ESRIUM

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Report on extension of C-ITS by EGNSS use case

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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.

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EXECUTIVE SUMMARY

Supplying EGNSS RTK correction as an extension of C-ITS was successfully demonstrated. The location accuracy that is achieved in the vehicle is 10 cm and is judged to be sufficient for automated driving.The prototype set up in Austria showed that all needed transmission formats from the RTK source to the transmission point are already - or are in the process of being – internationally standardized, are therefore readily implementable, and that, in Austria at least, an RTK source is available for deployment. The prototype was implemented on RTK infrastructure and C-ITS infrastructure currently operational or being deployed on the entire Austrian rail and highway networks, which adds to the confidence in this result. Operational costs for the RTK system are anticipated in the range of several 100,000 EUR annually, depending on the required Safety Integrity Level (SIL) and certification levels.

The software in the road side units which relays the RTK messages from the RTK source to the moving vehicles was implemented as a wrapper rather than integrating it into the software core. This resulted in a pulsating transmission characteristic as opposed to a precisely timed process. Still this did not compromise the precision and also allowed for testing of the vehicle client in the case of uncharacteristic transmission behaviour, which was successful.

The technical key results of the project are a precise plotting of the correspondence of localization accuracy in the vehicle with the availability of the EGNSS RTK data via C-ITS, the demonstrated usage of this accuracy for automated driving, and the concept for short term large scale roll-out. Further investigation should include a large scale test and focus on the effect of gaps in transmission coverage.

DOCUMENT REVISION

Version	Changes to content	Author	Status	Date
0.1	First version to determine scope and depth, possible after in depth test run analysis	Gottfried Allmer (ASF)	Draft	14.06.2023
0.2	Version after tests were conclusive that EPOSA could be used in a deployment solution	Gottfried Allmer (ASF)	Draft	04.07.2023
0.3	Version after in-depth discussion of the results	Gottfried Allmer (ASF)	Draft	19.07.2023
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0.5	Review comment 3 of Project Officer review from 14.09.2023 addressed: Figure 6 shows zooming-in into sections of Figure 5 to highlight where location accuracy improves dramatically because of C-ITS, and hereby RTK, coverage	Roman Lesjak (JRD)	Draft	18.10.2023

0.6	Review comments 3 of Project Officer review from 14.09.2023 addressed	Gottfried Allmer (ASF)	Final Review	06.11.2023
1.0	Input from EPOSA: Section 8 For RTK, NTRIP 3.1 is now available.	Gottfried Allmer (ASF)	Final	07.11.2023

ACRONYMS USED

Acronym	Explanation
ACC	Adaptive Cruise Control
C-ITS	Cooperative Intelligent Transport Systems. When specifically dealing with the transmission method, also abbreviated to ITS-G5, IEEE 802.11p, pWLAN, or WLANp. C-ITS uses WLAN-technology to enable short range car to car communication. Road operator infrastructure to car is also supported by using a string of road side units which broadcast the information to the vehicles passing by.
CAV	Cooperative Automated Vehicle
D-GNSS	Differential GNSS. To reach centimeter-level accuracy of positioning certain requirements pertaining to the used GNSS transmission frequencies have to be fulfilled (not discussed here). Furthermore, the received signals have to be processed using a differential GNSS algorithm, either Real Time Kinematic Positioning (RTK) or Post Processing Kinematik Positioning (PPK). RTK applies all corrections in real-time during the data collection, whereas PPK resolves errors after all the data has been collected.
EGNSS	Strictly speaking, EGNSS is the European Global Navigation Satellite System, but it is also used in colloquial terms to denote GNSS enhanced with EGNSS features. EGNSS in the exact definition consists of the European GNSS “Galileo” and the “EGNOS”. Galileo is a GNSS created by the European Union that went live in 2016. EGNOS, the European Geostationary Overlay Service, is Europe’s regional satellite-based augmentation system (SBAS) that is used to improve the performance of Galileo (also of GPS, the American GNSS).
EGNSS RTK	EGNSS used in conjuction with an RTK system. This improves position accuracy by two orders of magnitude from roughly 1-3 m to roughly 1-10 cm, admittedly at the cost of requiring an RTK provider, an additional system to be maintained.
Ego vehicle	Another term for Subject Vehicle (SV).
Galileo	see EGNSS
GNSS	Global Navigation Satellite System. The four available systems with global coverage are: • EGNSS or Galileo (European) • GPS (American)

	• GLONASS (Russian) • BeiDou (Chinese)
ITRF2020	ITRF2020 is the new realization of the International Terrrestrial Reference System. The ITRF2020 is expected to be an improved solution compared to ITF2014.
ITS G5	Transmission technology for C-ITS, based on WLAN.
IVIM	C-ITS In-Vehicle Information Message
LKA	Lane Keeping Assistant
OBU	On-Board Unit
Rover	A recipient of the RTK correction signals.
RSU	Roadside Unit of the ITS G5 transmission infrastructure.
RTCM	Radio Technology Commission for Maritime Services. A protocol for messages holding differential GNSS information in RTK applications. The D-GNSS system consists of the base station, data link, and user (rover). Among them, the data link plays a key role in the system, and whether it is effective and reliable determines whether the differential system is reliable and effective. The protocol for differential information is an important part of the data chain. Any data information has its own way of being generated, stored, and exchanged. This way of existence is the protocol. To facilitate the exchange and transmission of information, the need for a unified world-wide format protocol emerges. Currently, the most used differential information message formats are RTCM SC-104 and CMR. ESRIUM uses RTCM[1]. [1] What is RTCM? Why does RTK firmware updating matter? Lance Dong, Tersus GNSS, 8 April, 2022
RTCMEM	An RTCM Environmental Message. A standardized C-ITS (ITS-G5/802.p11) message to transmit RTCM information.
RTK	Real-time Kinematic Positioning. A D-GNSS application to correct for common errors in current satellite navigation EGNSS systems. EGNSS data corrections are applied in real-time, as opposed to Post Processing Kinematic Positioning (PPK) where data is processed after all data has been collected. RTK, not PPK, is used in the ESRIUM project for the localization of the end-user vehicle. Furthermore, ESRIUM uses the RTCM protocol as the RTK standard.
SIL	Safety Integration Level according to international standard IEC 61508.
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.
VIF	Virtual Vehicle Research GmbH

SECTION 1: INTRODUCTION

To extend C-ITS, the technical cooperation of traffic participants with each other by messaging using Wi-Fi, with the EGNSS use case, precise locationing using a satellite network, means to add C-ITS functions which are highly dependant on precise locationing. In ESRIUM the idea was to extend C-ITS two-fold: Firstly, by using C-ITS infrastructure to achieve continuous high location precision within the vehicles themselves, and secondly by transmitting C-ITS messages with C-ITS infrastructure containing precise location references and thereby enable new C-ITS use cases.

This document contains a report of how, using the example of Austria, a state-wide deployment of continuously supplying vehicles with EGNSS RTK correction information to calibrate their location coordinates is envisaged, and of the test results of a prototype containing key elements thereof. It specifically concentrates on and limits itself to the usage of ITS-G5 (also known as IEEE 802.11p, pWLAN or WLANp) technology for over-the-air transmission, henceforth abbreviated to “C-ITS”.

The **key findings** of this deliverable are a precise plotting of the correspondence of localization accuracy in the vehicle with the availability of the EGNSS RTK data via C-ITS in 7 RESULTS / “Achieved localization accuracy ” and the demonstrated usage of this accuracy for automated driving in 7 RESULTS / “Use in automated driving”, as well as the concept for short term large scale roll-out in 6 THE ENVISAGED TRANSMISSION NETWORK FOR THE EGNSS RTK CORRECTION DATA.

Additionally, it contains the test results of possible future C-ITS use cases, which require the location accuracy of EGNSS RTK, and are based on automatically directing vehicles to change their lateral position whilst driving on the highway, either by causing them to move slightly to the left or to the right, or to have them completely change the lane.

Organization of the sections in the report

Sections in the report are organized as follows.

- Section 1 introduces the report and offers a guideline.
- Section 2 explains the relation between EGNSS and C-ITS.
- Section 3 gives an account of how the testing unfolded.
- Section 4 shows how the extension of C-ITS by EGNSS works.
- Section 5 presents the EGNSS RTK provider used for the prototype.
- Section 6 outlines the envisaged future operative system for supplying EGNSS over C-ITS.
- Section 7 presents the RESULTS OF THE TESTING.
- Section 8 underlines the standardization state of the transmission protocols.
- Section 9 presents the prototype.
- Section 10 presents the relevant tested use cases.
- Section 11 holds the conclusion. It is positive and can pave the way for an implementation in scale after the project ends.

Context of the investigation

At the writing of this report, Austria was in the process of a full-scale rollout spanning from 2022 through 2028 to equip all its highways with C-ITS. Falling squarely within the timeline, it was possible for the project ESRIUM to implement the prototype on real-life deployment equipment and do the testing in real-life highway traffic.

The C-ITS extension use cases of lateral routing recommendations had been selected to ensure unambiguous necessity of utilizing RTK because of the high position accuracy required. They also serve as base use cases for a whole class of possible C-ITS extensions using EGNSS with RTK, where the resulting C-ITS messages to the vehicles are either in-lane or lane change lateral routing recommendations.

