C-Roads & C2C CC: C-ITS & CCAM – The data layer for sharing experiences in validation

C-Roads Platform

CAR 2 CAR Communication Consortium

Version 1.0
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About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). The Consortium members represent worldwide major vehicle manufactures, equipment suppliers and research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the CAR 2 CAR Communication Consortium and its members work in close cooperation with the European and international standardisation organisations.

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Scope

In the context of Cooperative Connected and Automated Mobility (CCAM) currently we are experiencing in Europe the introduction of C-ITS or cooperative systems into the mass market with road infrastructure operators and authorities investing in the road side stations and mobile trailers roll-out, and vehicle manufacturers inserting series vehicles equipped with C-ITS units into the market.

The basic element of cooperative systems is the data exchange in form of standardized messages between road infrastructures and vehicles in order to enhance road safety and driving comfort. In this market introduction phase with the involvement of many stakeholders the testing and validation of the data exchange between all partners involved plays the central role to enhance the overall quality of the C-ITS services.

This document describes the way data exchange was defined, organised and performed in a connected vehicle environment based on open standards and specifications in the C-ITS domain by the partners of the C-Roads platform, but also by external parties and members of the C2C CC in order to validate C-ITS day one applications in various member states in Europe.

It summarizes the experience gained and recommends procedures and process steps for the validation of future applications in the CCAM area.

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1 Executive summary:

This white paper related to data exchange in the connected vehicle domain is based on an extensive Test- and Validation experience in the European C-Roads project with x-test sessions performed in Q1 and Q2 of 2021 and in 2022 in ten countries and with the participation of external stakeholders and members of the C2C Communication Consortium from automotive and ITS service industry.

These partners from public authorities and industry have worked together and defined, agreed and used a process for data exchange based on openly available C-ITS specifications of basic messages available in C-Roads and shared the generated data messages for day 1 C-ITS applications in advance of the test sessions for analysis in different C-ITS stations involved in the testing and validation activity.

The testing and validation experience was considered very valuable by the partners and contributed to fast progress of information and data quality aspects in the shared C-ITS data sets and the basic C-ITS services.

Based on the gained experience and on several additional reasons of partners involved they intend to use this data exchange procedure also in the future in the context of C-ITS developments and extensions of services to other areas but also in the introduction phase of day 1.5 or possibly day 2 C-ITS services.

Partners involved in this testing and validation of C-ITS services are aware that there exist interesting options to extend this defined and mature process to other areas in the context of connected and automated mobility – e.g. like in the area of certification of services, or functional development of C-ITS applications, and these will for sure be explored soon and taken up by stakeholders interested in extensive and fast deployment of CCAM.

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Acronyms

BSP	Basic System Profile
C-ITS	Cooperative Intelligent Transport Systems
CAM	Cooperative Awareness Message
C2C CC	Car 2 Car Communication Consortium
CRW	Collision Risk Warning
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communications
ITS	Intelligent Transport Systems
ITS-G5	ITS-G5 is a European standard for ad-hoc short-range communication of vehicles among each other (V2V) and with Road ITS Stations (V2I). In this document, ITS-G5 stands for IEEE802.11p/ETSI ITS-G5.
ITS-S	Intelligent Transport Systems Station
IVI	Infrastructure to Vehicle Information
IVS	In-Vehicle Signage
IVIM	Infrastructure to Vehicle Information Message
MS	Member State
MSP	Mobile Roadside ITS-G5 System Profile
HLN	Hazardous Location Notification
RSP	Roadside ITS-G5 System Profile (short also Roadside System Profile)
RWW	Roadworks Warning
s	Seconds
SDO	Standard Development Organisation
TCC	Traffic Control Centre
Vev	Emergency vehicle

Glossary

ITS-S Application	Uses one or more FLSs with different parameters, depending on the situation, to provide an ITS service to the user. ETSI TR 102 638 [2] e.g. is RWW, IVS and CRW.
Use case scenario	Denotes a more specific way to execute an ITS-S application, e.g. the stand-alone mode of Roadworks Warning in case of safety trailers failing to connect to the centre.
Facilities Layer Service (FLS)	In this document, the term service is derived from the term ITS-S service as defined in ETSI EN 302 665 [1]. It describes a communication functionality offered by an ITS-S to an ITS-S application.

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Introduction

Partners of the C-Roads Platform at European Level have teamed up to bring interoperable “day one C-ITS services” on the Road networks and in vehicles on the market in order to enhance road safety and traffic efficiency as well as travelling comfort with connected vehicles. For this purpose, the 17 member states have defined and agreed on a test- and validation process for these C-ITS day one services according to their contractual obligations, but also in order to introduce interoperable services in the different countries.

