



M24 - EU-C-ITS INTEROPERABILITY REPORT PHASE 2 UPDATED VERSION 3.0.0

C-Roads Platform

Working Group 2 Technical Aspects

Taskforce 5 Cross-Testing and Validation

Chairmanship:

- Chair: Marwane Ayaida, UPHF, France
- Co-chair: Jan Schappacher, BASt, Germany

Publication History

Version	Date	Description, updates and changes	Status
0.1	26/03/2023	Document initiation	draft
0.2	02/05/2023	Contributions from DE (ch 1), SL (ch 2.1), GR (ch 2.2), IT (ch 3.2), FI (ch 4) merged	draft
0.3	14/05/2023	Merging all the inputs from different MS	Distributed for review to TF5
0.4	16/05/2023	Update based on TF5 internal review	Distributed for review to WG2
0.5	14/06/2023	Update based on WG2 review	Distributed for review to SCOM
1.0	30/06/2023	Finalized for distribution	Released and distributed to CINEA
1.1	11/05/2024	Update by TF5 to include the ITS-G5 and Hybrid 2023 CBT	Draft for WG2
1.2	24/05/2024	Updated based on WG2 Meeting review comments	Draft for SCOM
1.2	25.09.2024	Finalized for publication	Release
1.3	11.12.2024	Updated with results from C-Roads Hungary 2024 CBT	Release Update
3.0.0	31.10.2025	Update of the release version, new C-Roads Extended document template, test results from C-Roads Antwerp-Helmond project included	Release

Acronyms

Term	Meaning
AA	Authorization Authority
AT	Authorization Ticket
C2C-CC	CAR 2 CAR Communication Consortium
CBT	Cross Border Test
CPOC	C-ITS Point of Contact
CRL	Certificate Revocation List
EA	Enrollment Authority
ECTL	European Certificate trust List
HMI	Human-Machine Interface
MS	Member state
OBU	On Board Unit
PCAP	Packet Capture
PTS	Physical Testing Session
RCA	Root Certificate Authority
ROV	Road operator vehicle
RSU	Road Site Unit
TF	Task Force
TC	Test Case
TLM	Trust List Manager
UC	Use Case
VTs	Virtual Testing Session
WG	Working Group

Index

Acronyms.....	3
1. Introduction.....	6
1.1. C-Roads platform for harmonisation of C-ITS deployment	6
1.2. Story board C-Roads C-ITS deployment documentation.....	7
1.3. Scope of this document.....	8
1.4. Overview of the organized PTS and VTS.....	8
2. Methodology of the experimentation.....	10
2.1. General description of ITS-G5 PTS	10
2.2. General description of ITS-G5 VTS	12
2.3. General description of IP-based Tests.....	14
2.3.1. CBT 2022	14
2.3.2. CBT 2023.....	16
3. Cross Border Testing Results for ITS-G5	19
3.1. Quantitative results	19
3.2. Qualitative results.....	22
3.2.1 CBT 2022	22
3.2.2 CBT 2023	23
3.2.3 CBT 2024.....	25
4. Cross Border Testing Results for IP-based Tests	26
4.1. CBT 2022.....	26
4.1.1 Quantitative results	26
4.1.2 Qualitative results.....	27
4.2. CBT 2023.....	28
4.2.1 Quantitative results	28
4.2.2 Qualitative results.....	30
4.3. CBT 2024.....	31
4.2.3 Quantitative results	31
4.2.4 Qualitative results.....	32
5. Conclusion	34
5.1. European harmonization subjects to be raised.....	34
5.2. Learned lessons for cross border interoperability	35
5.3. Summary of the cross-border tests.....	37
6. Appendix A: List of European harmonization subjects.....	40
6.1. Point 1.....	40
6.2. Point 2.....	40

6.3.	Point 3.....	40
6.4.	Point 4.....	41
6.5.	Point 5.....	41
6.6.	Point 6.....	41
6.7.	Point 7.....	42
7.	Appendix B: List of all the detailed MS reports	43
7.1.	Detailed results for Austria.....	43
7.2.	Detailed results for France	43
7.3.	Detailed results for Germany	43
7.4.	Detailed results for Greece.....	43
7.5.	Detailed results for Hungary.....	43
7.6.	Detailed results for Italy	43
7.7.	Detailed results for Slovenia.....	44
7.8.	Detailed results for Nordic Countries (Sweden, Norway)	44
7.9.	Detailed results for Ireland.....	44
7.10.	Detailed results for Hybrid Testing Group.....	44
7.11.	Detailed results for Antwerp-Helmond (Flanders, the Netherlands).....	44

1. Introduction

1.1. C-Roads platform for harmonisation of C-ITS deployment

The C-Roads Platform is a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonisation and interoperability. Through the C-Roads Platform, authorities and road operators join together to harmonise the deployment activities of cooperative intelligent transport systems (C-ITS) across Europe. The goal is to achieve the deployment of interoperable cross-border C-ITS services for road users.

C-ITS enables vehicles to interact directly with each other and the surrounding road infrastructure. In road transport, C-ITS typically involves vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. In order to enable an efficient and undisturbed exchange of information within these services as well as a cross-border implementation, harmonised C-ITS specifications are indispensable. The approach starts from a functional perspective, then requirements applicable to all implementations and then towards technology specifications of currently validated implementations (ITS-G5 for short range communication, IP based for long range cellular). In order to meet these challenges, the C-Roads platform is divided into five Working Groups. The first Working Group is concerned with organisational tasks, the second with Technical Aspects and the third with Evaluation and Assessment. The fourth Working Group is about Urban C-ITS Harmonisation and Working Group 5 is about Digital Transport Infrastructure (DTI).

The C-Roads Platform is steered by the C-Roads Steering Committee which is composed by Member State representatives. With the support of the Supporting Secretariat, decisions for achieving the goal of the implementation of interoperable end-user services are taken. In this respect, specifications, plans and reports, which are proposed and recommended by specific Working Groups, are approved. Within WG2 these specifications are harmonised by 5 Task Forces and derived from pilot activities and are the basis for further pilot and implementation activities. This especially goes with technical decisions, which influence deployment and procurement decisions at pilot sites.

The Working Groups are installed as decision support for the Steering Committee to ensure proper decisions towards interoperable deployments. Individual experts participating in the single pilots work together in these Working Groups to prepare proposals and recommendations. Also, members of the single pilot activities as well as of the C-Roads-Working Groups actively contribute to the work of the EU C-ITS-Platform.



Figure 1: Overview of C-Roads coverage

1.2. Story board C-Roads C-ITS deployment documentation

This document is part of the C-Roads C-ITS Deployment Documentation and Requirements. The complete set of documents is much related to a common project life cycle of a system implementation. As a guide to the C-Roads Documentation, a story board based on such a project life cycle is provided in this section, with emphasis on role of this document *EU-C-ITS Interoperability Report Phase 2*. The story board should be read from left to right and shows the different stages of the project life cycle and how each C-Roads Documentation is related to it, thereby can be supportive to road authorities and other stakeholders.

A complete description of the story board of a C-ITS implementation project, the different stages and the related C-Roads documents is given in *“Introduction to the C-Roads WG2 Deployment Documentation and Requirements”*.

The documents cover a wide range of aspects related to several stages as described in section 1.4 of *“Introduction to the C-Roads WG2 Deployment Documentation and Requirements”*. Starting with stage 3, generic requirements and the required governance are specified - those are applicable for all services, use cases and scenarios in a similar way. On stage 4a and 4b, the more detailed specifications

are relevant - including service specific security requirements. Both levels, generic and specific requirements, have impact on the test cases derived on stage 5.

1.3.Scope of this document

This document is one of the deliverables of Taskforce 5 of Working Group 2 of the C-Roads Platform and contributes to stage 5 in the C-Roads workflow. The stage 5 deliverables provide the basis to validate the interoperability of a C-ITS implementation and guide through all aspects of interoperability testing for ITS-G5 systems, IP-Based communication and security elements, as specified by Working Group 2 of the C-Roads Platform by the other Task Forces, namely TF1, TF2, TF3 and TF4.

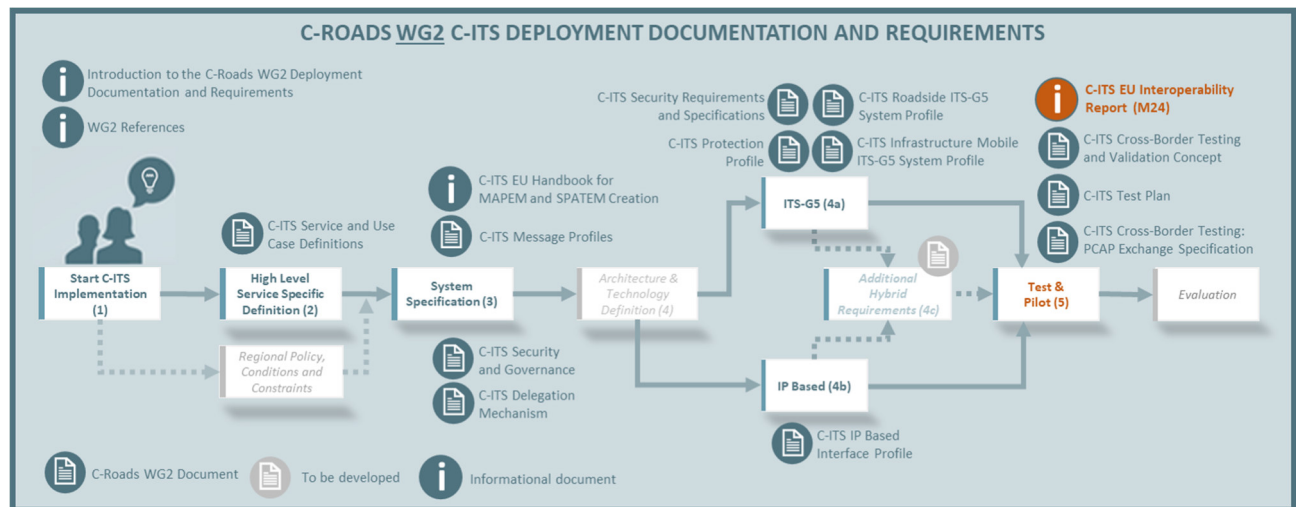


Figure 2: Highlight of WG2 document in complete story board

This document summarizes the results of the interoperability tests that were organized by different MSs and held during the 2022 autumn and winter in the first round, and during Q2, Q3, and Q4 2023 in the second round.