Technically, an extension of C-ITS using EGNSS consists of defining and sending out C-ITS messages for the suggested use cases as well as connecting an RTK source to the C-ITS infrastructure to enable the sending out of RTK messages (separate to the C-ITS messages). The vehicle uses the RTK message stream to continuously re-calibrate its positioning algorithm, thereby achieving an accuracy of its own location in the centimeter range. Any location information in a C-ITS message can then be interpreted and reacted upon with high geographical accuracy.

All transmission interfaces are already standardized or are in an ongoing standardization process or have a viable standardization path defined as outlined in section "Standardization".

SECTION 2: PROPOSED EXTENSION OF C-ITS USING EGNSS

This section explains the relation between EGNSS RTK and C-ITS, and why „Extension of C-ITS using EGNSS" involves testing the transmission of EGNSS RTK correction messages via C-ITS *as well as* extended C-ITS use cases at the same time.

As **EGNSS enabled use of smart road infrastructure (ESRIUM)** first and foremost depends upon having EGNSS RTK available, the provision of EGNSS RTK correction data was defined as the key investigation theme for infrastructure in the project.

Due to the complex nature of IT-Services, it was felt that, when the provision of EGNSS RTK via C-ITS messages has been demonstrated, use cases which make use of the accurate positioning that EGNSS RTK provides should be tested immediately thereafter. The idea is to go through the complete data chain to be confident such applications can work.

With a full deployment of C-ITS on the entire Austrian highway network underway, ASFINAG was perfectly positioned to provide smart messages as well as the inclusion of EGNSS related information to a moving client, i.e., a receptive vehicle, in real life environment on the highway.

When high location accuracy is provided using EGNSS RTK, vehicles could make use of a whole range of C-ITS use cases which involve receiving precise lateral guidance – for instance,

- having them avoid unexpected dangers on the road,
- having them avoid expected dangers on the road, i.e., roadworks,
- filing them into a moving queue on an adjacent lane,
- negotiating them through several tolling lanes, or
- statistically distributing vehicles laterally for a more even weight distribution on the road.

In the scope of ESRIUM the base use cases of

- in-lane routing recommendations, depicted in blue in Figure 1, and
- lane change routing recommendations, depicted in red in Figure 1

were implemented and tested. As concerns the C-ITS messages sent to the vehicles, these two base use cases would suffice to implement the above list of envisaged use cases.

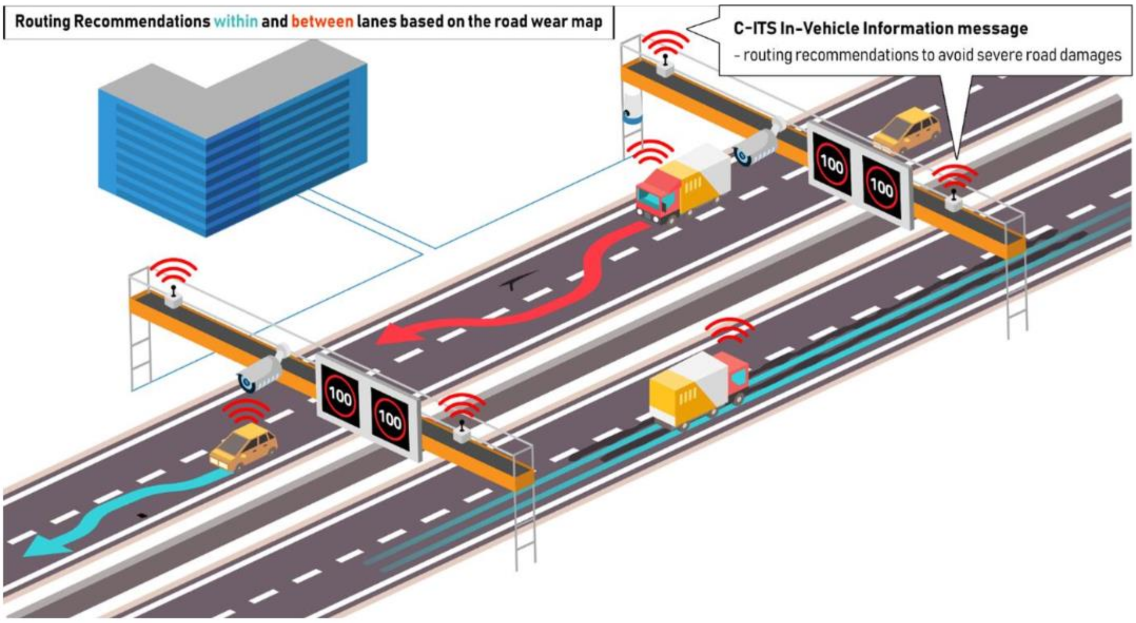

Figure 1: Proposed C-ITS extensions using EGNSS RTK.

SECTION 3: TEST PROCEEDINGS

In this section, we present the sequence of testing activities carried out to demonstrate EGNSS RTK correction information can be sent via C-ITS.

As stated above, the provision of EGNSS RTK correction data was defined as the key investigation theme for infrastructure in the project. Secondly, two C-ITS use cases, in-lane and lane change routing recommendations, were identified as test cases which would demonstrate a working data chain of providing accurate positioning within a context where accurate positioning is used.

The second task was deemed as more time critical as it involved sender as well as receiver, so this was implemented first and found test ready at the beginning of 2023. During that time task number one involved re-scanning the market for the most suitable EGNSS RTK provision, and after EPOSA, an Austrian private-public partnership already supplying the Austrian rail network, had been confirmed as the best viable choice, entering in negotiations with EPOSA about how to proceed up to a contract-ready situation.

ASFINAG always considered the visible outline of an actual deployment solution as the only way to demonstrate the project goal of using EGNSS RTK in the proposed manner. Therefore, it had to be demonstrated that the EGNSS RTK signals stemming from the operative EPOSA system could be transferred to a vehicle moving at highway speeds in real traffic. The first such test was conducted in February 2023. While it was overall successful in showing the data loop was possible via connected technology, specifically for C-ITS there were latency jumps at regular intervals. This was verified in a still test in May 2023, and the anomalous behaviour was pin-pointed to the software in the roadside unit (RSU) of the C-ITS system. The software in question had been developed by the company deploying the C-ITS rollout and revealed a trade-off that had been accepted. While a great asset of the chosen setup was that everything was tested in real operational environment, commercial milestones of the deployment contract did impose restrictions on implementation focus on anything outside of the deployment. The latency issue for the C-ITS RSU was analysed with the involved developers and put down to an imperfect implementation for the prototype.

This in mind, June 2023 saw a repeat of the tests in real environment which were successful in showing the complete path of trajectory changing messages and the included EGNSS RTK information both for connected and C-ITS transmission, both with EGNSS source data from EPOSA. The C-ITS issues remain at this point and will be addressed outside of the project.

SECTION 4: THE OPERATION PRINCIPLE

In this section, the operational principle of sending EGNSS RTK correction messages to obtain high position accuracy is presented.

When Cooperative Intelligent Transport Systems and Services (C-ITS) is used to deliver the EGNSS RTK correction messages, these are generated by an EGNSS RTK provider (in our case EPOSA) for the C-ITS roadside units (RSUs) requesting them according to their location. The RSUs broadcast these messages (with always slightly changing correction content due to athmospheric influences as well as orbit and clock errors of the satellites) once a second to allow the electronics onboard a passing vehicle to calibrate their positioning algorithms accordingly. Vehicles do not have to communicate directly with the EGNSS RTK provider, thus avoiding a lot of data traffic.

In terms of IT-modules, the EGNSS RTK information deployment is performed by an NTRIP caster, installed on the EGNSS RTK provider system, and an NTRIP client, installed on the RSUs.

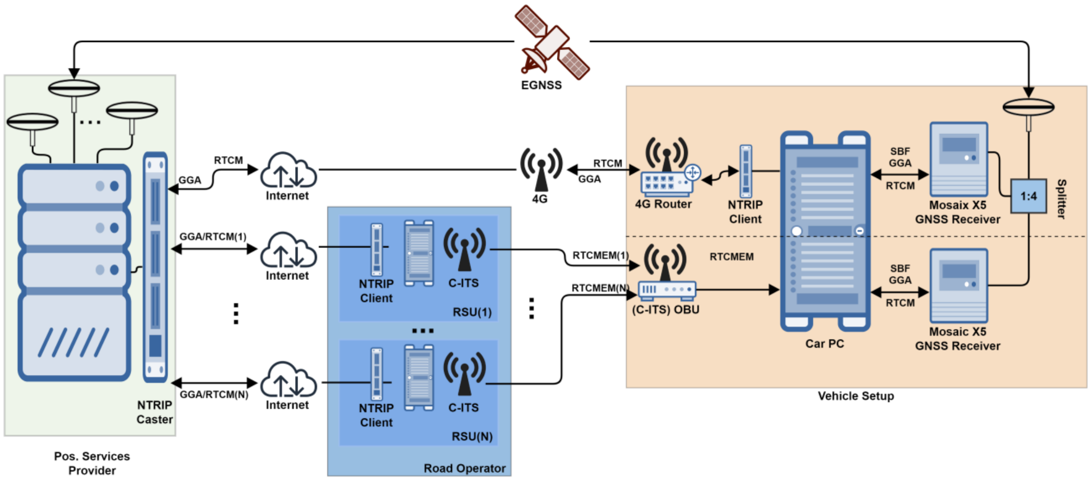

Figure 2: Schematic of the EGNSS RTK correction message flow to vehicle.