This test- and validation process is even more important because C-Roads was built on the principle of open specifications and communication profiles based on standards and has according to this principle also invited external parties from the Car2Car Communication Consortium and industry to the test- and validation procedures related to the respective releases of the specifications.

This means that the participation of external parties to this test- and validation process steps confirms not only the quality of the information provided in the specifications, but confirms also their open character and accessibility of single products and services to the C-ITS domain as a whole.

These agreed process steps have been successfully performed in 2020 and 2021 in a first test and validation cycle of the C-ITS development of C-Roads partners and external stakeholders e.g. from the C2C CC and resulted in interoperable day one C-ITS services presented and demonstrated at the C-Roads Roadshow in Brno in June 2021.

Additional to the service definitions and process steps for testing and validation also the experience gained by all participants is a valuable outcome of this overall process and this paper defines the additional learnings and cooperation procedures which define a sound basis at data level for the validation of openly specified C-ITS services and by this fosters the cooperation between road infrastructure operators, authorities, vehicle manufacturers and industry suppliers in the connected mobility area.

With the experience and learnings gained from a data exchange point of view in the testing and validation phase of day one C-ITS applications and the intention to use this process of open exchange of data also in the future the stakeholders expect to contribute to the faster and more efficient introduction of new services not only in the C-ITS (day 1.5 and probably day 2 services) but also in the CCAM domain in Europe.

The message based data exchange process is hereby the basis for providing evidence in the single activities and by this generates trust and cooperation options between the public and private stakeholders involved in validation and market introduction of connected and automated vehicles.

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2 Background and X-Testing

2.1 C-Roads X-Testing and Validation

C-Roads partners which have installed C-ITS stations and operate the respective C-ITS service generation chain in their road infrastructure networks and traffic management centers in cooperation with external parties from industry and vehicle manufacturers performed extensive X-Test for C-ITS applications mostly in Q2/ Q3 2021. They defined and prepared a respective process from the initial freezing of the basic release specification for the test session, to the definition of the test locations and the respective generation of test messages for the single test cases in the agreed C-ITS messages and their data format definitions.

The responsible partners for the event distributed this complete C-ITS message set ahead of the testing session to all interested and participating partners and explained the details of their message sets in additional Q&A sessions. Following these preparations, the partners started the analysis on their C-ITS stations and elaborated on the coding, the message structure and the content of the single elements of the C-ITS messages in order to check consistency with the release specifications.

At the same time, also the implementation of the C-ITS service use case for the single message was cross checked between all participating partners of the C-Roads members in Europe. The detailed message analysis was followed up by the organisations responsible for the single test session in several online “feedback sessions with participants” were comments have been collected and issues stated and followed up according to the defined methodology.

The issues were defined at implementation level, at message level of the single use case but also at the general level of the C-ITS specifications, when the understanding of the participating partners and organisations was not the same and differentiated in details. At the end of such a C-ITS test– and validation session many improvements at the various levels have been implemented and contributed hereby to the faster and more efficient definition of high quality day one C-ITS services.

2.2 Participation of C2C CC members

The data exchange of the test- and validation sessions included the road operators in the EU member states, public authorities, Cities but also external parties and stakeholders to C-Roads like vehicle manufacturers and C2C CC members which participated in the X-test´s sessions and analysed the data sets provided from the responsible partners and commented C-ITS messages, and details of data structures, use cases and service implementations according to the understanding of the latest releases of specifications from C-Roads. This not only supported consistency of C-ITS service implementation in the participating EU member countries, but contributed also to an extensive data set of C-ITS messages related to day one use cases, which was and is accessible to partners and their further work at application level.

2.3 C-ITS data generated, shared and used for analysis

As has been described in the previous chapters the x-test and validation sessions in the C-ITS domain have been concentrating their efforts and activities on the messages defined in the standards of different SDOs for the implementation and transmission between road infrastructures and vehicles of the day one C-ITS service applications and their respective messages, in defined and agreed data sets. This was done based on the general agreement of partners involved that every partner makes available the messages generated and processed within his C-ITS units to others for their analysis and feedback loop in order to improve the C-ITS

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contents and data. The agreed data sets of messages and contents have been shared between partners involved, explained in detail and commented before the test, and then analysed in single test runs and under different conditions of the C-ITS stations.

2.4 Process used for C-ITS information services – day one applications

The data exchange process is now used for testing and validation, but also for improving C-ITS day one services quickly and support their progress in information quality compared with the expectations of the mobile and connected travellers in Europe. It supports the service rollout in various regions and member states and offers a possibility to compare new C-ITS implementations with existing ones and their established or setup C-ITS service generation chain.