1.4.Overview of the organized PTS and VTS

Many different Cross Border Tests (CBT) were organized by the different Member States (MSs). An overview of all these tests sessions is presented in the Matrix depicted by the Figure 3. As one can see, there were testing sessions organized by 10 MSs: Austria, France, Germany, Greece, Hungary, Ireland, Italy, Norway, Slovenia and Sweden.

During these CBTs, other MSs were invited to take part as visiting members, either physically or virtually and test the C-ITS implementation of the hosting MS. Besides, the test sessions were also open to other third parties such as CAR 2 CAR Communication Consortium (C2C-CC) members. So, some car manufacturers or equipment providers joined these sessions, which is very important and may enhance the quality of the tests and guarantee that road service providers and consumers understand each other and contribute to reach the interoperability of C-ITS between all the stakeholders.

ITS-GS Tests		MS Hosting																	
MS Travelling (physical tests)	Austria	Belgium/Fland	Belgium/Wa	Czech Republic	Denmark	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Netherlands	Norway	Portugal	Slovenia	Spain	Sweden	UK
C2C-CC and	Hyundai																		
	Consider-IT (Germany)																		
	V-Tion (Netherlands)																		
	Siemens																		
	Kapsch																		

Note:

- ITS-GS Virtual Testing
- ITS-GS Physical Testing
- ITS-GS Hybrid Testing
- IP-based Virtual Testing
- IP-based Physical Testing
- IP-based Hybrid Testing

Figure 3: Overview of the different PTS and VTS

2. Methodology of the experimentation

The methodology for the C-Roads CBT for the validation of the interoperability is mainly focusing on two means of testing sessions: Physical Testing Session (PTS); and Virtual Testing Session (VTS). The general procedures of these two methods are depicted in Figure 4 and will be described in detail in the following sections.

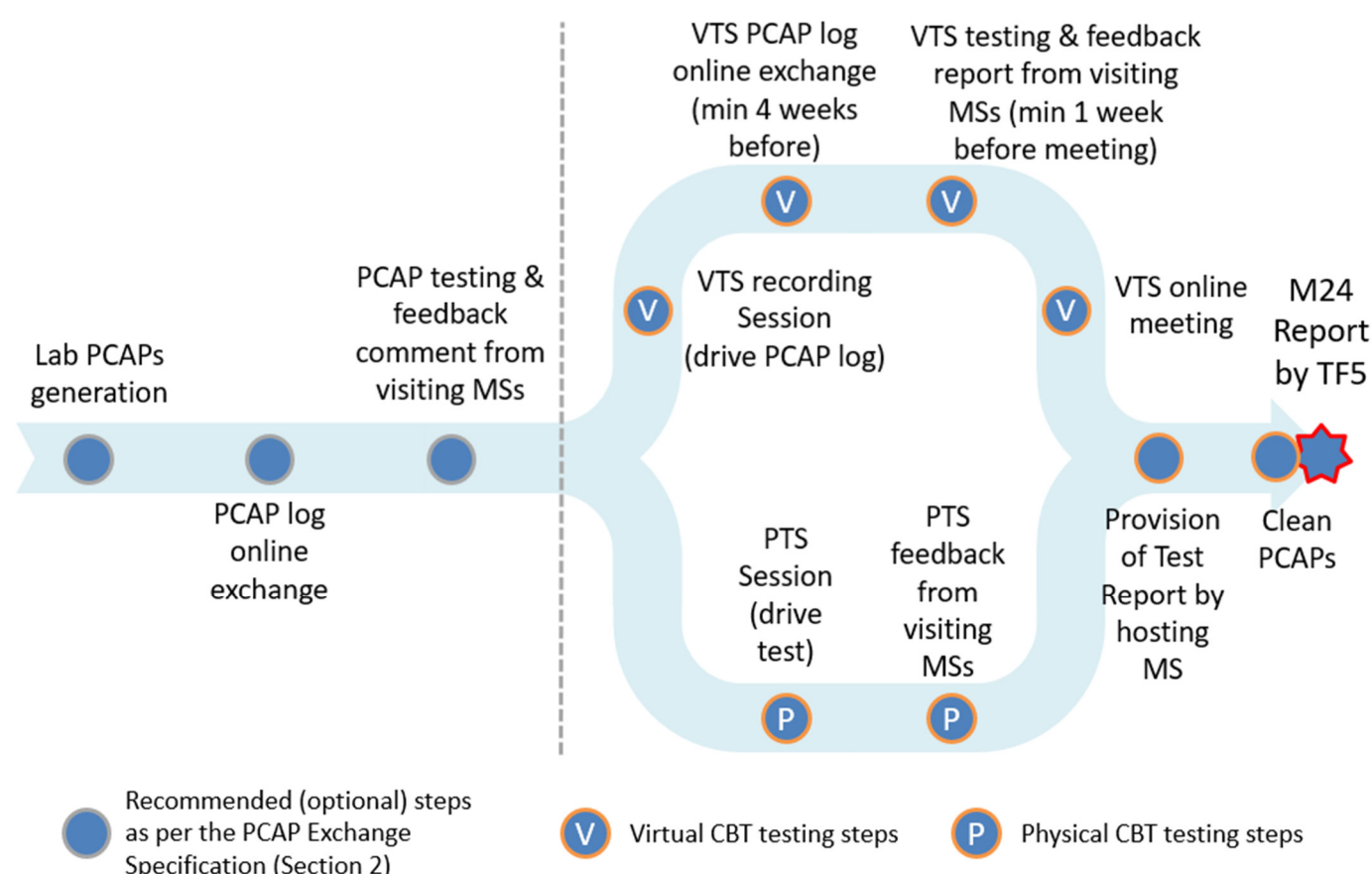


Figure 4: Procedure of PTS and VTS sessions

2.1. General description of ITS-G5 PTS

PTSs were planned on the C-Roads platform level during the second round of CBT in Q2, Q3, and Q4 2023. All interested member states first announced their dates in which they could organize the PTS. In this regard, it was desirable that the dates of testing among different member states do not overlap allowing to carry out as many testing sessions as possible. Additionally, a coordinated effort was made to conduct testing activities in connection with physical WG2 meetings in Dublin and Verona. Based on the information from member states, a calendar overview was created.

Preparations for testing began with the creation of a Cross Testing Fact Sheet individually for each pilot site. The document had to be prepared 6 weeks before testing and was intended for visitors. It contained all important information about the organization of testing and the pilot site:

- Disclaimer on openness for testing: to whom the pilot site is open for testing.
- Point of Contact: contact details, availability.
- Service overview: list of Services and UCs based on the Common C-ITS Service and Use Case Definitions.
- Time schedule: recommended times for testing, availability of specific services or maintenance vehicles, prepared test situations, specific scenarios.
- Pilot site description / recommendations for testing: description of the location, map with RSU/ROV locations, suggested start/endpoint for testing, estimated time needed for testing the available services.
- Legal and safety advices: code of conduct, permissions to drive on a specific track.
- Technical basis: standards/specification used, configuration, support of C-Roads specifications (release), security configurations.
- List of supported test cases (TCs).

A recommended step before conducting CBT was to prepare and share PCAP files. Files have been generated for all C-ITS services/UCs that were subject to testing. C-ITS messages were recorded in the laboratory environment and saved in PCAP file format. The PCAP log files were then submitted to an online exchange with other MSs. All interested visiting MSs and other interested organizations had the possibility to preliminary test and analyse the PCAP files. In the case that deviations from the C-Roads specifications were discovered, the hosting MS was informed of this, which was then able to eliminate the identified deficiencies in its system before the CBT was carried out.

The PTS usually started with an introductory meeting where the hosting member state welcomed the participants and made a presentation about the pilot site and the C-ITS services available for testing there. A testing plan with recommended test drives was also presented. Visitors used their own test equipment during the test drives, which differed from member state to member state. Common to all versions of test equipment was the OBU with HMI for the visualization of received C-ITS messages, and additionally there could be added functionality that enabled the deeper analysis of messages. During the test drives, the participants observed the display of C-ITS messages on the HMI, they could also record the messages in PCAP format and/or take screenshots of the HMI for later analysis. After the completed test drives, there was usually a wrap-up meeting where the participants shared their findings and test results with the hosting MS.

Each visiting MS or organization prepared its own report after test drives and sent it to the hosting MS. The report contained the following information:

- list of participants,
- number of TCs passed/failed,
- how the C-ITS services worked,
- identified deviations of DE/DF in the C-ITS messages according to C-Roads specifications, and
- identified interoperability issues.

The findings from the reports significantly contributed to hosting MS being able to make an appropriate update on their systems.