The NTRIP clients of the RSUs establish a connection with the NTRIP caster of the Position Services Provider, the EGNSS RTK provider (in our case EPOSA). In each connection, the RSU requests EGNSS RTK messages corresponding to its geographic location. The NTRIP caster responds with EGNSS RTK correction messages customized for the RSU's geographic position (strictly speaking virtual measurement data in case of RTK). The RSU then encapsulates the received RTCM messages into RTCM extended messages (RTCMEMs) and broadcasts them. The on-board unit (OBU) of a car passing the RSU receives the RTCMEM messages, converts them back into RTCM messages, hands them over to the internal GNSS receiver, which produces a highly accurate self position.

As vehicles move fast, great precision is needed for correct matching, and low latency in the transmission to process the current athmosperic influence. Automakers calculate with a requirement of 1 m precision and a latency of 1 s. A GNSS provider provides location accuracy of 1-3 m. With EGNSS RTK a Differential GNSS (D-GNSS) service, 1-10 cm accuracy is possible.

While the connected infrastructure is in the business domain of Mobile Network Operators, C-ITS can be operated and maintained by Road Operators, thereby enabling a prioritization of traffic related issues. C-ITS could also include the sending out of RTCM messages provided by an RTCM provider.

Each of the transmission technologies has its own characteristics regarding unwanted shielding and coverage gaps. Despite the intrinsic coverage advantage of 4G/LTE, tight maintenance control of C-ITS could make it more reliable for RTCM in the long run. On highways, transmission gaps between C-ITS road side units will be similar in size in a state-wide roll-out. If the loss of transmission in gaps of that size and their effect on localization accuracy is thoroughly investigated, a well known system behaviour could be established, perhaps more predictable than with 4G/LTE.

A viable deployment rollout was selected and the key link of the source data to the C-ITS network was realised in form of a prototype. The operational principle of this is explained, the actual prototype implementation is described, and the envisaged final deployment rollout is laid out.

SECTION 5: THE SOURCE OF THE EGNSS RTK CORRECTION DATA

In this section we present an actual operational setup that could be used in the case of a deployment decision for sending EGNSS RTK correction messages for vehicles with a C-ITS system in Austria.

The GNSS correction data in the form of RTCM messages is generated by EPOSA. EPOSA (Echtzeit Positionierung Austria, which translates to “real time position data for Austria”) is the technological leader in satellite-based positioning in Austria. They offer GNSS services for GNSS users to get coordinates accurate to the centimetre for the entire country as well as neighbouring regions. The following information is from EPOSA and can be found on EPOSA’s web page.

The EPOSA brand was founded in 2009. It consists of a group of large companies in Austria, which are leaders in their respective fields. Together they operate a nationwide GNSS reference station network. The correction data are available throughout Austria as well as approximately 80 kilometres beyond the national border. The group is coordinated by Wiener Netze GmbH, the biggest power supplier in Austria. TU Wien, the Technical University of Vienna, the biggest scientific research institution in Austria, is the group’s scientific partner and performs all technical development as well as continuous quality management. The other partners are Austria’s biggest transport company ÖBB Infra, Austria’s railway infrastructure company, which forms the base of EPOSA infrastructure with its telecom lines and railway stations, and Energie Burgenland, the power supply company of Burgenland, one of Austria’s nine counties, which was the first GNSS reference net provider in Austria.

Figure 3: EPOSA station overview.

EPOSA has its own base of over 40 reference stations and includes 9 external ones. Data are acquired from around 100 satellites on 11 signal frequencies. The high availability core servers are located at Wiener Netze and ÖBB Infra. All reference stations are equipped with antennas for Galileo, GPS, GLONASS, and Beidou. The communication network between the reference stations is owned by EPOSA.

EPOSA will update to the 2020ITRF correction base system in 2023, which brings it to the newest data base currently available.

SECTION 6: THE ENVISAGED TRANSMISSION NETWORK FOR THE EGNSS RTK CORRECTION DATA

In the course of ESRIUM, a rollout concept for EGNSS RTK correction data for vehicles was developed for Austria, using C-ITS for transmission and EPOSA as the data source.

The implementation for the Austrian national rail operator, which uses EPOSA in fully operational mode, served as a template. At any given time, approximately 700 locomotives are in service, each acting as a “rover”, who is in constant connection with the EPOSA central system and receives the current correction signals in a data stream.

For C-ITS on the highway network, this would translate to providing each of the approximately 525 C-ITS roadside units with a correction data stream in similar fashion, where the RSUs take over the role of (non-moving) rovers.

It is envisaged to optimize the system at a later stage by reducing the number of NTRIP connections to EPOSA by assigning “lead-RSUs” for every area, which distribute the correction data stream to the RSUs in their respective vicinity. Only the lead-RSUs would receive the RTCM correction signals, in this way the current scale may also sufficiently scale to include the secondary road system.

A business model was discussed with EPOSA which would technically consist of segmenting the system and providing a separate segment for the RTK provision via C-ITS in order to meet Network

Information Security standards. Fault ticketing could be connected to ASFINAG's Service Management. The out sourcing of entire technological entities is practiced by ASFINAG with its tolling and traffic management system and will therefore not pose unknown challenges. Because of the replication of an existing system the required implementation cost is expected to be affordable. For operational costs for an Austrian-wide rollout, several 100,000 EUR are anticipated, strongly dependant on the required SIL and certification level. However, it has to be stressed, that this would only make sense, if this kind of RTK transmission is utilized by the automotive industry.

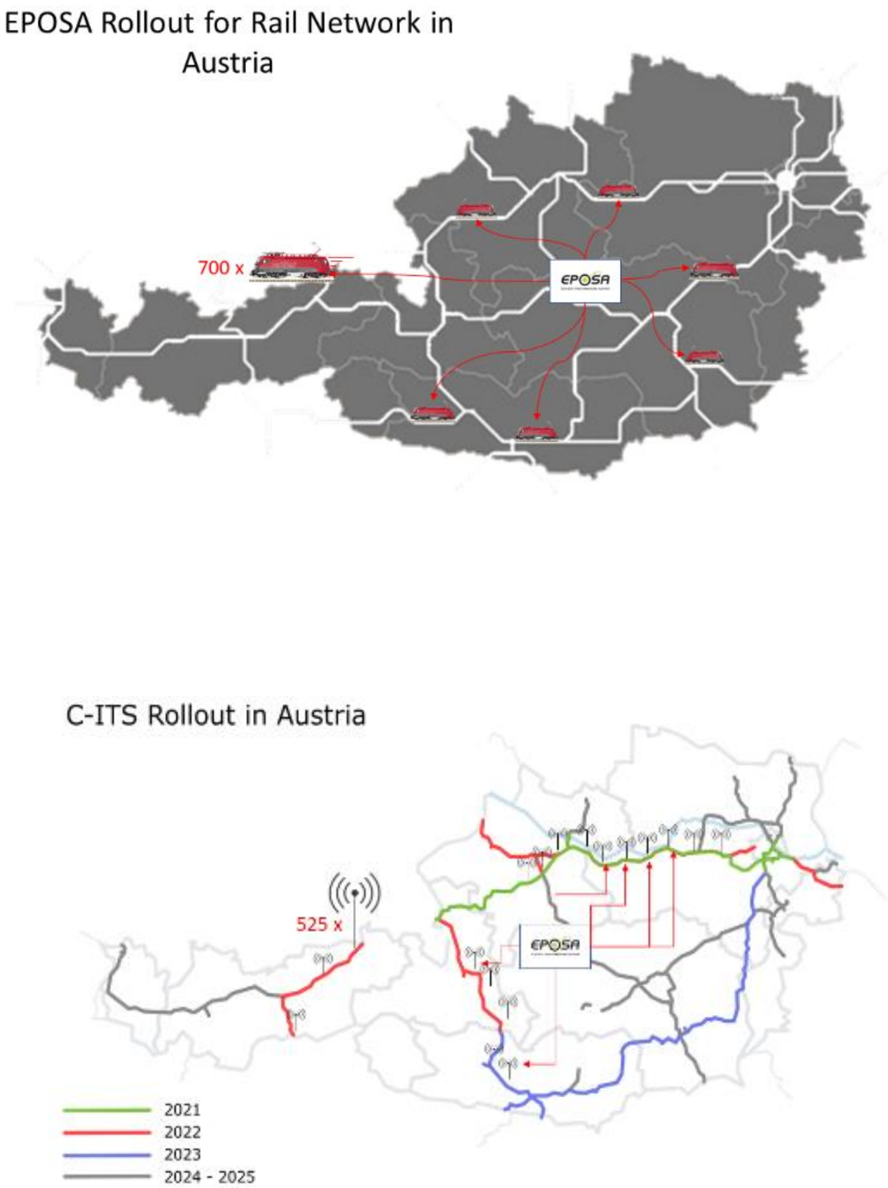

Figure 4: EPOSA connection to railway locomotives and to C-ITS base stations extensions using EGNSS.