2.5 C-ITS messages are the basis:

The content of C-ITS messages provides a various range of information for vehicles, road side units and other road users. Each type of content is thereby represented by a dedicated message format. Today, the following messages are already used in deployments or will be used and deployed in the near future:

- Cooperative Awareness Message (CAM): This message is originated by road users like vehicles. It contains position information and details about the object's dynamics (like speed, heading, acceleration). Furthermore, it contains the recent position history of the object and further status information. Details can be found in [3].
- Decentralized Environmental Notification Message (DENM): This message informs about events along the road network. Such events could be a stopped or crashed vehicle, a vehicle that performs an emergency braking, a roadwork warning or other events that could affect the traffic flow. Details can be found in [4].
- Signal Phase And Timing Extended Message (SPATEM) and MAP (topology) Extended Message (MAPEM): Those messages are generated by the road side units at intersections. They contain detailed information about the topology of the intersection (like about available lanes and connection between lanes) and about the current and future signal phases of the related traffic lights (including their remaining time). Details can be found in [5].
- Infrastructure to Vehicle Information Message (IVIM): This message contains mandatory or advisory road signage for the road users, like speed limits or information about road works. IVIMs are used to digitalize the traffic signs along the road. Details can be found in [5].
- Signal Request Extended Message (SREM): This message is used to request priority for a specific lane at a signalized intersection (e.g. for public transport). Details can be found in [5].

The listed messages are essential for the road users and the road infrastructure. They enable a proper behaviour adoption in different situations and provide an up to date overview of the traffic situation. However, to transport a message from one participant to another, a message is encapsulated in different headers (see Figure 1). Those headers contain details about the destination area for the information and support the security objectives (like integrity of the content). Consequently, parts of the header's content have to be aligned to the message content. Otherwise, a warning about a hazardous situation could be disseminated to the wrong destination area and thus provide no safety benefit, because the event is located at a very different position.

AccessLayer Header	GeoNetworing Header (including Security)	BasicTransport Header	Facility payload (e.g. CAM)

Figure 1: General packet structure for C-ITS messages:

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As a result, it is required to record the content of the messages **and** the headers. This enables an offline analysis of the recorded data, which can check if the generated data is valid and if the headers and the content are properly aligned. Onside testing (e.g. across different regions) can be started, when the offline analysis is done and indicates that the data quality is sufficiently high.

The recording format for the offline analysis shall be harmonized. This ensures that a common set of tools can be used for the all analysis and offline validation across different test location / regions. A harmonized approach can speed up the analysis process, because the used tools do not have to be adopted for each recording format. Furthermore, a harmonized format can be a basis for future use cases and tools. They can be (partially) evaluated / tested with previously recorded data.

The virtual tests of the C-Roads project had been the trigger to start such a harmonization process. Due to the Covid-19 pandemic, the onside testing was not possible and a virtual replacement was required. In front of this background, the C-Roads partners agreed on a recording format. They aligned it with the C2C-CC members, which also participated at the virtual tests. The general concept for virtual test events and the final format had been put into a deliverable of the C-Roads project (see [6]). Briefly summarized, C-Roads agreed on PCAP as general format (see [10]) and proposed the following two options:

Option #1:

Figure 2: Frame format for option #1. Source: [6]

Each package in this format consists of:

- An Ethernet II Frame, see [9]
- The GeoNetoworking content (including security – if applicable), according to [7]
- The Basic Transport Protocol, according to [8]
- The Facility payload as UPER encoded ASN.1 data, according to the related ETSI specification

Option #2:

Figure 3: Frame format for option #2. Source: [6]

Each package in this format consists of:

- The Radiotap Header, see [11]
- The IEEE 802.11 Frame (QoS), see [12]
- The LLC Header, see [12]
- The GeoNetoworking content (including security – if applicable), according to [7]
- The Basic Transport Protocol, according to [8]
- The Facility payload as UPER encoded ASN.1 data, according to the related ETSI specification

Regardless of the selected option, it is essential that the recorded data align strictly with that format. Even slight deviations from the format (like different or additional headers) break the benefit of the harmonized

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approach. All users of the data would have to adopt their tooling to deal with such a deviation. This adds additional costs and eliminates the intended speed boost for the validation.