Finally, after conducting PTS and receiving reports from the visiting MSs /organizations, each hosting MS had to provide its own national Cross-Border Test report. For the ITS-G5, this report summarizes the findings and test results from the participants and contains the following contents:

- introduction.
- methodology of the experimentation:
 - logistics: meeting place, test run description, participants.
 - technical configurations: pre-conditions, ITS-G5 configurations, security configurations, visiting member state configurations, used tools for validation.
 - testing program: tested services and use-cases, events description, testing scenarios, testing planning.
- cross-border testing results.
- conclusion:
 - general conclusion about the test,
 - lessons learnt for cross-border interoperability, and
 - harmonization points to be raised to the C-Roads WG2.

2.2. General description of ITS-G5 VTS

This sub-section describes the way of organizing virtual testing sessions. Thus, they have been specified to be as close as possible to physical tests and to cover most of the aspects that could be tested physically. They were organized in the same way as the physical ones. Each hosting MS organized its own session that was open to the other MSs and to third parties such as C2C-CC members. The hosting MS has captured and stored all the messages sent from its RSUs and/or ROVs using an OBU in the PCAP format. Then, it shared them with the visiting MSs to test them remotely. After that, the feedbacks of these tests were sent to the hosting MS. This allowed it to organize an online web-meeting, which was scheduled to discuss the different issues that were identified during these tests. Finally, the hosting MS provided a testing report that summarized all the results of these virtual tests.

For more details, the hosting MS recorded the PCAPs while driving through its On-Road Test Track of its Pilot Site. To do so, there were different steps:

1. Drive through the Test Track with a vehicle equipped with an OBU.
2. Log all the sent and received messages (CAM, DENM, IVIM, SPATEM, MAPEM, SSRM, SSEM, etc.) by the OBU and store them as PCAP files.

Then, the hosting MS shared with the visiting MS:

- All the stored PCAPs,
- The exact positions of all the expected events,
- The exact positions of all the RSUs that are used in the virtual testing, and
- The PCAPs were generally provided four weeks before the virtual session.

On the other side, after receiving the PCAPs, the visiting MS replayed them virtually. To do so, each MS implemented these functionalities:

- Online PCAPs replaying which is a mandatory feature for such tests.
- Modification of the receiver's location:
 - Recommended solution: virtually following the drive test path given by the hosting MS that is included in the PCAPs (extracted from CAMs).
 - If not possible: modifying manually the position of the receiver.
- Managing the validity time of the receiver:

- Recommended solution: Automatically modifying the timing from PCAPs (extracted from CAMs).
- If not possible: modifying manually the timing of the receiver.

VTs can be conducted with security enabled or not depending on implementation of hosting MS.

If security is enabled, it was generally enabled by the sender (hosting MS) when storing the PCAPs. Therefore, the stored messages need to include security fields to test the security implementation by the visiting MSs. Therefore, the usage of the security when executing the tests virtually was recommended if the receiver can manage it. Otherwise, the receiver disabled it and ignored the security fields.

Besides, the hosting MS distributed in general all its certificates used to generate the PCAPs to be used by the visiting MSs for validating the security implementation when replaying the PCAPs. For the C-ITS message based security verifications, the replaying tool required all the trust chain elements of the sender. This includes:

- the AA certificate (to verify the permissions and signature of the AT used to sign the message),
- the RCA CRL (to verify that the AA has not been revoked),
- the RCA certificate (to verify the permissions and signature of the AA certificate and the CRL),
- the LO ECTL (to verify that the RCA can be trusted), and
- the TLM certificate (to verify the signature of the ECTL).

In general, all these elements are public:

- AA, CRL, RCA are available on the RCA Distribution Center (DC). Provision of these elements to receiving testers can be done under two different ways:
 - By going to the DC whose URL can be provided by the sender or retrieved from the LO ECTL (since December 2020).

NOTE: In case stations cannot automatically retrieve the required elements and several versions have been used (e.g., 2 different AAs have been involved in tests), the sender should point the appropriate elements to be used.

- By attaching them directly to the PCAP files.
- LO ECTL (<https://cpoc.jrc.ec.europa.eu/ECTL.html>) and TLM certificate (<https://cpoc.jrc.ec.europa.eu/TLMCertificates.html>) are available on the CPOC. Like RCA elements, they can be provided directly in PCAP files.

After conducting the VTs, the visiting MS sent a report containing its feedback from these tests to the hosting MS one week prior to the virtual meeting to allow the host to prepare for the meeting.

All the previous statements were applicable for RSUs. However, if the tests concern V_{ro} (Vehicle of road operators), the mechanism is almost the same. In this specific case, there is no need to use another vehicle by the visiting MS. Thus, the V_{ro} moves and stores its own messages in PCAP files. These PCAPs could be used in the same way as mentioned previously with the OBU in the case of RSUs.

2.3. General description of IP-based Tests

2.3.1. CBT 2022

In order to be able to describe the details of the hybrid testing performed by various partners in C-Roads a short reminder of the technical elements involved in hybrid C-ITS message transmission is necessary and will be linked with the testing procedures and elements that have been prepared by C-Roads partners in several countries for this. In a later chapter of this report the details of the tested elements and the achieved results will be described in detail.

The common understanding of hybrid C-ITS in C-Roads consists of the following technical elements which have a link to C-Roads specifications as an overview:

Hybrid Interface: Basic roles

- AMQP 1.0 based Server interface
- for geographic Areas called „Tiles“ (defined with Quadtree)
- C-ITS Messages are published
- **Brokers** (based on AMQP) distribute these messages to „all C-ITS actors“
- **Clients** subscribe to the messages „on their way“ and deliver them to the in vehicle C-ITS stations

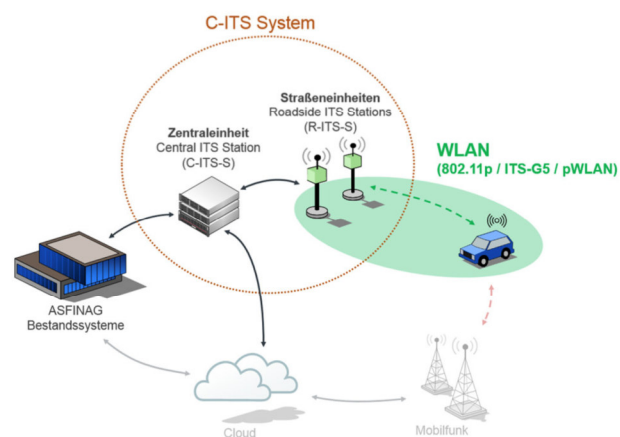


Figure 5: Hybrid C-ITS in C-Roads

The first general statement related to the C-Roads specifications and the elements related to hybrid transmission of messages is that the partners have agreed to use as a common basis for sending and receiving the messages via long range communication network using the protocol AMQP in the version 1.0 for all the interfaces implemented to connect existing and newly defined additional elements in this communication chains between C-ITS actors. And this statement applies for all elements involved in the hybrid transmission chain, from servers, to brokers, and clients which have been defined and use the specification of the BI – Basic interface to connect between each other.

Secondly the generic link between the C-ITS message positioning from a geographical point of view and the access to these messages of all types of C-ITS standard messages is defined with an algorithm which is called Quadtree¹, where the geographic positions are organized in areas and so-called respective Zoom levels. In simple words the rectangle of zoom level 0 contains the complete earth surface, and level 1 contains a quarter of it in each area described with a double-digit code and the respective areas are coded as follows (00, 01, 10, 11). The logic is based on the same principle and the support within C-Roads has commonly been defined from level 1 to level 18, where you see an

¹See: C-ITS IP Based Interface Profile

example of areas at an intersection below with an angle length of approximately 100 meters. At this level you would receive the C-ITS messages from a single intersection like SPAT/MAP in a city.

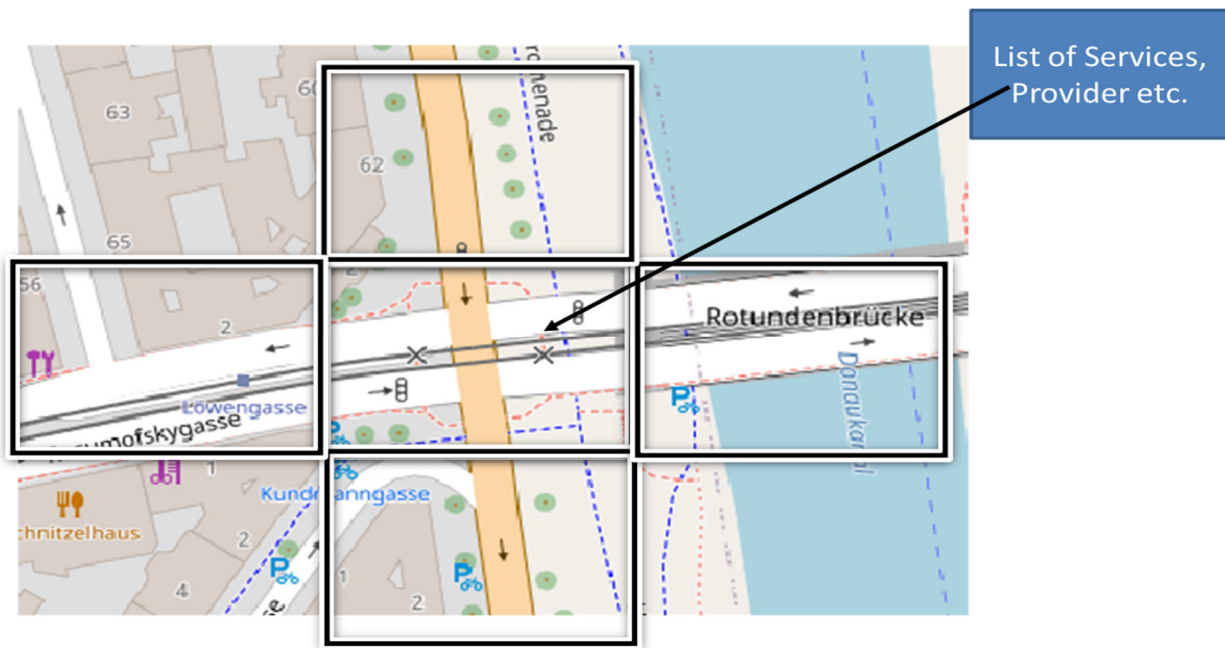


Figure 6: Example of zoom level 18 of the quadtree coding of the area: e.g. 100100111001111011

But the first elements of hybrid testing have been pure connection tests between the following elements:

- servers,
- brokers, and
- clients

implemented within the single C-Roads MS by one or more of the partners involved. In most cases this implementing partner was the respective road operator, in some MSs also a division between server or broker partners has been defined and used for testing.