SECTION 7: RESULTS

The overall result is that the generic concept of transmitting EGNSS RTK correction data via C-ITS works as concerns the provision of the data, the transmission of the data and the reception and processing of the data in the vehicle. There has not been a large scale test and the effect of coverage gaps has not been tested.

Achieved localization accuracy

Presenting the results, we have distinguished between the observed prototype performance and the determined achievable performance in an operative deployment when optimizations are applied.

The observed **prototype position accuracy** in the vehicle using EGNSS RTK over C-ITS was **10 cm.**

The **projected achievable operative position accuracy** in the vehicle using EGNSS RTK over C-ITS was determined to not be able to exceed that, so also **10 cm**.

This compares to 300 cm (3 m) using EGNSS without RTK.

It also compares to 2 cm theoretically achievable with the EGNSS RTK prototype source EPOSA.

A maximum error of 10 cm in 99.4% of cases is deemed **sufficient for Automated Driving** by project partner Virtual Vehicle, who have provided the automated car functions for the project.

The source used for the correction data was EPOSA, an Austrian private public partnership already supplying the Austrian Rail Network, with an accuracy benchmark of 2 cm.

In the following graphic, location accuracy is plotted against the movement of the vehicle along the track.

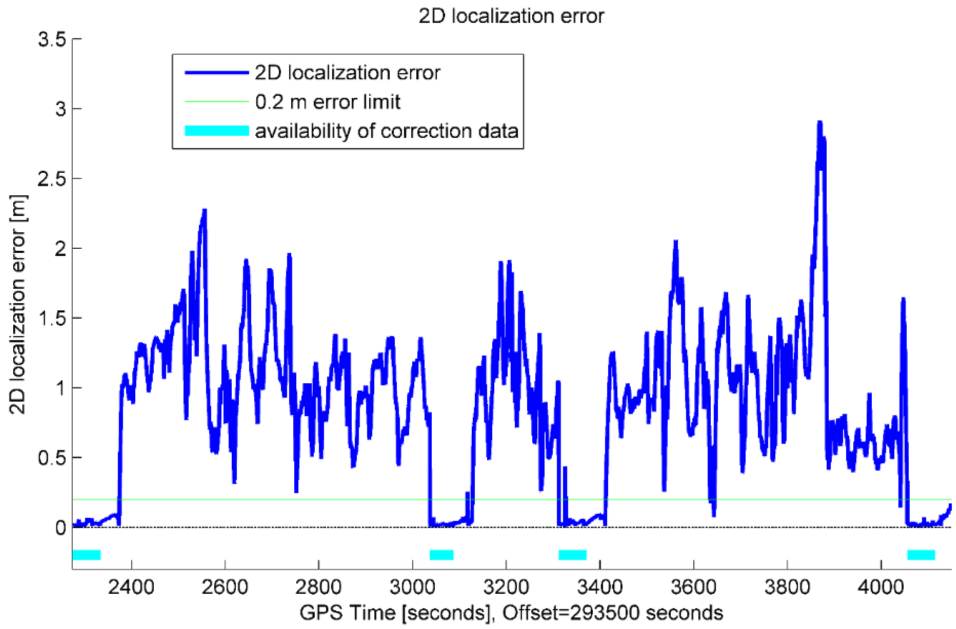

Figure 5: Localization accuracy along the track.

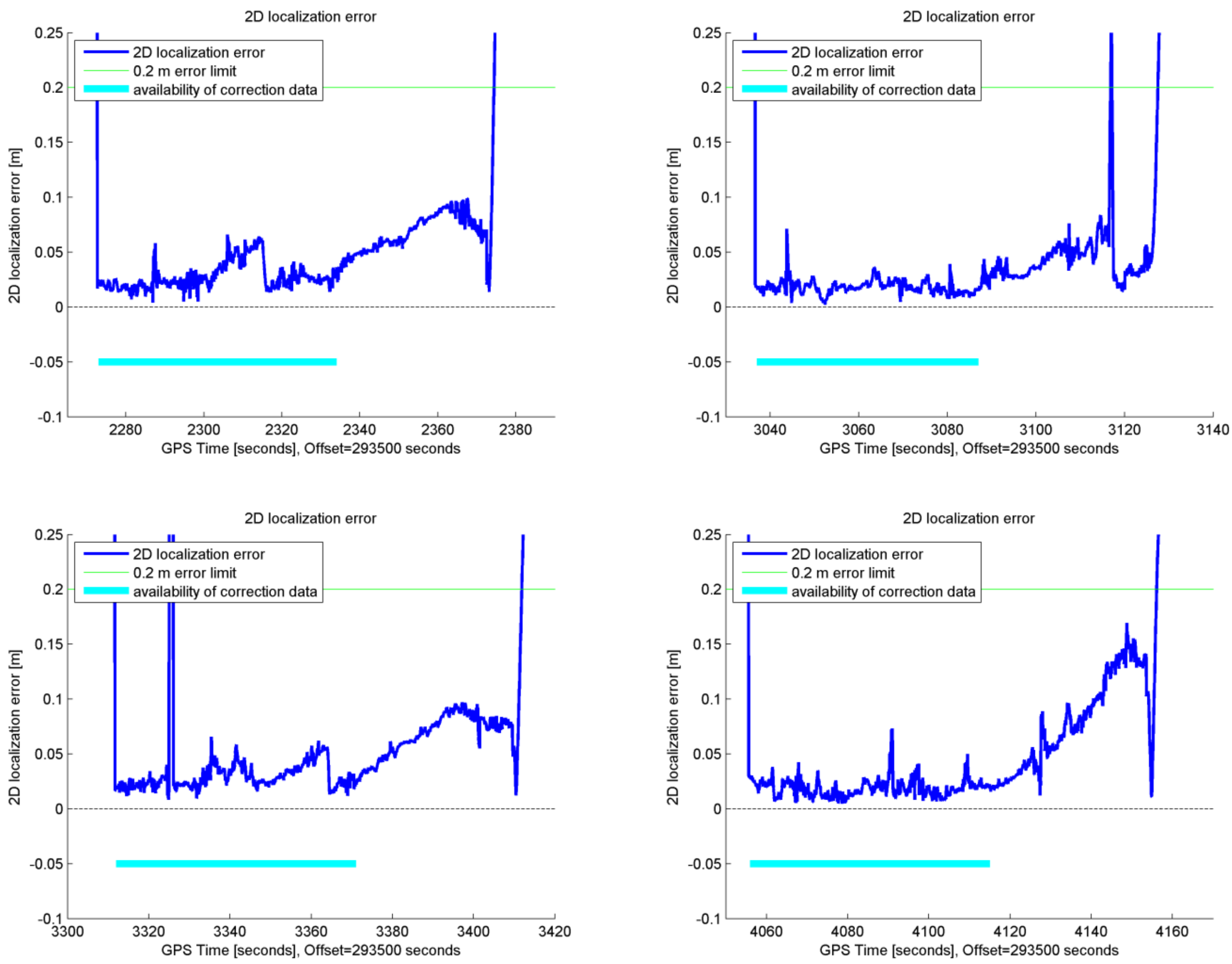

Figure 6: Detailed look on the observed localization accuracy along the track.

The targeted accuracy is clearly reached where EGNSS RTK correction data is available. As soon as the correction data becomes unavailable, the localization errors spike after a few seconds. While the mean increases only slowly, the average deviation is so high, that it would be difficult to confidently determine the lane the vehicle is driving on.

<u>Test Coverage</u>

The prototype has demonstrated the complete ESRIUM Use Case 3 (EUC-003), titled "C-ITS Message ‘GNSS-correction data’ provision".

<u>Resilience</u>

A difference in transmission latency from the RTK source to the car between 1 and 3 seconds does not have a significant impact.

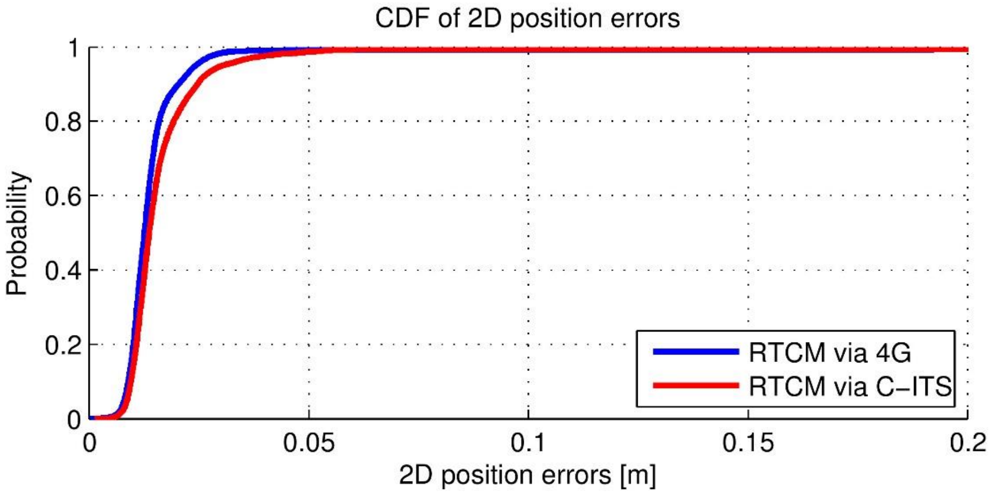

Figure 7: Localization accuracy gain caused by EGNSS RTK signals from 4G versus from C-ITS.