2.5.1 From Road Infrastructure: DENM, IVIM, SPAT/MAP

In the general definition of the used data exchange process the principle to share the messages, generated by the respective partners, was agreed and for this reason the road infrastructure operators made available for the test sessions data sets containing the generated C-ITS messages send out from their C-ITS stations at specific locations, containing examples of traffic event information coded in the selected message types. For these road infrastructure related messages the details of the message coding are explained in the chapter above, examples and representations of messages in a geographically localised or map context are included in ANNEX I of this report. The C-ITS messages used in the test and validation sessions in C-Roads have been the following ones:

- DENM - Decentralized Environmental Notification Message (I2V)
- IVIM - Infrastructure to Vehicle Information Message
- SPAT/MAP – messages at road intersections in urban areas

2.5.2 From Vehicles: CAM, DENM, SREM

From the vehicle partners in the context of the x-test and validation sessions the received messages have been processed in C-ITS stations together with vehicle trajectories and their registration / logging in related CAM traces of the participating C-ITS stations and in-vehicle units. The format of the messages has shown the suitability and the necessary level of detail in order to asses C-ITS services related to specific dynamic transport environments on road networks. For these vehicle related C-ITS messages the details of the message coding are explained in the chapter above, examples and representations of messages in a map context are included in ANNEX I of this report. The C-ITS messages used in the test and validation sessions in C-Roads have been the following ones:

- CAM - Cooperative Awareness Message
- DENM - Decentralized Environmental Notification Message (V2I)
- SREM – messages for priority of vehicles

2.6 Data exchange methodology used by C-ITS partners

Based on the experience made by the involved partners in the x-test and validation sessions of C-ITS in laboratories and on public roads in the various participating member states of C-Roads the stakeholders on road infrastructure side and from the vehicle manufacturers state their intention to use this defined and proven methodology of data exchange for C-ITS service validation also in the future. We propose this openly defined methodology in the connected vehicle domain as a general way of cooperation between different parties interested in providing data evidence of their own test activities to external partners and stakeholders. This proposal for providing data evidence in C-ITS testing and connected vehicle validation is based on the following reasons:

- The basis for the data exchange are standardized messages used in the C-ITS domain
- The data structures and formats agreed in the methodology are openly available and can be used by all stakeholders for the purpose of testing and validation of C-ITS services, and also for CCAM aspects of connected mobility

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- The exchange of data and their exact definitions of the respective data sets can be adapted to the purpose and agreed by the public or private partners involved in order to fully comply with the agreed overall targets of the activity
- The data exchange and processing of C-ITS messages can be performed by a series of different software tools and are therefore also defined in an open and accessible way for many stakeholders.

Overall the involved partners agree that a common method to share data evidence from infrastructure and vehicle side in testing and service validation enables fast progress also in complex connected vehicle environments and supports high quality C-ITS services.

2.7 In the future . . . use data from Infrastructures and vehicles – for advancing CCAM

A harmonized data layer and data exchange process provides immediate benefits for Day 1 (cross) testing. In addition to that, it also paves the way for future harmonized, save and secure V2X communications. The future vision of 100% Cooperative, Connected and Automated Mobility (CCAM) requires this as one essential building block. In order to achieve this, certification schemes and repeatable as well as reliable testing procedures are of basic importance.

This section provides some insights how the harmonized data layer and data exchange process opens up the path to achieve these goals in order to advance CCAM developments for all stakeholders.

As previously described, the process presented in this document largely supports testing and harmonisation activities. All units involved in data traffic for CCAM applications send and receive data and therefore have to confirm their interoperability and compliance with basic sets of requirements. A harmonized data layer enables all stakeholders to create and share a collection of data sets for testing with ease.

Thereby, implementers (for both sending and receiving side) have the means to test their implementation concerning mutual interoperability. On the receiving side, a reliable data basis can be used to check the functionality and improve potential bugs before the first field test. On the sending side, the recorded behaviour of other stations can be used to compare the own implementation with and to check the correctness and conformity of the implementation with standards, communication profiles and other sending side implementations.

The agreed harmonized data layer ensures that this can be done with a quick data exchange without further overhead to agree on suitable data formats or travelling to dedicated test locations for first field tests.

Building on these direct multilateral enhanced interoperability checks, this activity also fosters the improvement and further development of harmonized standards and profiles. The direct comparison of different message implementations for a certain use case will show every little difference. Tiny gaps or inconsistencies existing in the standards and profiles can thus be revealed early on. Those gaps are very hard to find by pure text work or might take years until they are noticed by chance in deployments. However, those gaps or inconsistencies can have a significant impact on the function on the receiving side.

