses, Opportunities, Threats
TAM3	Technology Acceptance Model 3
TP	Trajectory Planner
TRAFICOM	Finnish Transport and Communications Agency
TRL	Technology Readiness Level
UTAUT	Unified Theory of Acceptance and Use of Technology
UHD	Ultra High Definition
UHF	Ultra-High Frequency
V2I	Vehicle-to-Infrastructure
V2X	Vehicle to everything
VIF	Virtual Vehicle Research GmbH
VMS	Variable Message Signs
WP	Work Package