Emphasis from a road operator's point of view was placed on proving the ESRIUM solution is possible in actually deployed infrastructure. This meant implementing the software in the road side units, which relays the RTK messages from the RTK source to the moving vehicles, was implemented as a wrapper rather than an embedded solution, as this would have interfered with contractual deployment milestones. This resulted in a pulsating transmission characteristic as opposed to a precisely timed process. Therefore measured latency cannot be assumed as final for the solution which would eventually be deployed. But this did not compromise the system functionality, on the contrary, it allowed for the additional testing of the vehicle client in case of uncharacteristic transmission behaviour, which was successful.

The measurements showed that although latency values typically varied between 0.5 and 2.5 seconds and varied between the C-ITS and the 4G transmission, this did not have a significant impact on the achieved localization accuracy:

Solution	***95 %***	***99.5 %***	***≤ 10 cm***	***≤ 20 cm***
4G	*2.4 cm*	*37.9 cm*	*99.2 %*	*99.3 %*
C-ITS	*3.1 cm*	*43.4 cm*	*99.4 %*	*99.4 %*

Table 1: Moderate latency increases do not impact localization accuracy.

Details of the measurements are provided in the ESRIUM Deliverable D5.3 "Test results analysis report".

Error accumulation

Error accumulation can come from either geolocation imprecision or latency of correction data during the transmission EPOSA to vehicle. Geolocation imprecision should be negligible in the prototype as the transmitting roadside unit whose geolocation was used for the correction data was very close to the vehicle. In an operative deployment this may not hold true as several roadside units may be grouped together to receive a single correction. On the other hand, the measured latency of 1.5 seconds in the prototype was determined to be reducable to about 0.5 seconds with optimized implementation, as indicated by parallel transmission and measurement over 4G/LTE, which would make an error because of latency negligible. Both assumptions have not yet been scientifically verified.

Observations

The localization accuracy gain shows a steep drop off for confidence of 99.5% and higher, suggesting a limit which cannot be overcome with this technology (Figure 6).

On the other hand there is a striking resilience against moderate latency increases in the transmission of the correction signal. Mean latency for 4G was around 1 s, whereas for C-ITS it was around 3 s. Still results are very nearly the same (Figure 6).

The transmission of EGNSS RTK data via ITS G5 (also known as 802.p11) showed anomalies which could not be resolved at the submission of this report. The software in the road side units which relays the RTK messages from the RTK source to the moving vehicles was implemented as a wrapper rather than integrating it into the software core. This resulted in a pulsating transmission characteristic as opposed to a precisely timed process. Still this did not compromise the precision and also allowed for testing of the vehicle client in the case of uncharacteristic transmission behaviour, which was successful.

Though the anomalies are not considered to be stoppers in operation, they should nevertheless be fixed for a deployment in scale. Further investigation should include a large scale test and focus on the effect of gaps in transmission coverage. To this end, a demonstration for the Austrian Ministry for Climate and Transport will be performed in Nov 2023 as a repetition of the relevant ESRIUM tests and the next steps will be decided thereafter.

Use in automated driving

Finally, the usage of the concept. Automated driving sets the highest requirements for accurate and reliable positioning and can serve as a benchmark for all other traffic information transmission use cases in this respect. The ESRIUM Extension of C-ITS with EGNSS RTK positioning correction data was used in combination with C-ITS recommendations for changing the lateral position of a car driving automatically. In the plot below, the car was driving at a speed of 130 kph and can be seen (blue “actual” line) to follow the C-ITS recommendations (red “CITS offset” line) closely, with no human interactions.

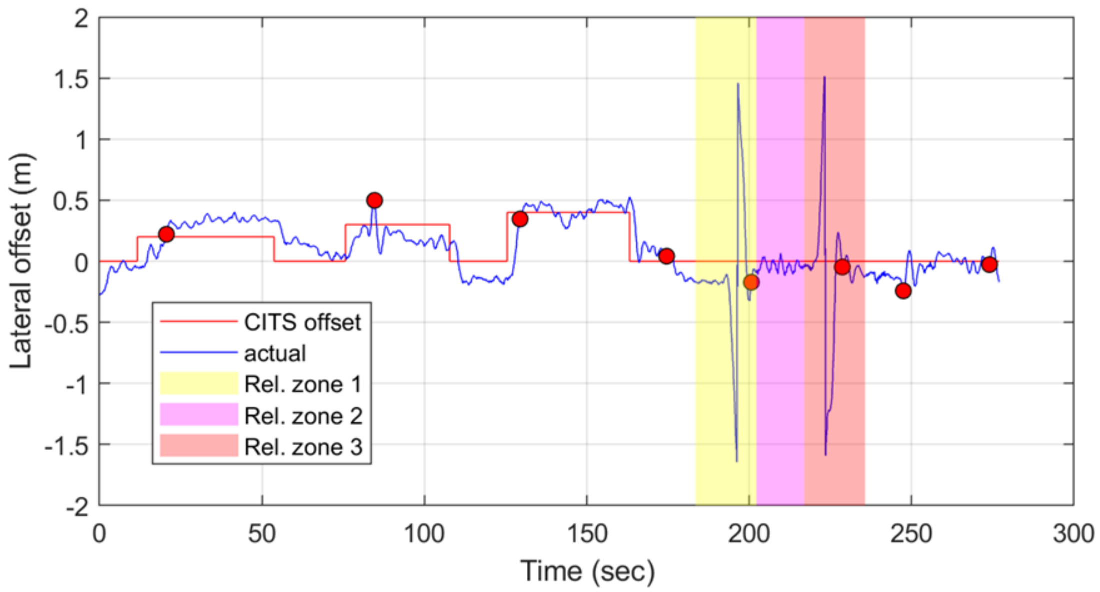

Figure 8: Automated car reacting to C-ITS recommendations using ESRIUM EGNSS RTK.

Details of the test drives are provided in the ESRIUM Deliverable D5.3 “Test results analysis report”. A larger scale test should follow by performing the same tests on the complete A2 highway.

SECTION 8: STANDARDIZATION

For an ecosystem like EGNSS provision for automotive traffic to gain traction throughout Europe, standardization of transmission protocols for the involved interfaces is essential. This will enable all stakeholders, infrastructure providers and clients alike, to setup their parts of the transmission data loop autonomously and avoid lengthy bilateral development efforts.

For the infrastructure part of the ESRIUM prototype, ASFINAG ensured that all interfaces had a viable path to international standardization.

<u>RTK transmission</u>

The interface from the RTK source EPOSA to the RTK recipients the RSUs is standardized according to NTRIP Version 3.1.

The interface from the RSUs to the vehicles is standardized according to ETSI 103 246-2 and ETSI TS 103 301 (RTCMEM).

<u>Data fields for influencing vehicle trajectories</u>

For in-lane offset recommendations the prototype used proprietary fields. The fields for actual future operation were identified, formulated and submitted to the standardization committee as ISO/TS 19321 TC 204 DRAFT.

For track change recommendations the prototype also used proprietary fields. In actual future operation no new fields are required, just an enhancement of an existing catalogue of values in an existing data field in ISO/TS 14823. This would be submitted when the decision for actual operation is taken.

SECTION 9: THE ESRIUM TRANSMISSION PROTOTYPE

In this section the prototype for the demonstration of the extended C-ITS use cases is presented.

9.1. General

In order to demonstrate EGNSS correction data delivery via C-ITS, RTCM messages are sent in regular intervals to the vehicles to re-calibrate their positioning and IVIM messages were sent to communicate required changes in trajectory, like evading an assumed obstacle by changing the lane or moving a few centimetres to the left or the rigt in order to reduce road wear.

The following key assumptions and use-case specific requirements applied to the protoype.

1. C-ITS recommendations in the form of an IVI message (for lane choice and lane offset information) leading to guidance within and in-between lanes are available.
2. C-ITS communication infrastructure and RSUs (RoadSide Units) are available.
3. EGNSS receiver and a localization solution in the end-user vehicle is available.
4. The end-user vehicle, which is an automated demonstrator vehicle (from VIF) with adaptable driving functions and is capable of receiving and interpreting IVI messages with an integrated OBU (on-board unit) for triggering the recommended vehicle actions, is available.
5. A conventional end-user vehicle (only for Scenario-4, i.e., EUC-002-SC4) with an integrated OBU and a HMI for displaying the infrastructure recommendations is available.

Messages are broadcast with a default of 2 Hz rate (but can be made faster if necessary). The transmission range is minimum 400 meters but up to 2000 meters was measured (depending on the site).

Messages are signed according to TS 103 097 and the European Certificate Policy. The ECTL level will be level 0.