In the next step, testing can be made more efficient, reliable and independent. Thanks to the harmonized data layer the aforementioned tests, comparisons and conformity checks can be automatized and do not need to be done “by an expert’s eye” anymore. Conformity and interoperability tests require a lot of effort when done purely with the human eye, are error prone and it is not possible to check every little (but important) detail. With automation, all these shortcomings can be resolved. In a small fracture of the time needed for “human testing”, many more details can be verified and compared and the results are fully replicable. This in turn again fosters interoperability as well as standard and profile conformity. Additionally, due to a large data basis, harmonized formats and open standards, the testing environment is not bound to the implementer. Third parties could develop tests and provide reliable testing results too. Many parties with different views on the requirements will eliminate most of the misinterpretation in the requirements.

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In consequence, looking further into the future, this is the stepping-stone for certification. In order to achieve a 100% rate of CCAM, V2X communication will need to be introduced into a legal traffic framework. This will only be possible through certification schemes and respective defined processes. The harmonized data layer and exchange process, enables in turn automated testing as the basis for this kind of certification.

The previous passages show how the process presented in this document paves the way to interoperability, more mature, harmonized standards and profiles as well as test automation and certification.

Another aspect, not yet considered here, is the benefit of this approach for traffic analysis and traffic management. Those tasks are highly relying on detailed and holistic traffic data, preferable in real time. Nowadays quite some efforts are required to obtain these data by roadside sensors and the more detailed information is needed, the higher the effort required.

A high penetration rate with V2X will decrease the cost to collect such data, because less roadside sensors are required for traffic observation. Every vehicle automatically provides detailed data, which just have to be recorded. The presented harmonized data layer can be used for storing and sharing such very detailed vehicle and traffic data. Accumulated over passing by vehicles this is an ideal basis for traffic analysis. Here again the harmonized data layer ensures that no additional overhead is needed.

The same data sets of single C-ITS services cannot only be used for traffic management. In general every function developer (for example on the vehicle side), could benefit from such a categorized and specific data set. They could check if their intended function would work with the data that is already available today. This would lead to functions that are more robust when the necessary data is provided by different vehicle or roadside unit manufacturers.

Another point to consider is the comparability and documentation of (local) deployments. As done in the C-Roads project, different regions can compare their implementation against each other. Vehicles, that would have to operate in all these regions, could check if they are able to handle all the different implementations. First testing can be done offline and remotely, prior to visiting each other. Concerning the documentation, the harmonized format is open to everyone and projects can easily show to everyone, which level of success they achieved. Such an openly accessible project documentation can help to make project results more transparent by sharing not just reports but also the related data sets.

In summary, this consideration and look into the future shows that this activity for a harmonized data exchange process and data layer is a crucial stepping stone to foster C-ITS interoperability, enhance the standards and defined communication profiles, improve and automatize testing and thus in turn enable the means for certification needed for the vision of a 100% testing and validation rate of CCAM.

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3 References

Table 2: Table of normative key references

#	Reference
[1]	EN 302 665
[2]	ETSI TR 102 638
[3]	EN 302 637-2
[4]	EN 302 637-3
[5]	TS 103 301
[6]	C-ITS Cross-Border Testing: PCAP Exchange Specification
[7]	EN 302 636-4-1
[8]	EN 302 636-5-1
[9]	https://en.wikipedia.org/wiki/Ethernet_frame#Ethernet_II
[10]	https://gitlab.com/wireshark/wireshark/-/wikis/Development/LibpcapFileFormat
[11]	https://www.radiotap.org/
[12]	EN 302 663