In the first step of this hybrid testing, it was agreed to establish and test bilateral links between the two partners involved in the link of their back-office systems via the BI interface and include the basic information elements for all partners in a “registry table” which would also form the basis for the future testing phases and an extension of functionalities. Following this establishment of the connection, common definitions of parameters as sending and receiving entity were used and basic data sets were stored at both ends for testing if the data sets can be transmitted between the involved parties.

One additional limitation of the first testing phase consisted of the missing general mechanism for the security provisions of this data channel – which will only be implemented in the following testing sessions by all parties. In this early version bilaterally agreed credentials and passwords were used and taken into account in the setup and transmission of data.

Based on these preparations and procedures partners started the hybrid testing sessions between them and reported the work progress in a common subgroup of TF4 in C-Roads – WG2. The results of the first test sessions will be described in chapter 4.

2.3.2. CBT 2023

In the last few years, several C-Roads Member states have implemented the necessary IT systems to exchange standard C-ITS messages via IP-based networks, as it was always planned since the start of the C-Roads Platform in 2016 and defined as the approach of hybrid C-ITS. The overall objective is to use all available networks (short-range and IP-based ones) that complement each other in the transmission of high-quality traffic information to all consumers.

Some active C-Roads member states have started to contribute to the development of IP-based Interface specifications, and after a first version was agreed, completed, and published, some of them have also implemented the respective back-office systems in their C-ITS pilots.

By the end of 2022 six countries (FRA, ITA, SLO, SPA, AUT, CZE) have completed their first system implementations and have formed a WG2, TF4 – subgroup, for supporting the partners in the mutual connections setup and testing, and also shared the information and best practices between them. By December 2022 all connections between partners have been established and were able to exchange C-ITS messages for testing and validation, as well as for longer operating periods if required – for further details please see the respective report at <https://www.c-roads.eu/platform/documents.html>.

Broker and Client Information C-Roads

Overview of active C-ITS Brokers implemented in C-Roads (status 12/2023)

-  Number of countries: 8
-  SPAIN
-  FRANCE
-  ITALY
-  SLOVENIA
-  AUSTRIA
-  CZECH REPUBLIC
-  SWEDEN
-  NORWAY
-  IP-based connections between C-ITS brokers active during C-Roads CBT's in Q4/2023.



Figure 7: C-ITS Broker and Clients installation status 12/2023

In addition, the partners in the TF4 hybrid testing subgroup decided to open the subgroup to external partners if they are interested in setting up and operating a C-ITS broker, and let external cooperation partners, not only have access to all C-Roads related documentation but also to the common testing and validation activities from the subgroup partners.

For these reasons, it was decided to organise a common CBT event in Q4/2023 with the possibility for external partners (e.g. members of the C2C-CC) to participate in the CBT. This is because an internal work item in C2C CC called “After Market Devices” has completed a respective profile document and opened the C-ITS Vehicle implementations to fleet operators with the additional after-market C-ITS enabled onboard units - for further details please see <https://www.car-2-car.org/documents>.

The C-Roads hybrid CBT was organised in November 2023 with the Agenda setting as follows:

- day 1, 7.11.2023 for checking all the IP based connections between partners
- day 2, 10.11.2023 for detailed C-ITS message analysis of partners and feedback collection
- day 3: 24.11 Additional analysis feedback day for the participants, after realizing that the message numbers and types published and transferred were high and further work was needed for analysing details.

The C-Roads hybrid CBT was performed as planned and the respective activities and outcomes are reported in the next chapters of this report.

Test data was obtained from own test data received from connecting to various C-Roads C-ITS Brokers that are active and sending out C-ITS messages.

The correct term for this process step is, that C-ITS Brokers are publishing C-ITS messages on so called AMQP based message queues, and external clients are accessing them and requesting to collect them according to their filter settings and criteria, also defined in AMQP.

The C-Roads hybrid CBT aim was to check for a successful message delivery and if the DENM, IVI messages, SPAT/MAP and parking related messages POI and PAM are properly coded compared with the selected version of the C-Roads specifications and the basic standards.

Additionally, C-Roads partners agreed to share C-ITS messages with and without security headers directly included at message level, in order to test both data security related variants.

Here the scope is to test all bilateral connections between the brokers of partners and cross check their message exchange functions, in order to come to a fully meshed network of C-ITS Brokers at the end with the first big step to set the basis for scalability of C-ITS related message exchanges in Europe. The next development steps will then enable access of additional partners (with their C-ITS brokers according to specifications) from Cities, Regions or large fleet operators as C-ITS partners extending the traffic information outreach of connected vehicles extensively.

Following the connection test phase between C-ITS brokers, the message analysis phase in the hybrid CBT is planned and performed by partners, and here the first step is the message check according to the basic message related standards, and in a second step also the cross check for the used versions of the C-Roads communication profiles or the respective vehicle related Basic System Profiles.

As these analysis steps need the full software chain for performing the task along with various competences in the respective teams, it was not done by all the participating partners completely, but there are good examples of message analysis of single partners included in the Hybrid CBT final report.

3. Cross Border Testing Results for ITS-G5

3.1. Quantitative results

Table 1 shows the total numbers of the Test-cases (TCs) that were available to be executed depending on the C-Roads specification release implemented by the MS.

Table 1: Summary of the number of available test cases

Category	N# from R 1.3	N# from R 1.6	N# from R 1.7	N# from R 1.8	N# from R 2.0.1	N# from R 2.0.3	N# from R 2.0.4	N# from R 2.0.5
On-Lab Security test cases	97	0	2	99	88	88	88	88
On-Lab Hybrid test cases	10	0	0	10	10	10	10	10
On-road ITS-G5 test cases	46	29	9	84	105	116	157	165
DENM	25	18	1		85	85	90	98
IVIM	21	4	4		17	28	26	26
SPaTEM-MAPEM	0	7	0		0	0	16	16
SREM – SSEM	0	0	1		0	0	6	6
CAM	0	0	3		3	3	19	19
On-road Hybrid test cases	42	29	6	77	102	113	138	146
DENM	21	18	1		85	85	90	98
IVIM	21	4	4		17	28	26	26
SPaTEM-MAPEM	0	7	0		0	0	16	16
SREM - SSEM	0	0	1		0	0	6	6
Total of test cases	195	58	17	270	305	327	393	409
On-Lab test cases	107	0	2	109	98	98	98	98
On-Road test cases	88	58	15	161	207	229	295	311

For up to five C-Roads releases have been made available PCAP files with nearly 300 test cases for each release, this shows the high effort of partners, but also the many details that need to be checked to confirm C-ITS service interoperability.

Some of the involved MSs executed the tests specifically during PTS. The results are summarized in the Table 2.

Table 2: Summary of the ITS-G5 test case result

Hosting MS	Number of Tested TCs by MS	Passed TCs		Failed TCs		Inconclusive TCs	
		#	%	#	%	#	%
AT	20	18	90 %	1	5 %	1	5 %
DE	13	10	76 %	2	16 %	1	8 %
FL	18	18	100 %	0	0 %	0	0 %
GR	51	40	78 %	1	2 %	10	20 %
HU	35	34	97 %	0	0 %	1	3 %
IT	304	296	97 %	6	2 %	2	1 %
SL	30	30	100 %	0	0 %	0	0 %
IE	66	51	79 %	1	2 %	12	14 %
Total	519	479	92 %	11	2 %	27	6 %

Overall more than 90 % of all CBT test cases (the absolute number is 519) of the C-Roads test campaign were performed successfully and only a rate below 3 % was not concluded successfully, with a rate of not conclusive test cases being 6%.

Finally, many services and Use-Cases (UCs) were validated during these tests. The Table 3 shows the final obtained results.