9.2. RTCMEM

RTCMEM were broadcast according to TS 103 301 V2.1.1 and EN 320 890-2 V2.1.1.
(Clause 7.2.2 Table 5):
https://www.etsi.org/deliver/etsi_en/302800_302899/30289002/02.01.01_60/en_30289002v020101p.pdf

9.3. IVIM

IVIM was broadcast according to TS 103 301 V2.1.1 and ISO 19321: 2020. The ASN.1 module is available here:

https://standards.iso.org/iso/ts/19321/ed-2/en/ISO19321IVIv2.asn

Lane Change use case

The lane change recommendation was broadcast using the following pictograms identified by their GDD ISO 14823 code

<table>
<tr><th>ISO 14823 code</th><th>Meaning (lane recommendation)</th><th>Pictogram</th><td rowspan="5">The pictograms code was broadcast in the automated vehicle container in the following component: IviStructure.optional.avc.AvcPart.automatedVehicleRules.road SignCodes.code. iso14823</td></tr>
<tr><td>13 660</td><td>Lane Free</td><td></td></tr>
<tr><td>13 661</td><td>Clear lane to left</td><td></td></tr>
<tr><td>13 662</td><td>Clear lane to right (optional, not sure if needed)</td><td></td></tr>
<tr><td>13 659</td><td>(Lane closed, optional not sure if needed)</td><td></td></tr>
</table>

Table 2: IVIM lane change use case GDD codes.

The IVIM contained four zones in its GeographicLocationContainer: one detection zone and three consecutive relevance zones as depicted below:

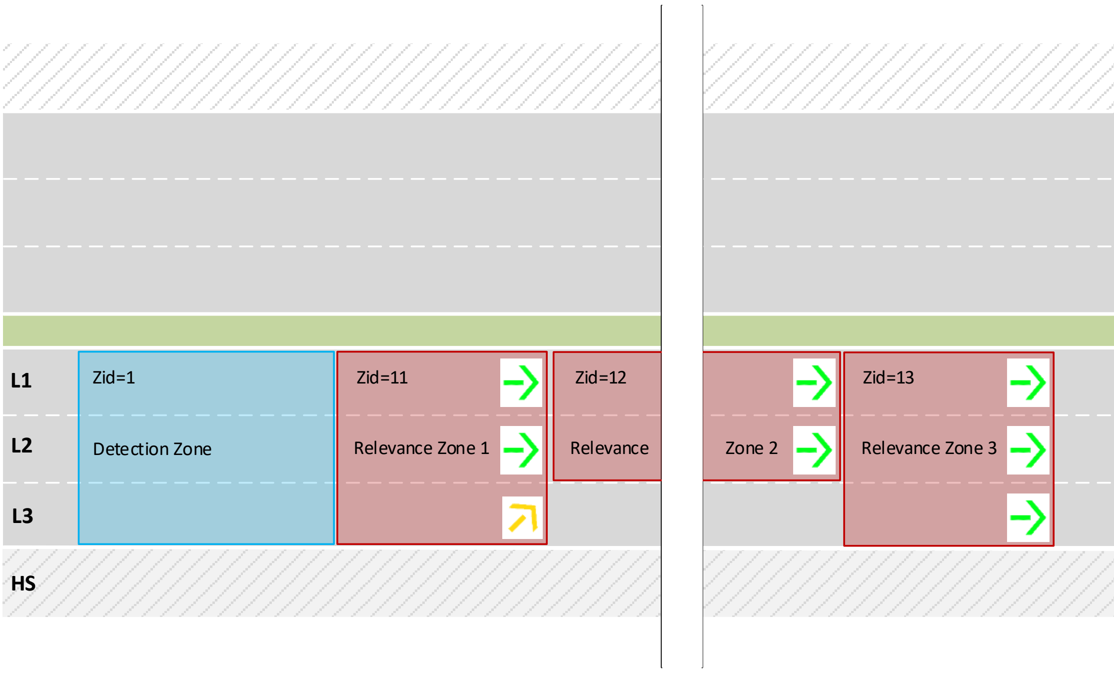

Figure 9: IVIM lane change use case.

Note: in the figure above the arrows are shown in direction of traffic from "birds eye" and not from "drivers view". Relevance zone 1 and 2 also serve as the detection zone for relevance zone 2 and 3 respectively.

Each lane recommendation was coded as one AvcPart:

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 3: IVIM lane change use case AvcParts.

Lane offset use case

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

The free text contained the "+" or "-"symbol followed by the offset in centimeters.

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

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

The IVIM contained one detection zone and one relevance zone as depicted below:

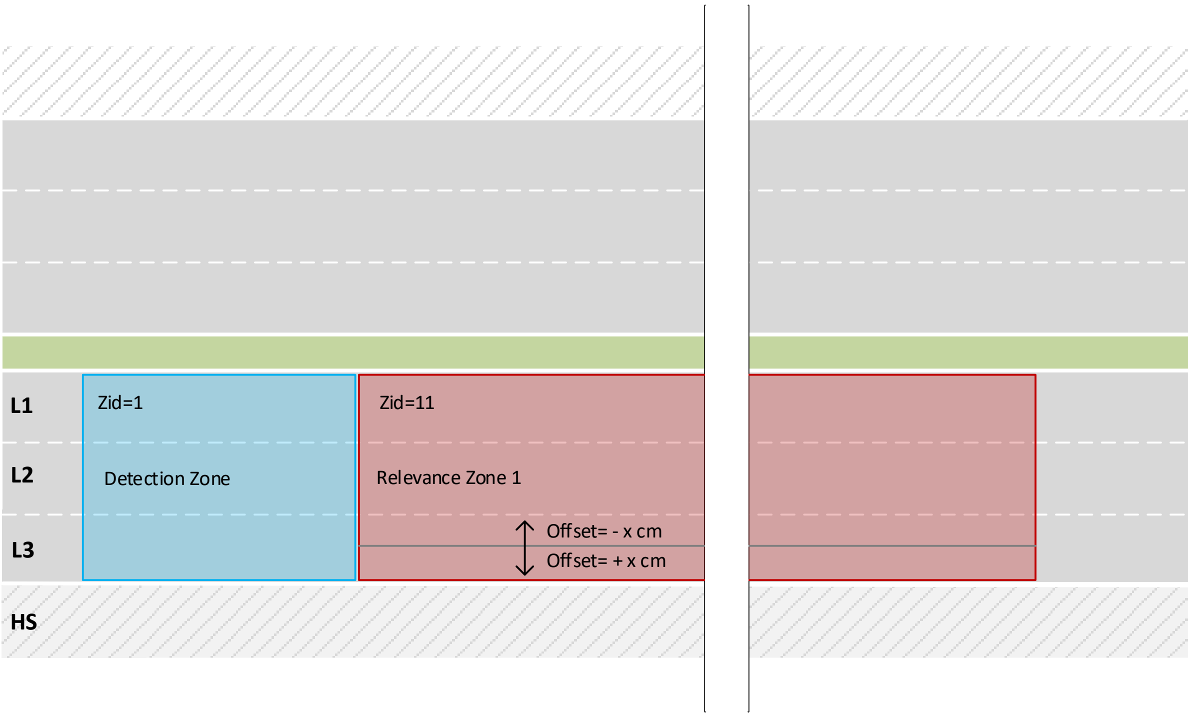

Figure 10: IVIM lane offset use case.

The lane offset recommendation was coded as one AvcPart per lane, 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 4: IVIM lane offset use case AvcParts.

9.4. Test environment conditions

All tests were performed preferably under ideal operational conditions as described below:

1. Dry road conditions.
2. Daylight conditions.
3. No significant wind conditions (ideally less than 10 km/h).
4. No rain, fog, hail, snow and icy conditions.

9.5. Test tracks

The tests were conducted on the ALP.Lab Test-site (for Scenarios-1 and Scenario-2, that is EUC-002-SC1 and EUC-002-SC2), and the test site for the Scenario-3 (EUC-002-SC3) has to be a closed proving ground. The tests for the Scenario-4 (EUC-002-SC4) were conducted respectively on the DigiTrans Test-site.

The ALP.Lab Test-site is located in the Graz region, on the motorway A2 between Graz West and Lassnitzhöhe. More than 20 km of the motorway segment are equipped with the state-of-the-art and innovative sensors and communication equipment.

The ALP.Lab Test-site is equipped with gantries in 12 positions. Most of the special sensory equipment is mounted on these gantries. 12 roadside units are mounted on already existing gantries on the ASFINAG Network.