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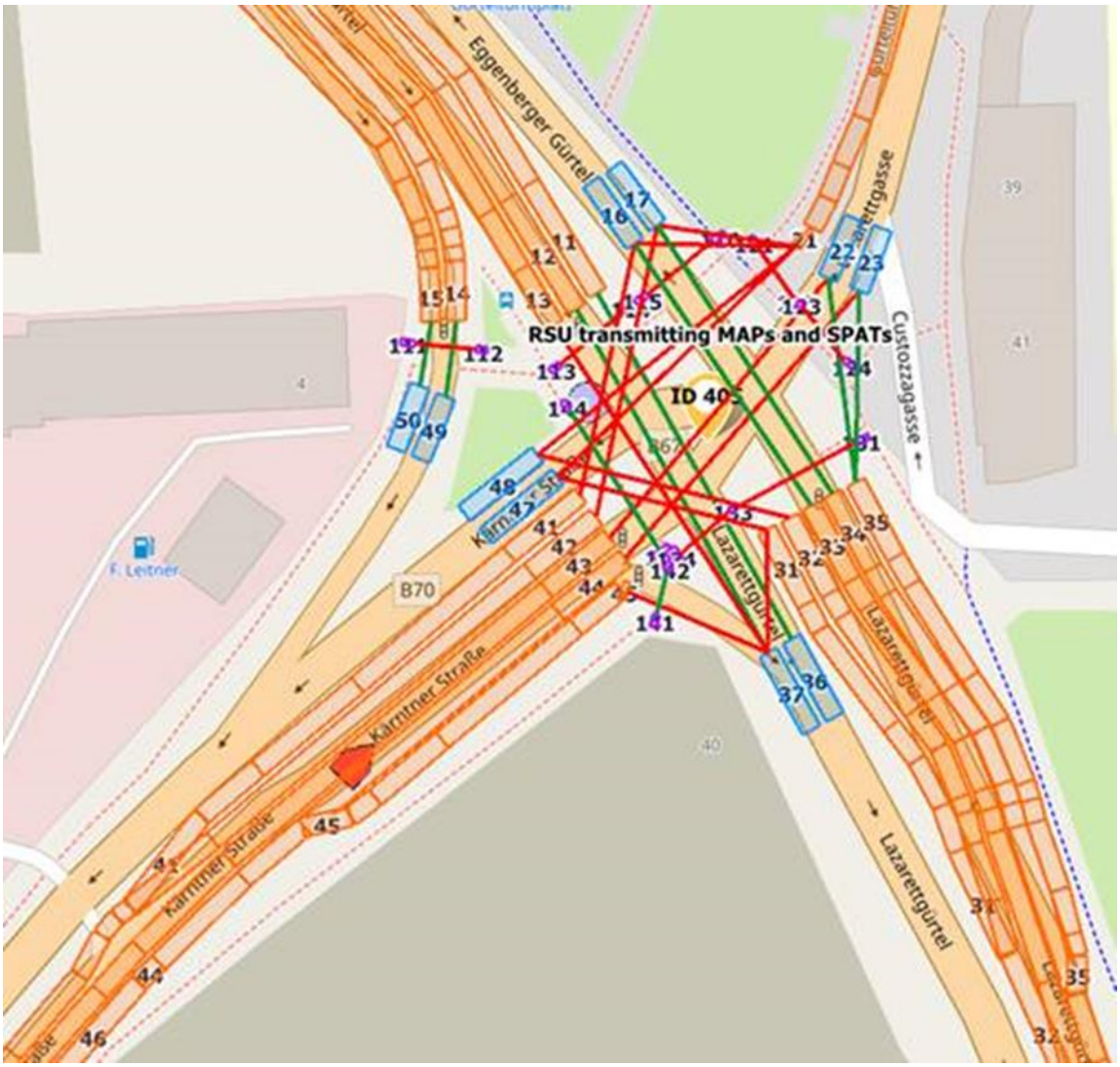
4 ANNEX

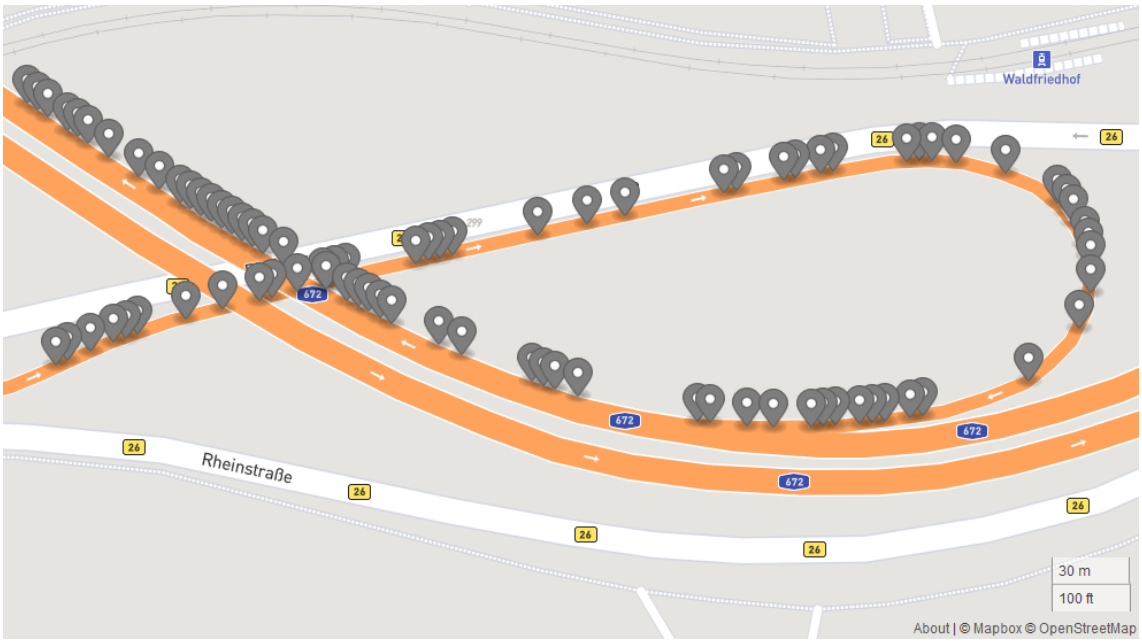
Picture 1: DENM Message example on the S1, Austria