Table 3: Summary of the ITS-G5 use case summary result by hosting member state

Services	Use-cases	Hosting Member States								
		AT	DE	FL	FR	GR	HU	IT	SL	IE
In-Vehicle Signage (IVS)	Traffic Signs (IVS-TS)			OK		Partial	OK	OK	OK	Partial
	Free Text (IVS-FT)	OK				Partial	OK	OK		OK

Hazardous Locations Notification (HLN)	Accident Zone (HLN-AZ)				OK		OK	OK	OK	
	Traffic Jam Ahead (HLN-TJA)				OK		OK	OK		OK
	Stationary vehicle (HLN - SV)				OK	OK		OK		OK
	Weather Condition Warning (HLN-WCW)				OK	OK	OK	OK		OK
	Temporarily slippery road (HLN-TSR)				OK		OK	OK		
	Animal or person on the road (HLN-APR)				OK		OK	OK	OK	
	Obstacle on the road (HLN-OR)				OK	OK	OK	OK		
	Emergency or Rescue/Recovery Vehicle in Intervention (HLN-ERVI)									
	Emergency or Prioritized Vehicle Approaching (HLN-EPVA)									
	Railway Level Crossing (HLN-RLX)									
	Unsecured Blockage of a Road (HLN-UBR)									
	Alert Wrong Way Driving (HLN-AWWD)									
	Public Transport Vehicle Crossing (HLN-PTVC)									
	Public Transport Vehicle at a Stop (HLN-PTVS)									
Road Works Warning (RWW)	Lane closure (and other restrictions) (RWW-LC)	OK	partial	OK		OK	OK	OK	OK	OK
	Road Closure (RWW – RC)						OK			OK
	Road Works Mobile (RWW-RM)						OK			
	Winter Maintenance (RWW-WM)									
Signalized Intersections (SI)	Signal Phase and Timing Information (SI-SPTI)	OK					OK			
	Green Light Optimal Speed Advisory (SI-GLOSA)	OK	partial		OK		partial			
	Imminent Signal Violation Warning (SI-ISVW)									
	Traffic Light Prioritisation (SI-TLP)									
	Emergency Vehicle Priority (SI-EVP)									
Automated Vehicle Guidance (AVG)	SAE Level Guidance (AVG-SAELG)									
	Platoon Support Information (AVG-PSI)									
Probe Vehicle Data (PVD)	Vehicle Data Collection (PVD-VDC)									
	Event Data Collection (PVD-EDC)									

This shows that RWW and IVS use cases have been implemented and tested by nearly all C-Roads partners and test results were comparable and ok. And overall nine different C-ITS uses cases have been tested by four or more C-Roads partners with a comparable and positive test result. This confirms that also the C-ITS implementations of new C-Roads members are technically mature and C-ITS service oriented.

3.2. Qualitative results

3.2.1 CBT 2022

All participating MSs have found the testing organized efficiently and useful to verify the interoperability not only in terms of the technical requirements but also the interpretations of such requirements. The overall feedback from all participating MSs has been positive. As the quantitative results testify, C-ITS messages met the interoperability requirements in most cases. The summary of qualitative feedbacks exchanged between the MSs is reported in the following Table 4.

Table 4: Summary of the qualitative results of CBT 2022

CBT 2022		
#	Positive	Negative
1	No issues with security (L0)	Malformed packets in the initial PCAPs
2	No packet loss has been observed and, in most cases, packets were well-formed	Event History not present
3	In majority of cases, C-ITS DENM messages were interpreted correctly with event positions, traces, cause and subcauseCode	C-ITS message unsigned
4	In almost all cases, C-ITS IVI messages were interpreted correctly with reference positions, detection, and relevance areas	À-la-carte container empty or missing information
5		traces with overlapping points or nodes arranged inconsistently with the real road
6		Floating RSU positions
7		Absence of logs in the RWW-LC DENM
8		Wrong country code used in IVI messages
9		Communication issues via IP channel / HW issues in some RSU

1 0		Traces shorter than required minimum of 600m
1 1		Incorrect causeCode – subCauseCode

- (1) Malformed packets in the initial PCAPs - the source of the problem was due the threshold of the received signal strength on the V-ITS-S used to capture the PCAPs. For instance, in case of a low RSSI from other ITS stations, the packet may be incomplete or malformed. Necessary steps have been taken to fix this problem, and the new PCAPs have been shared with the partners through the C-Roads cloud.
- (2) Event history is not present in the PCAP for roadworks, weather condition warning use cases. For events that cover an area should include event history to indicate the relevance area of the event.
- (3) In some IVIM messages used for example for Traffic Signs UC appears unsigned C-ITS messages.
- (4) À la carte container: - In some cases the container was present but empty or missing some data (for example on closed lanes, typically because the information was not provided by the road operator). Maybe a definition of closedLanes DE in AlaCarteContainer would be useful for RWW-LC use case.
- (5) In some UCs the first point of the trace is overlapped to the event position. The RWW trailer used for sending out this service was located on an emergency stop bay on the motorway and was slightly moved from time to time prior to the PCAP recording. Usually, a system to mitigate location issues related to GPS jittering is in place. Anyway, there was no impact on interoperability.
- (6) RSU positions provided in Geonet were set dynamically resulting in the fluctuations in its positions. As per requirement RS_RSU_004 in C-ITS Roadside ITS-G5 System Profile document, the RSU position should be measured accurately and set permanently.
- (7) There weren't DENM RWW reporting the closedLanes information expected in the alacarte container. The country code for IVI messages were set incorrectly (Hungary, Italy).
- (8) There were some communication / HW issues in the area of a Junction in Győr, Hungary. Similar issues were also observed during hybrid testing in Italy in intersection areas due to presence of obstacles (trees or buildings).
- (9) In some DENM messages, traces were shorter than 600m, the minimum length required in C-Roads.
- (10) For some use cases (where more than 1 combination of causeCode and subCauseCode are allowed - such as RWW, HLN-WCW or HLN-TJA), incorrect causeCode and subCauseCode were used. Messages themselves did not cause problems for the OBUs but the message delivered to the user was not what was intended (e.g., Road closure instead of Lane closure; Traffic jam over a linear area instead of Dangerous end of queue).

3.2.2 CBT 2023

Though the overall testing has been highly successful with most of messages being received and interpreted correctly, it would be worthwhile to dive into the issues reported to improve the quality of C-ITS services as well as to maximize the harmonization among MSs. One thing to note is that some of the issues reported in CBT 2022 were reported again in CBT 2023 (highlighted in Orange in Table 5). Therefore, it might be necessary to understand as to why these issues tend to resurface and discuss how they can be prevented.

Table 5: Summary of the qualitative results of CBT 2023

CBT 2023		
1	No packet loss has been observed and all packets were well-formed	EventHistory not present
2	In majority of cases, C-ITS DENM messages were interpreted correctly with event positions, traces, cause and subcauseCode	Traces points not in the right sequence or not aligned with the actual road
3	In majority of cases, C-ITS IVIM messages were interpreted correctly with reference positions, detection and relevance zones	Floating RSU positions
4		extraText empty
5		ValidTo missing
6		Spatem - timestamp does not increase by each second
7		Mapem - some ingress and egress not connected correctly in an intersection
8		Mapem - failed to be visualized at some intersections

- (1) EventHistory was missing in some of the use cases (RWW, WCW). Since this is a mandatory field for events that cover an area, it might be necessary that implementers pay more attention to distinguish between point-based and area-based events. This issue was observed also during CBT 2022.
- (2) Same as in CBT 2022, there were some issues discovered for traces. The points of traces were not in the right sequence (overlapping, reverse sequence, etc.) or they were not aligned with the actual road topology. More rigorous field-testing by hosting MS can help prevent such issues during CBT, since the wrong sequence or the misalignment of delta points of a trace is not discernible by looking at the decoded DENM messages.
- (3) Jittering GPS - floating RSU position issues was reported also in CBT 2023. This is a requirement specified in the Roadside C-ITS G5 System Profile but is not included in the test cases. To fix the position of each RSU, the operator (TCC or TMC) needs to modify the default configuration of each RSU (also different for each RSU vendor); which makes it challenging to know the possibility of such a problem in advance.
- (4) Some elements of IVIM such as ValidTo and extraText were observed missing. However, these two elements are no longer “Mandatory” in the recent releases of C-Roads documents.
- (5) Signalized Intersection use cases were tested for the first time during CBT 2023. At most intersections, both SPATEM and MAPEM were received and visualized correctly. Nevertheless, some

SPATEMs did not have timestamp incremented by every second and a few MAPEMS were incorrect: ingress and egress were not connected correctly or the map could not be visualized. More sufficient testing might be necessary to understand the root cause of the issues discovered.

3.2.3 CBT 2024

The cross-border tests in 2024 were fruitful. However, a few harmonization issues were noticed.

Table 6: Summary of the qualitative results of CBT 2024

CBT 2024		
<i>Results from C-Roads Hungary</i>		
1	Lanes for SPTI are sometimes inaccurate	Pre-defined MAPEM information sometimes inaccurate and should be longer.
2	GLOSA suggests lower speed than necessary	The advised speed from GLOSA is lower what would be needed to reach green phase.
3	Crossborder compatibility needs test	Functions OK and tested with various national stakeholders even beyond the project partners. But no CBT with other C-Roads MS were done, due to the lack of participation, even though the tests were well promoted and organized.
<i>Results from C-Roads Antwerp-Helmond</i>		
#	Positive	Negative
1	In all cases, C-ITS DENM messages were interpreted correctly with event positions, traces, cause and subcauseCode	Implementation of security not yet executed.
2	In all cases, C-ITS IVI messages were interpreted correctly with reference positions, detection, and relevance areas	No CBT with other C-Roads MS were done due to timing issues. However, CBT were performed between internal partners, cross-border between Flanders and the Netherlands.

4. Cross Border Testing Results for IP-based Tests

4.1.CBT 2022

4.1.1 Quantitative results

In 2022, additional to the physical or virtual CBT performed by many C-Roads members, also hybrid tests with BI were performed in Austria, France, Italy, Norway and Slovenia with first C-ITS messages and test cases.

Table 7: Summary of the hybrid test case result

Hosting MS	Number of Tested TCs by MS	Passed TCs		Failed TCs		Inconclusive TCs	
		#	%	#	%	#	%
AT	8	5	62	2	25	1	13
Total	8	5	62	2	25	1	13

Note: The information for Table 7 was only provided by Austria.