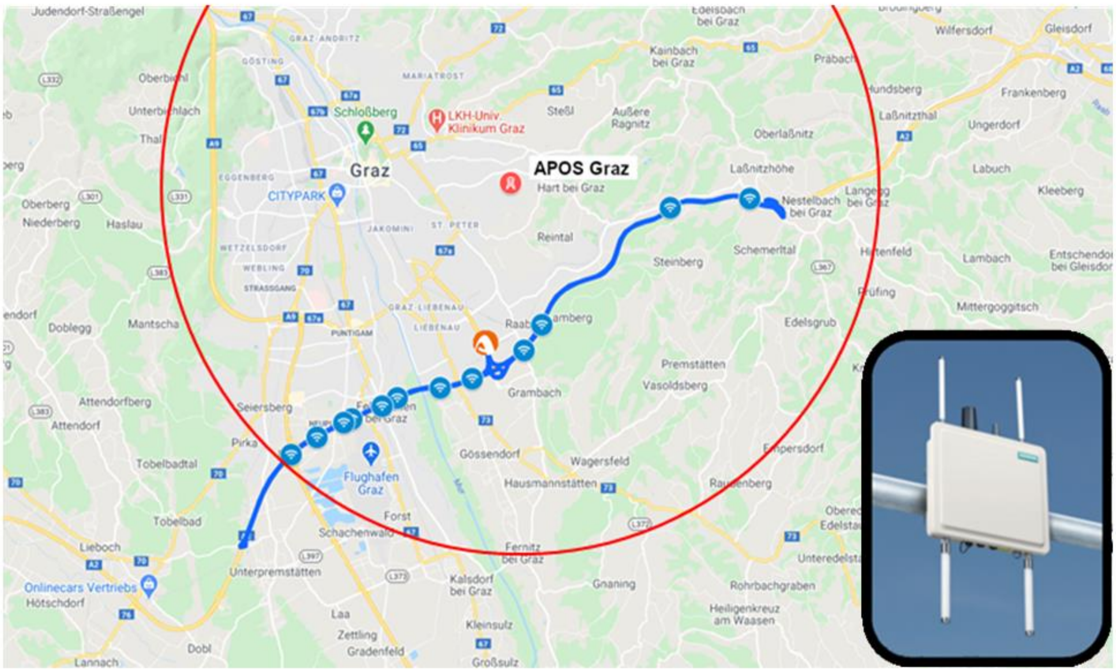

Figure 11: ALP.Lab Test-site illustrated along the Austrian A2 motorway.

Along a stretch of about 1.5 km, traffic data sensor sets have been installed. They cover both driving directions and each of the lanes. In 29 positions, sensory equipment for weather and environmental data is installed. 26 cameras with automatic incident detection are located on the Austrian test site in both driving directions.

In the southern part of the test track radar sensors are installed covering a stretch of around 1.5 km with high resolution. The radar equipment is currently being upgraded in order to support the creation of collective perception messages (CPM) within the next months.

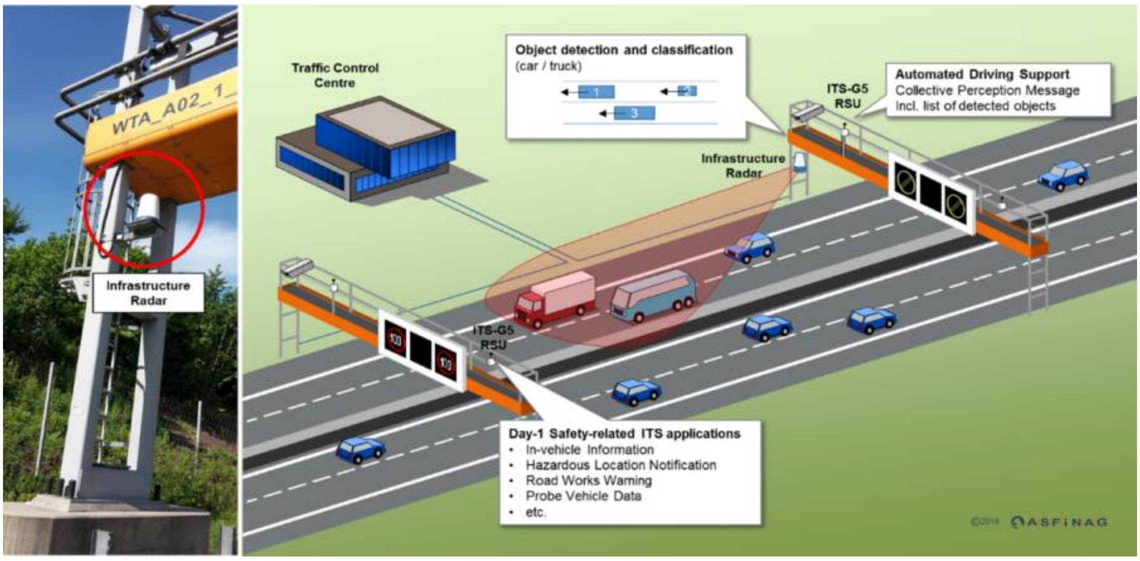

Figure 12: Infrastructure equipped with radar sensors.

SECTION 10: ENHANCEMENTS OF C-ITS BY EGNSS AS USE CASE SCENARIOS

Each of these scenarios were tested under different parameter configurations such as different offset values, vehicle velocities and under randomized traffic conditions.

10.1. Use Case Scenario-1 (EUC-002-SC1): In-lane offset recommendations

In this scenario, the test was carried out on the ALP.Lab Test-track. According to the scenario, the subject vehicle (SV), drove in automated mode (SAE Level-3 equivalent Motorway Chauffeur combining ACC and LKA driving functions) in a detection zone when it received an IVI message containing a recommended lane-offset information (see Figure 13). Here detection zone refers to the region at which the vehicle must receive the routing recommendations, which need to be conducted in the relevance zone. The C-ITS routing recommendations in the form of IVIM come from an infrastructure RSU and are received by an OBU on the SV, which are then interpreted by the linked automated driving functions. The IVIM also includes the geo-locations of the detection and relevance zones corresponding to the routing recommendation. Before entering the relevance zone (this is the zone, where the recommended action by the IVIM needs to be implemented), the SV adapts the typical LKA task of tracking the center of the existing lane and transitions to driving along the same lane with the given in-lane offset. The SV is expected to drive throughout the relevance zone with the recommended in-lane offset in case traffic conditions permit it. Immediately after leaving the relevance zone the SV is expected to follow the default centerline tracking task unless otherwise recommended.

The vehicle speed was between 80km/h and 130km/h.

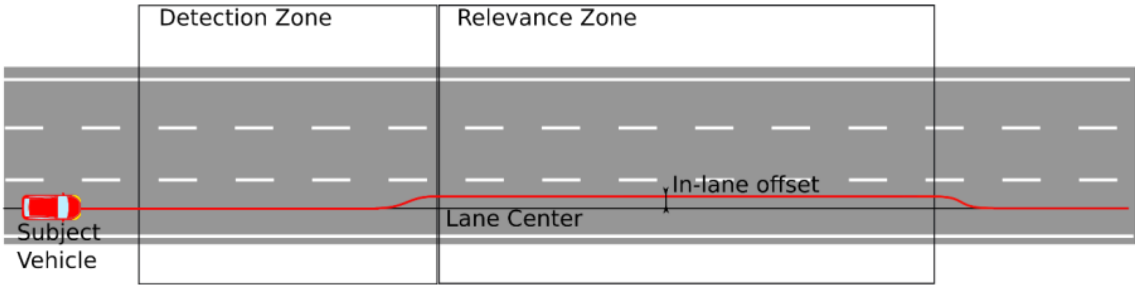

Figure 13: In-lane offset recommendation scenario description for Scenario-1 (EUC-002-SC1).

The lane offset recommendation was broadcast using the free text option in the automated vehicle container of the existing IVI message standard according to TS 103 301 V2.1.1 and ISO 19321: 2020:

- The free text contains the "+" or "-"symbol followed by the offset in centimeters.
- "+" indicates an offset to the right of the lane center.
- "-"indicates an offset to the left of the lane center.

In this scenario the driver steers the SV to the rightmost lane and activates the automated driving mode. Within the detection zone the SV gets via IVIM the routing recommendation in the relevance zone with a pre-defined offset. It will not leave the rightmost lane while driving along the relevance zone with the defined offset from the lane center in automated mode. After leaving the relevance zone the SV will steer back to the center of the lane and on the HMI the information that the test was finished will be displayed.

10.2. Use Case Scenario-2 (EUC-002-SC2): Lane change recommendations

In this scenario, the test was be carried out on the ALP.Lab Test-track. According to the scenario, the SV shall drive in automated mode (SAE Level-3 equivalent Motorway Chauffeur combining ACC and LKA driving functions) in a detection zone when it receives an IVIM containing a set of three relevance zones with instructions to change the lane. The lane change recommendation is broadcast using the following pictograms:

ISO 14823 code	***Meaning (lane recommendation)***	***Pictogram***
13 660	*Lane Free*	
- *(Custom)*	*Clear lane to left*	

Table 5: Used pictograms and codes.

The pictograms codes were broadcast in the automated vehicle container of the IVIM. For this specific IVIM, the message contains four zones in its "Geographic Location" container; one detection zone and three consecutive relevance zones as depicted in Figure 14:

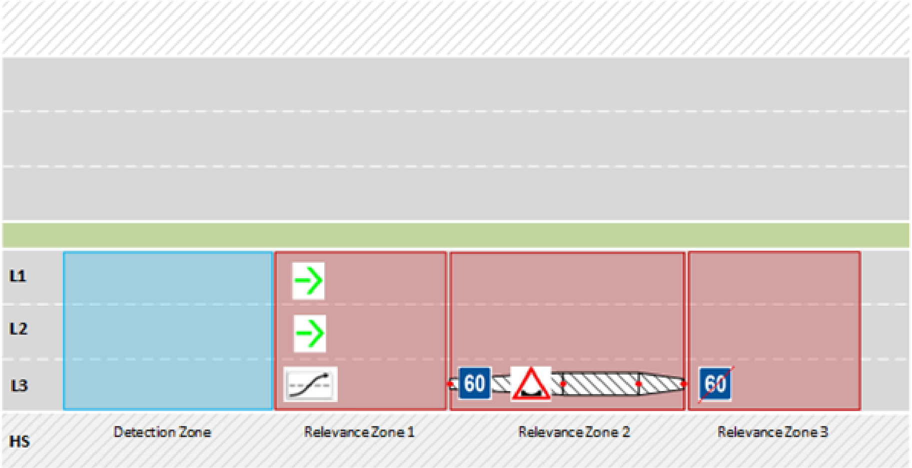

Figure 14: Lane Change recommendation scenario description for Scenario-2 (EUC-002-SC2) and Scenario-4 (EUC-002-SC4).