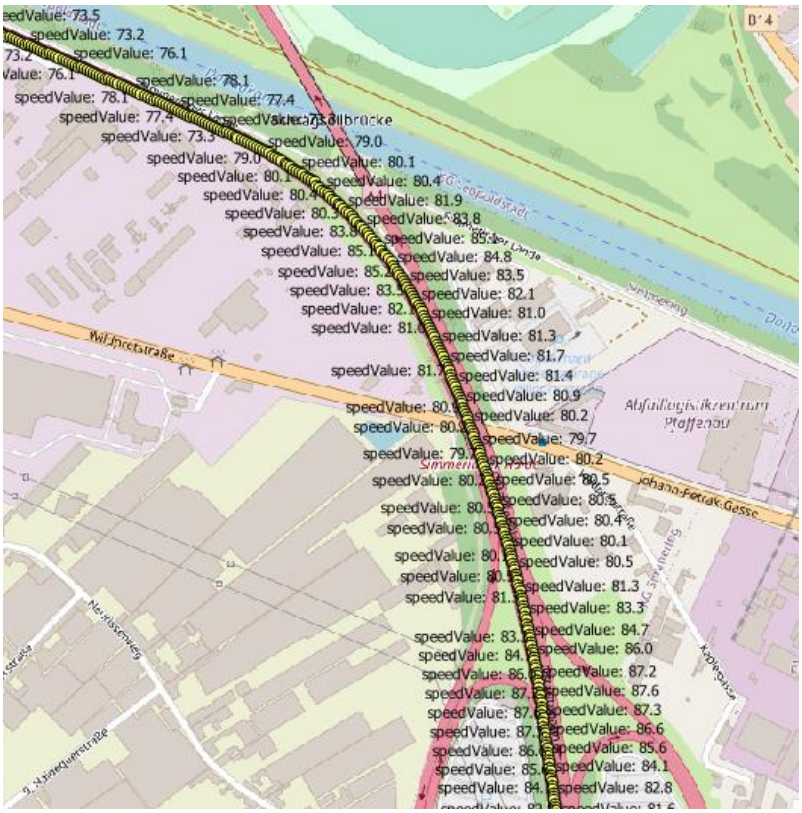
Picture 2: IVIM Message example on the motorway A4 – Austria: Speed limit and truck ban on passing

Picture 3: SPAT/MAP Message from the City of Graz/ Austria (Intersection: Lazarettgürtel / Kärtnerstraße)



Picture 4 and 5: vehicle CAM Traces: picture 4 without, picture 5 with vehicle speedValues – plotted