Table 8: Summary of the hybrid use case summary result by hosting member state

Services	Use-cases	Hosting Member States				
		AT	FR	IT	NO	SI
In-Vehicle Signage (IVS)	Traffic Signs (IVS-TS)		OK			
	Free Text (IVS-FT)		OK			
Hazardous Locations Notification (HLN)	Accident Zone (HLN-AZ)	OK	OK			OK
	Traffic Jam Ahead (HLN-TJA)	Partial	OK			OK
	Stationary vehicle (HLN - SV)		OK			OK
	Weather Condition Warning (HLN-WCW)		OK			OK
	Temporarily slippery road (HLN-TSR)		OK			OK
	Animal or person on the road (HLN-APR)		OK			OK
	Obstacle on the road (HLN-OR)		OK			OK
	Emergency or Rescue/Recovery Vehicle in Intervention (HLN-ERVI)					
	Emergency or Prioritized Vehicle Approaching (HLN-EPVA)					
	Railway Level Crossing (HLN-RLX)		OK			
	Unsecured Blockage of a Road (HLN-UBR)		OK			

	Alert Wrong Way Driving (HLN-AWWD)		OK			OK
	Public Transport Vehicle Crossing (HLN-PTVC)					
	Public Transport Vehicle at a Stop (HLN-PTVS)					
Road Works Warning (RWW)	Lane closure (and other restrictions) (RWW-LC)		OK			OK
	Road Closure (RWW – RC)		OK			OK
	Road Works Mobile (RWW-RM)		OK		Partial	
	Winter Maintenance (RWW-WM)		OK			
Signalized Intersections (SI)	Signal Phase and Timing Information (SI-SPTI)					
	Green Light Optimal Speed Advisory (SI-GLOSA)		OK	OK		
	Imminent Signal Violation Warning (SI-ISVW)			OK		
	Traffic Light Prioritisation (SI-TLP)					
	Emergency Vehicle Priority (SI-EVP)					
Automated Vehicle Guidance (AVG)	SAE Level Guidance (AVG-SAELG)					
	Platoon Support Information (AVG-PSI)					
Probe Vehicle Data (PVD)	Vehicle Data Collection (PVD-VDC)					
	Event Data Collection (PVD-EDC)					

In addition, Italy did some testing for the Vulnerable Road User (VRU). The results are detailed in the Italian report.

4.1.2 Qualitative results

For CBT 2022, external partners participated in the tests: Hyundai, Consider-it and V-Tron to tests in Austria, Stellantis to tests in Italy. The following Table 9 gives an overview of the experiences.

Table 9: Summary of the hybrid qualitative results in CBT 2022

CBT 2022		
#	Positive	Negative
1	Messages were successfully received and satisfied interoperability requirements.	Connection to the server took longer than expected
2	Feedback concerning technical issues like response time as well as concerning readability and recognition of content, was very positive.	SPATEM Messages did not always arrive in a fixed time interval – sudden jumping of phases, possibly due to latency or missed reception

3	Most messages were received within acceptable latency range over IP	Messages in Norway were not completely following C-ROADS specifications
4	Messages with security headers were successfully received.	MAPEM – lateral offset too large

- (1) In France, connection took a longer time to be established than initially estimated because it can only be done through an IPSEC tunnel.
- (2) In Italy, sometimes SPATEM did not arrive in a fixed time interval (some received in less than 1 second apart with different phase information, abruptly jumping from one phase to another, and other times, SPATEM arriving too late). This could have been caused by irregular intervals (SPATEM arriving too early or late) or missed reception. More investigation is needed to pinpoint the cause. This made it difficult for vehicles to provide a smooth transition between acceleration and deceleration when approaching the traffic light and to provide a correct warning for signal violation.
- (3) Some of the fields in the Norwegian messages, e.g., informationQuality, was not according to the C-Roads specifications. This will be corrected in the coming months.
- (4) In some intersections, the lateral offset was too large for vehicles to correctly understand its current position on the lane. Currently lateral offset is allowed up to 3m but this value is too high. Needs discussion with car makers as to which value is acceptable.

4.2.CBT 2023

4.2.1 Quantitative results

In CBT 2023, several MS participated in analyzing C-ITS messages received from the brokers of Italy, Austria and Slovenia. From the participating C-Roads Members FRA, ITA, SLO, AUT and Nordic way (Sweden, Norway) and external partners from C2C CC connections between brokers have been established and message exchange has been done between most of them.

Generally, an impressive amount of C-ITS messages has been made available and shared between the participating countries and partners. As a snapshot value, over 2.28 million active and valid C-ITS messages were available for an hour as shown in the table below.

Table 10: C-ITS Broker in Slovenia and message counts on the C-Roads CBT day, 7.11 – 10.00 to 11.00 message count

Country	Type	Count	Notes
AT	IVIM	41.541	
AT	DENM	7.348	
FR	SPATEM	1.923.165	
FR	DENM	2.410	
FR	IVIM	5.406	
FR	POI	1.086	

FR	MAPEM	3.526	
IT	MAPEM	125.878	
IT	SPATEM	125.878	
IT	IVIM	38.802	
IT	DENM	2.005	
IT	PAM	3.100	
IT	DENM - WARN	269	DENM with problems when decoding
SI	DENM	7.080	

Over the one hour period of the C-Roads CBT event 18.000 traffic events (and the respective DENMs as warnings) were online and therefore present on the involved roads of the TEN-T network.

Another representation of the exchanged messages to one of the participating partners in the CBT is the following diagram.

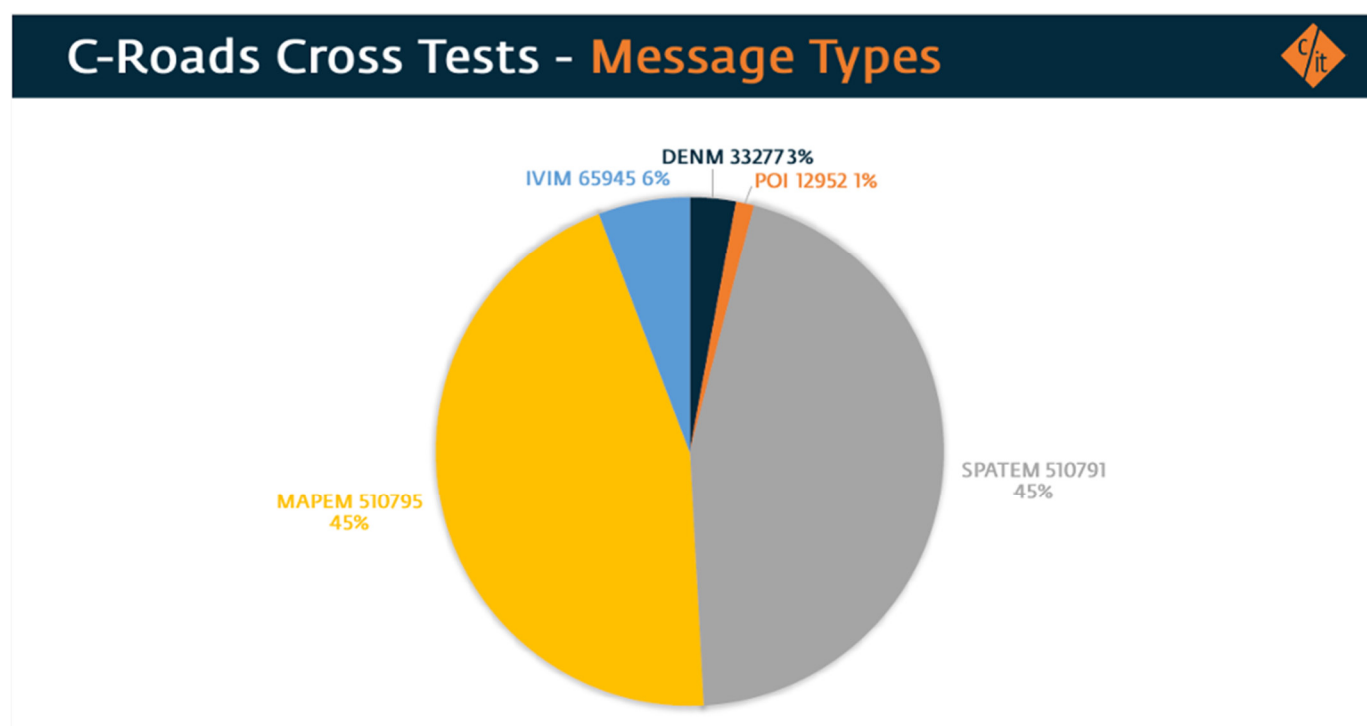


Figure 8: C-ITS message types transferred from participating Brokers, source Consider-IT Hamburg, Germany

More details for the connections and overall insights can also be gained from the feedbacks collected from involved partners from C2C CC with their message statistics but also other representations, e.g. like C-ITS message heatmaps.



Figure 9: C-ITS message transferred from participating Brokers and their geographic locations, Italy, Slovenia, source Consider-IT Hamburg, Germany

4.2.2 Qualitative results

The C-ITS message analysis was done by some of the partners and first outcomes of this message-based analysis are included in the following chapters of the report, with the limitations that not all partners have performed a complete message analysis for various reasons.

CBT 2023		
#	Positive	Negative
1	Most messages were successfully received and satisfied interoperability requirements	Some messages did not have security headers
2	Most messages were received within acceptable latency range over IP	DENMs received from Slovenia did not have some mandatory data elements
3	Most messages had security headers	Some IVIM, SPATEM messages did not have correct Geonet settings sometimes (payload length, port, etc.)
4		MAPEM - lane width always set to 3m and sometimes the reference point was not in the center of the intersections
5		Some IVIMs from Italy were mal-formed and could not be decoded

6		Some service providers could not be discerned in IVIMs
---	--	--

Table 11: Summary of the hybrid qualitative results in CBT 2023

- (1) Messages from Italy except A22 did not have security headers. The PKI had been switched off to prevent latency issues during testing. This issue has been fixed by amplifying the capacity of backend C-ITS server
- (2) All DENMs received from Slovenia were missing traces, semiMajorConfidence, semiMajorOrientation, semiMinorConfidence and altitudeValue
- (3) IVIMs from Italy did not have the payload length correctly set in Geonet. Some DENMs / SPATEMs also had incorrect port information
- (4) The lane width was already set to 3m in MAPEM which rendered Delta elements zero. The lane width should be set dynamically to match the actual width of the lane. Sometimes the reference point was not set in the center of the intersections.
- (5) Some IVIMs from Verona, Italy were malformed due to the extraText element being larger than max allowed.
- (6) Service providers in IVIMs could not be discerned. This was caused by some partners in Italy not yet assigned official provider IDs. IVIMs used temporary service provider IDs during the test.