Note: In Figure 14 the arrows are shown in direction of traffic from "birds' eye view" and not from "drivers' view".

Note: Relevance zone 1 and 2 also serve as the detection zone for relevance zone 2 and 3 respectively.

Table 6 shows the mapping of the pictograms to the detection zones and relevance zones and to the different lanes.

Detection Zone IDs	***Relevance Zone IDs***	***Applicable Lanes***	***ISO 14823 Pictogram code***
1	*11*	*1, 2*	*13 660*
1	*11*	*3*	*custom (clear lane to the left)*
11	*12*	*1, 2*	*13 660*
12	*13*	*1, 2, 3*	*13 660*

Table 6: Pictogram code for the different relevance zones and lanes.

In this scenario the SV initially drives along the road until it enters the detection zone. In the detection zone, SV receives the IVIM with the above-described information describing the route choice recommendation in the following relevance zones. In the first relevance zone the SV is asked to change to the left lane. Afterwards, during the whole relevance zone 2 the SV is informed to keep to this lane, and therefore should not change to the right lane. In the relevance zone 3 the SV is requested to change to the rightmost lane, depending on the traffic conditions.

During the course of the scenario, the driver is responsible for the safe execution of the lane changes.

10.3. Use Case Scenario-3 (EUC-002-SC3): EGNSS-based local lane recommendations

In this scenario, the test was carried out at the ÖAMTC (Österreichischer Automobil-, Motorrad- und Touring Club) Fahrtechnikzentrum in Lang/Lebring, which is located about 30 km south of Graz, Austria (see Figure 15). This test track is also part of the Alp.Lab test region. The FT4 section of the proving ground, shown in the figure with a virtual lane overlay, is to be utilized as the test track for the demonstration of this scenario. The FT4 features a straight road section with an approximate usable length of 250 m and width of at least 10 m, allowing modelling of 3 virtual lanes with a width of 3.5m each along the track.

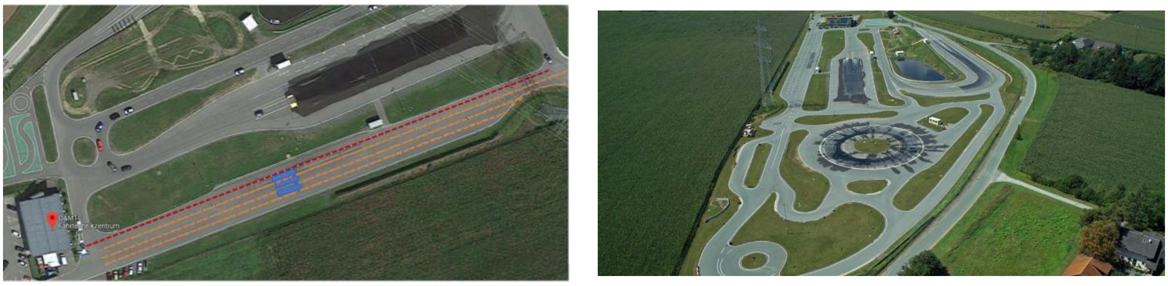

Figure 15: [ÖAMTC Lang/Lebring]() Test Track and FT-4 section to be utilized for the demonstration of Scenario-3 (EUC-002-SC3).

According to the scenario, the SV shall drive in automated mode (SAE Level-3 equivalent Motorway Chauffeur combining ACC and LKA driving functions) along the test track to follow the speed and the trajectory reference as defined from the infrastructure. The reason why this scenario will not be demonstrated on the A2 motorway is the fact that testing of such a driving function on public roads, based only on the EGNSS location information, is not permitted according to the Austrian government's directive on testing of automated functions.
In this scenario no RSU shall be utilized, and rather the C-ITS communication will be emulated with the parsed route recommendation information in the form of a pre-defined reference path. Normally, such a routing recommendation based on C-ITS should be coming from an RSU utilizing a MAPEM message, which would then be received by the OBU and parsed accordingly for utilization in the automated driving functions on the SV for trajectory following purposes. The process flow for the Scenario-3 demonstrations is shown in Figure 16.

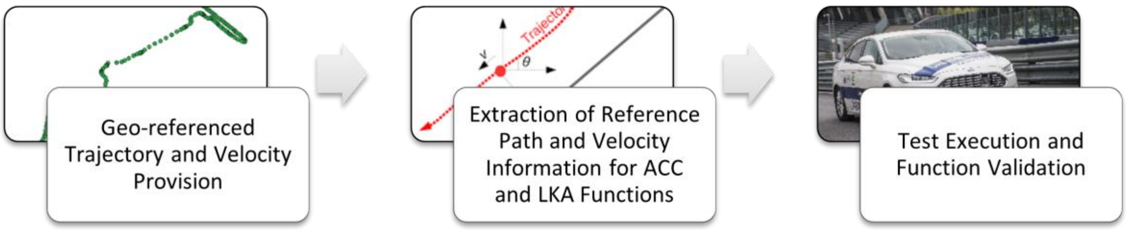

Figure 16: Process flow for EGNSS-based local lane recommendation demonstration for the Scenario-3 (EUC-002-SC3).

10.4. Use Case Scenario-4 (EUC-002-SC4): Lane change recommendations – manually driven

This scenario is very similar to Scenario-2 (EUC-002-SC2), except that the test vehicle is not driven by an automated driving function but by a human driver. In this scenario, the test shall be carried out at the DigiTrans test track (Upper Austria area).

According to the scenario, the test vehicle shall be driven in a detection zone when it receives an IVI message containing a set of three relevance zones with recommendation to avoid the rightmost lane because of a minor road damage. In relevance zone 1, the driver is informed via a HMI that he shall change the lane to the left, if the vehicle is driving an the rightmost lane. The driver must decide if he can safely follow this recommendation, according to the traffic situation. Afterwards, during the whole relevance zone 2, the driver is informed to keep to this lane, and therefore should not change to the right lane. And in relevance zone 3 he is informed that he can safely change back to the rightmost lane, if traffic allows it.

SECTION 11: CONCLUSION

The ESRIUM use case 3, the provision of GNSS-correction data provision with C-ITS messages, was implemented in Austria by a prototype consisting of a highway track with C-ITS infrastructure connected to a commercial EGNSS RTK provider and an automated vehicle. It was demonstrated that the generic concept of transmitting EGNSS RTK correction data via C-ITS works as concerns the provision of the data, the transmission of the data, and the reception and processing of the data in the vehicle. The location accuracy that is achieved in the vehicle is 10 cm and judged to be sufficient for automated driving. An Austrian-wide rollout would require annual maintenance costs anticipated at several 100,000 EUR, heavily dependant on the required Safety Integrity Level (SIL) and certification level.

It was shown that all needed transmission formats from the EGNSS RTK source to the transmission point are already - or are in the process of being – internationally standardized, are therefore readily implementable and that, in Austria at least, an EGNSS RTK source is commercially available. The prototype was implemented on EGNSS RTK correction infrastructure currently in operation on the entire Austrian rail network and C-ITS infrastructure currently being deployed on the entire Austrian highway network, which adds to the confidence in this result, though some observations appeared which could not be resolved within the scope of the project.

The major takeaway from this project is that docking onto current roll-out infrastructure works and leads to the discussion of relevant issues. The ESRIUM EU project has successfully connected the dots and enabled the involvement of the relevant infrastructure stakeholders.

The observed **prototype position accuracy** in the vehicle using EGNSS RTK over C-ITS was **10 cm.** The **projected achievable operative position accuracy** in the vehicle using EGNSS RTK over C-ITS was determined to not be able to exceed that, so also **10 cm**. This compares to 300 cm (3 m) using EGNSS without RTK. It also compares to 2 cm theoretically achievable with the EGNSS RTK prototype source EPOSA. A maximum error of 10 cm in 99.4% of cases is deemed **sufficient for Automated Driving** by project partner Virtual Vehicle, who have provided the automated car functions for the project.

Technically, the key findings are a precise plotting of the correspondence of localization accuracy in the vehicle with the availability of the EGNSS RTK data via C-ITS and the demonstrated usage of this accuracy for automated driving.

The software solution in the road side units was implemented as a wrapper rather than an embedded solution, in order to test the ESRIUM solution directly on the current C-ITS roll-out in Austria. The resulting slight latency rise allowed the testing of uncharacteristic behaviour and it was established that the achieved localization accuracy is resilient against transmission latencies and holds up for some time after signal loss. The concept could therefore also be envisaged for C-ITS rollouts with transmission gaps between road side units. There has not been a large scale test and the effect of coverage gaps has not been tested.

As a next step, a further investigation should include a large scale test and focus on the effect of gaps in transmission coverage. This will be decided following an ESRIUM presentation for the Austrian Ministry for Climate and Transport in November of 2023.