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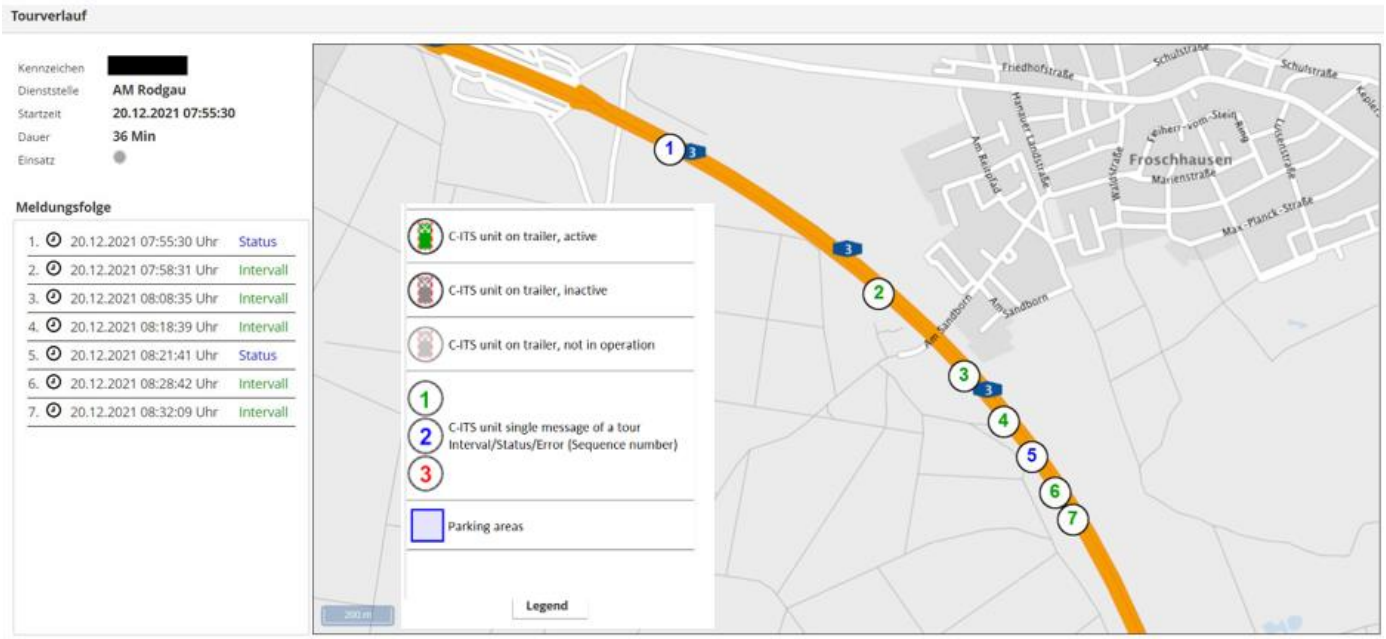
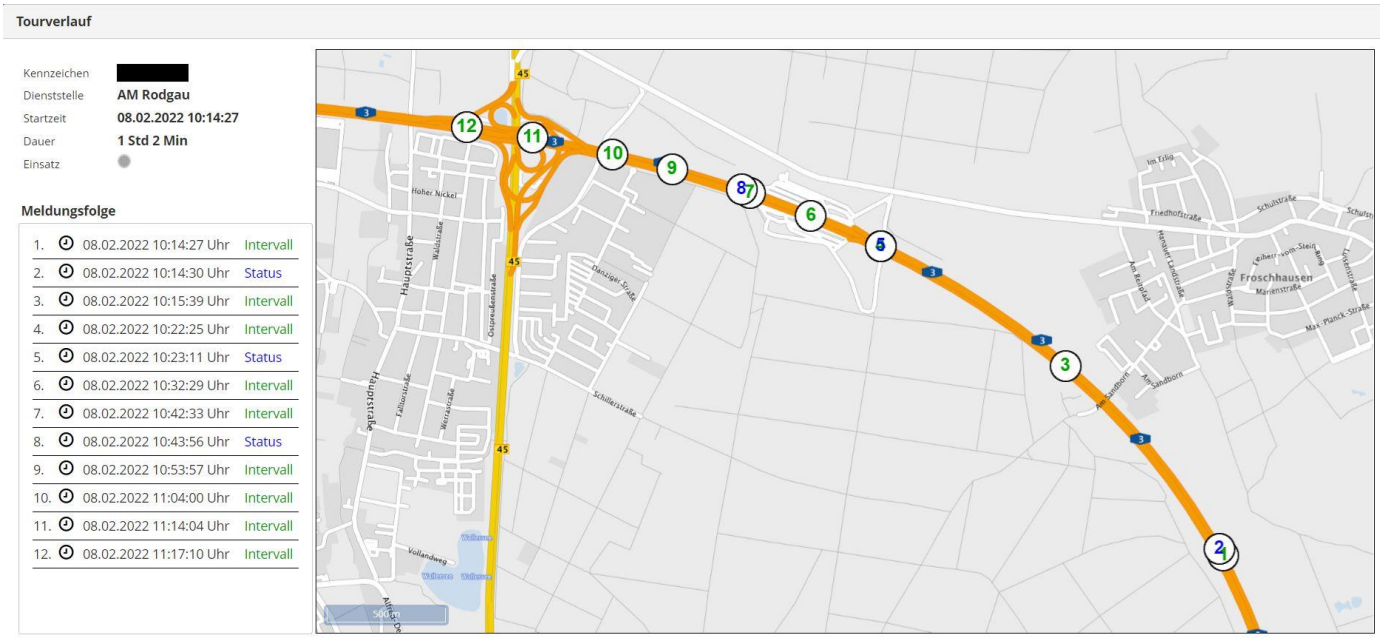


Pictures 6 and 7: vehicle positions based on CAM Messages along a stretch of the motorway A3 near Rodgau, Rhine-Main area. Source the motorway operator Autobahn GmbH, pictures and materials collected in the project "Test Field Germany".



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