4.3.CBT 2024

4.2.3 Quantitative results

In 2024, cross-border tests took place between Flanders and the Netherlands. In Flanders, the Mobilidata Interchange functions as the BI and broker. No security headers were used, as the communication channels are only accessible to parties that have been IP whitelisted.

Table 12: Summary of the hybrid test case result

Hosting MS	Number of Tested TCs by MS	Passed TCs		Failed TCs		Inconclusive TCs	
		#	%	#	%	#	%
FL	118	118	100	0	0	0	0
Total	118	118	100	0	0	0	0

Table 13: Summary of the hybrid use case result by hosting member state

Services	Use-cases	Hosting Member States
		FL
In-Vehicle Signage (IVS)	Traffic Signs (IVS-TS)	OK
	Free Text (IVS-FT)	
Hazardous Locations Notification (HLN)	Accident Zone (HLN-AZ)	OK
	Traffic Jam Ahead (HLN-TJA)	OK

	Stationary vehicle (HLN - SV)	OK
	Weather Condition Warning (HLN-WCW)	
	Temporarily slippery road (HLN-TSR)	
	Animal or person on the road (HLN-APR)	OK
	Obstacle on the road (HLN-OR)	OK
	Emergency or Rescue/Recovery Vehicle in Intervention (HLN-ERVI)	OK
	Emergency or Prioritized Vehicle Approaching (HLN-EPVA)	
	Railway Level Crossing (HLN-RLX)	
	Unsecured Blockage of a Road (HLN-UBR)	
	Alert Wrong Way Driving (HLN-AWWD)	OK
	Public Transport Vehicle Crossing (HLN-PTVC)	
	Public Transport Vehicle at a Stop (HLN-PTVS)	
Road Works Warning (RWW)	Lane closure (and other restrictions) (RWW-LC)	OK
	Road Closure (RWW – RC)	OK
	Road Works Mobile (RWW-RM)	OK
	Winter Maintenance (RWW-WM)	
Signalized Intersections (SI)	Signal Phase and Timing Information (SI-SPTI)	
	Green Light Optimal Speed Advisory (SI-GLOSA)	
	Imminent Signal Violation Warning (SI-ISVW)	
	Traffic Light Prioritisation (SI-TLP)	
	Emergency Vehicle Priority (SI-EVP)	
Automated Vehicle Guidance (AVG)	SAE Level Guidance (AVG-SAELG)	
	Platoon Support Information (AVG-PSI)	
Probe Vehicle Data (PVD)	Vehicle Data Collection (PVD-VDC)	
	Event Data Collection (PVD-EDC)	

4.2.4 Qualitative results

The hybrid cross-border tests in 2024 were insightful. A few issues were noticed, addressing these on C-Roads Platform level could improve harmonization and overall service quality and availability.

Table 14: Summary of the hybrid qualitative results in CBT 2024

CBT 2024		
#	Positive	Negative
1	Messages were successfully received and satisfied interoperability requirements.	Quality of the GPS positions.
2	Feedback concerning technical issues like response time as well as concerning readability and recognition of content, was very positive.	No CBT with other C-Roads MS were done due to the duration of administrative processes and required external approval to connect to the BI. Tests were only performed between internal partners, cross-border between Flanders and the Netherlands.
3	Most messages were received within acceptable latency range over IP.	

- (1) The occurrence of jittering of GPS positions was noticed. This can be counteracted through high performing map-matching algorithms and tools that translate possibly inaccurate GPS positions to accurate GPS positions as map-matching float car data (FCD). Therefore, impact on the outcome of the IP-based tests could be avoided.

5. Conclusion

5.1. European harmonization subjects to be raised

This chapter summarizes the European harmonized subjects to be raised to other TFs and Standardization organisations. The corresponding list of related issues with full descriptions and proposals can be found in the Appendix A. It is possible that some issues are already clear in the profile without any need for revision.

DENM

- Traces of DENM not visualised properly
- Coding of warnings for area events is not clear in current specifications

SPATEM & MAPEM

- Latency problem needs to be considered for IP channel
- Missing signs
- Standards
- Length of entry lanes
- Distribution of messages
- Incorrect timestamps
- Intersection names
- Sending frequency

USE CASES

- Not all data element options are implemented at the UC RWW-LC
- Issues with RWW notifications
- Traces, trace points
- Coding for area events

C-ITS

- Messages from other stations
- Data broker, message container
- Duplicated test messages
- Completeness of details
- Need for testing of effects caused by “GPS jittering”

GENERAL

- Improper county code, junction not working
- Few messages do not comply with C-Roads specifications

5.2. Learned lessons for cross border interoperability

Learned lessons from these CBTs can be grouped into two broader categories: one is the learned lessons related to the cross-border ‘interoperability’ of C-ITS services implemented by the member states; and the second one is the learned lessons related to the cross-border ‘tests’ themselves.

Learned lessons related to cross border interoperability

Most of the members participated in the CBT find that the C-ITS messages broadcasted by the CBT hosting MSs were generally compliant with the C-Roads specifications, which made the implementations generally interoperable. However, there are some lessons learned during these CBTs by the participants shows that there are still rooms for improvements to ensure better interoperability of C-ITS implementation across Europe.

The CBTs in Greece that performed with PTS by Ireland and VTS by Italy highlight that the C-ITS messages are well coded, and the visiting OBUs received and decoded the C-ITS messages as expected. Based on the overall results and findings, interoperability of the implemented services in Greek pilot site complied to the C-Roads specifications.

However, as stated by the Irish reviewers in their feedback report, beyond interoperability of messages based on current C-Roads specifications, some issues regarding the content of the C-ITS messages need further attention both at implementers level and C-Roads WG2 specifications level. For example, the proper way of setting various data element parameters in DENMs like “relevanceDistance” and “Traces” to some event (especially for weather condition warnings) create a need for more explicit clarification of the specifications in order to warn the drivers more accurately and meaningfully. These ambiguities are addressed recently by the new version of DENM/CCD V2.1.1 (ETSI TS 103 831] V2.1.1), which allows more properly encoding of all types of geographical situations (i.e. relevanceDistance becomes awarenessDistance, relevance area becomes awareness area, etc.).

Another issue that seems that might lead to “missing messages” by the OBUs/drivers is in the case of road sections with complex layout including long tunnels or successive close-up tunnels where it is possible for the OBU to miss the GPS signal and cannot decide anymore which messages are relevant to it. This finding might need further elaboration from both WG2 and OBU OEMs.

Similarly, Italian reviewers stated in their feedback report that beyond interoperability of messages according to the C-Roads specifications, there are some issues regarding the content of the C-ITS messages, especially, some traces of the DENM are not well coded, i.e. some of the traces had overlapping points or nodes arranged inconsistently with the real road. In addition, the RWW-DENM were spatially valid only in the reference position of the DENM since there was no event history in the situation container: if a working area on the road is present, the DENM event history should cover all that area.

In addition, during the physical CBT session in Italian pilot site Autostrada BSPD, the Irish participants reported that one of the RWW-LC use case events that contained 2 closed lanes was notified with a separate DENM for each closed lane (i.e., 2 DENMs for 2 closed lanes). Although the DENMs are

referenced to each other, their OBU showed this event as 2 separate lane closure notifications (please see the 10 below). Meanwhile, another CBT participant's OBU showed only one lane closure notification since it was designed to show only one DENM event at a time.

It is worth noting that notifying multiple lane closures with multiple DENMs is not against the current C-Roads specification. However, it has highlighted a key issue with regard to the harmonization/interpretation of different OBUs. This issue was discussed with the host and raised at the TF3 and TF5 technical meetings. It is expected that the new RWW handbook that is being prepared by WG2 will address this issue and provide a common approach for harmonization.



Figure 10: Example of 2 separate lane closure notifications

Learned lessons related to cross border tests

In general, the methodology developed by C-Roads to execute cross-border tests to achieve and prove interoperability has proven well during these CBT activities. This includes the defined CBT process with access to test materials and files well in advance of the scheduled test to all partners, sharing all C-ITS use case related messages in PCAP file format, including the security headers, if they are part of the CBT test. However, there are few points suggested by the MSs who participated in the CBT for a further improvement for CBT.

Suggestion by France:

- During the CBT (via Hybrid interface), the members need to take into consideration the fact that connection to the central station (Nfr-ITS-S) take longer to be established than usual when it is done through an IPSEC tunnel.
- It is better to coordinate on the method of analysis and its scope between all stakeholders, before the CBT.
- Also, it is vital to have a preparatory meeting with the partners involved and making sure that participants have clear understanding of all the necessary procedures of the CBT.

Suggestion by Germany:

- For a virtual CBT, better feedback on who has downloaded the shared material provided for the CBT can provide some indication on the level of interest in the CBT, even if no further testing is done and no test report is shared.
- A common report template for the visitors could provide an easier compilation of the results by the hosting member.
- In addition to the data elements critical for interoperability, some additional elements can be validated during cross-tests with various partners to check for a good presentation of the service to the road users.

Suggestion by Hungary:

- For a C-ITS system that is connected to the real traffic management system (as in Hungary), not all supported use cases may be available during the CBT, since the available use cases are dependent on the real events on the road networks. Therefore, it is better to have a separate module/component that enables simulated events of all supported use cases for the CBT.

Suggestion by Slovenia:

- Like Hungary, Slovenia finds that a functionality for manual triggering and sending C-ITS messages from C-ITS back-office system was very useful for testing purposes.

The following suggestions were made from the CBT 2023

Suggestion by France (from the Irish CBT):

- France indicated that harmonisation of pictograms displayed for C-ITS use cases should be needed to improve common understanding of the events. However, it was understood that the pictograms displayed on the HMI in response to the C-ITS use cases are out of scope for C-Roads.

Suggestion by Italy:

- It would be very important to check if the visiting MS and hosting MS are following the “compatible” versions of C-Roads requirements before the CBT.

5.3. Summary of the cross-border tests

As mentioned in the previous sections, several bilateral physical and virtual cross border tests were conducted between the participating member states. The tests covered both short range (ITS-G5) and Hybrid (IP based) communication.

Cross border testing is summarized in the following:

Preparations and call of interest:

The test runs were conducted in the period between 2022-2024. Prior to testing a call of interest to participate in CBT was sent out to the C-Roads partners. Fact sheets explaining the pilot sites and use-cases supported were made public by the hosting MSs and technical meetings were held with the visiting MSs before the actual test runs.

ITS-G5 2022, 2023 and 2024:

The physical tests (PTS) with ITS-G5 went smoothly with a high success rate (>92%), where almost all the use-cases /services supported by the individual test site were tested successfully and no significant interoperability issues were found. Some tests were deemed to be inconclusive, but that can be attributed to interpretation of specifications. Same is the case for other minor issues reported by the pilots, where setting of DE like “relevanceDistance” and “Traces” in DENM need further clarifications in the specifications.

Due to non-availability of testing partners for PTS, a few MSs chose to conduct VTS only, which involved exchanging and decoding PCAP files. The overall results have proven to be positive with no major interoperability issues.

Hybrid (IP-based) 2022:

Hybrid testing was carried out by connecting to interchange node of the hosting country and checking if the published messages were received correctly. This was merely a test of interface between the sender and the receiver and did not involve checking the content of the received messages. Tests to investigate the concept of federated interchange nodes was also carried out.

No anomalies were reported for the hybrid test cases and the participating MSs were able to connect and receive messages successfully. A member state reported longer connection times due to use of secure tunnels. Otherwise, no interoperability issues have been reported.

Hybrid (IP-based) 2023:

This time a coordinated Hybrid testing with detailed validation of the C-Roads specifications were carried out. It was highlighted that testing and validation of a profile specification is a high effort for all partners involved. However, additional insights are gained as well – e.g. very high number of messages exchanged and stability of the implemented systems found to be already high.

Hybrid (IP-based) 2024:

This year, hybrid testing took place between Flanders and the Netherlands. The tests were not open to other MS or external parties, due to the duration of administrative processes and required external approval to connect to the BI. No issues were raised to the WG2.

6. Appendix A: List of European harmonization subjects

6.1. Point 1

USE CASES: Not all data element options are implemented at the UC RWW-LC

Reported by: Germany

Comment: According to the C-Roads specifications, the UC RWW-LC with the essential information of a closed lane can be communicated by using the trafficFlowRule as part of the roadWorks container or with the data element closedLanes in the alacarte container.

These two options are properly included in the C-Roads specifications. During the tests however, the receiving side from the testers had only implemented one of these options which has caused an inconclusive test result.

Proposal from TF3: centrally generated DENMs shall include the closedLanes. Locally generated DENMs shall at least provide trafficFlowRule and can additionally provide closedLanes, if available.

6.2. Point 2

USE CASES: Issues with RWW notifications

Reported by: Italy

Test site: Autostrada BSPD Test Site

Comment: Comment: There were some issues identified with the RWW notifications. For example, one of the RWW-LC use case events contained 2 closed lanes. This event was notified with a separate DENM for each closed lane (i.e., 2 DENMs for 2 closed lanes). In our opinion, these are the result of not very clear or explicit guidance in the C-Roads specifications, which leads to different interpretations by the implementors.

Proposal from TF5: the new RWW handbook that is being prepared by WG2 should address this issue and provide proper guidance for implementors.

6.3. Point 3

DENM: Coding of warnings for area events is not clear in current specifications

Reported by: Italy

Test site: Autostrada BSPD Test Site

Comment: Coding of DENM warnings for area events such as WCW for fog is not very clear in the current specifications. For example, it allows the implementors to choose either relevanceDistance or eventHistory, as well as options to choose relevanceTrafficDirection based on event types. In our opinion, these leaves more room for different interpretations by the implementors. For example, in the tested HLN-WCW use case (i.e., fog warning), the warning was sent out as a separate DENM for each direction with eventHistory and the relevanceTrafficDirection set to upstreamTraffic. This works for the

tests, but in reality, it is difficult to provide accurate eventHistory for such large area events, especially if the event covers a complex road section such as an intersection.

Proposal from TF3: The DENM release 2 update contains a proper guidance on how to indicate the relevance for area events. This is from our perspective already resolved with C-Roads release 2.0.7.

6.4. Point 4

SPATEM & MAPEM: Latency problem needs to be considered for IP channel

Reported by: Italy

Test site: Turin and Trento Test Site

Comment: For IP channel, it is important to take into consideration the latency problem. Especially for messages like SPATEM, MAPEM that need to be updated frequently, it would be necessary to set a range of acceptable latency over the IP channel. As seen in the testing by Stellantis (real physical vehicle) in Turin and Trento, SPATEMs in general arrived on time but there were some occasions where the SPATEM arrived too early or too late with changed phase information (note: both Trento and Turin have the “adaptive” traffic light control system, hence phase timing may change often and abruptly), resulting the vehicles to provide false positive or false negative information to the drivers.

Proposal from TF5: the current specification for lateral offset for MAP should be revised. It is currently allowed up to 3m lateral offset but this results to be too wide for the vehicles to understand its correct position on the lanes.

6.5. Point 5

USE CASES: Traces, trace points (Hungarian test)

Reported by: Austria

Comment: Many trace points of the RWW trailer were inserted in the trace and heading in different directions, (because it was moved in the ABM Inzersdorf this way). Such a trace would be misleading on the roads (especially motorways) and not make it possible to be interpreted correctly by the vehicle. The length of the trace, especially for IVIM on the S1 motorway was very extensive (up to 5 kilometres length).

Proposal from TF3: In C-Roads release 2.0.8, an update on that will be provided.

6.6. Point 6

USE CASE Weather Condition Warning (HLN-WCW): Coding for area events (Irish test)

An issue/inconsistency in the C-Roads specifications for implementation of HLN-WCW use case was identified. Specifically, the message profile settings of DENM for area events such as WCW is not very clear in the current specification. For example, the current C-Roads specifications for DENM events allows the implementors to choose either relevanceDistance or eventHistory, as well as options to

choose relevanceTrafficDirection based on event types. This may leave different interpretations by different implementors and result in interoperability issues. Therefore, a clear harmonised approach is needed in C-Roads specifications for notifying area events such as weather events.

6.7.Point 7

USE CASES: Need for testing of effects caused by “GPS jittering” (Italian test)

One of the important issues discovered during the CBT was the “jittering GPS” of the RSU. This is actually listed as one of the requirements in the Roadside ITS-G5 profile of C-Roads but it was not possible to mark it as “fail” since there is no test case. It might be useful to review the Roadside ITS-G5 document to see if there are some requirements for which we can create some test cases for verification.

7. Appendix B: List of all the detailed MS reports

The full document including the Appendix B will be provided to CINEA for the validation of the milestone. The publication status of the single MS reports will be analysed further by the Supporting Secretariat for a potential later publication. The separation by “-” in the following list indicates if the respective report was available for the first version of this report or if it was included during the update process.

7.1. Detailed results for Austria

C-Roads_TF5_TestReport_AT

Testreport_AT_Vienna_Innering_v01_03Novr22_v1.0_15Nov (CBT 2022)

-

C-Roads_TF5_TestReport_Austria_Dresden (CBT 2023)

7.2. Detailed results for France

C-Roads_TF5_French Tests Report for CBT_V0.8 (CBT 2022)

-

7.3. Detailed results for Germany

C-Roads_TF5_TestReport_Germany_V1-0 (CBT 2022)

-

C-Roads_TF5_TestReport_Germany_V1-1 (CBT 2023)

7.4. Detailed results for Greece

C-Roads_TF5_TestReport_Template_V1.1_GREECE_v0.2 (CBT 2022)

-

7.5. Detailed results for Hungary

C-Roads_TF5_TestReport_HU (CBT 2022)

-

C-Roads_TF5_TestReport_HU_2024 (CBT 2024)

7.6. Detailed results for Italy

C-Roads_TF5_TestReport_Italy_November2022_V1.2 (CBT 2022)

-

C-Roads_TF5_TestReport_2023_Italy_v1.3 (CBT 2023)

7.7.Detailed results for Slovenia

C-Roads_TF5_TestReport_SI_V2.1 (CBT 2022)

-

7.8.Detailed results for Nordic Countries (Sweden, Norway)

C-Roads_TF5_TestReport_Nordic (CBT 2022)

-

7.9.Detailed results for Ireland

-

C-Roads_TF5_M26_TestReport_Ireland v1.1 (CBT 2023)

7.10. Detailed results for Hybrid Testing Group

-

Testreport_Hybrid_Crosstest_112023_C-Roads_v6 (CBT 2023)

7.11. Detailed results for Antwerp-Helmond (Flanders, the Netherlands)

-

C-Roads_TF5_TestReport_Flanders_(CBT_2024)