Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

Trusted Integrity and Authenticity for Road Applications (TIARA)

Operation of Public Key Infrastructures: State-of-the-art and best practices

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Deliverable D2.1 Version 1.0

Date 30/08/2024

CEDR Call 2022 Data: Integrity, Authenticity, and Non-Repudiation integrated in Trust Models for C-ITS applications

Trusted Integrity and Authenticity for Road Applications (TIARA)

D2.1 Operation of Public Key Infrastructures: State-of-the-art and best practices

Due date of deliverable: 30/06/2024

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1 Executive summary

We use digital certification to assure the identity of people and devices, as well as the authenticity and secrecy of information. A Public Key Infrastructure (PKI) makes sure that the certificates can be trusted, and involves the set of roles, policies, hardware, software, and procedures needed to create, manage, distribute, use, store, and revoke digital certificates. For cooperative intelligent transport systems (C-ITS), digital certificates can be used to establish trust between vehicles and traffic infrastructures. This again allows them to interact with each other, share data and make decisions in a safe and secure manner.

The work started with conduction of interviews with relevant stakeholders. We have carried out seven interviews which provided input from a total of ten informants, mainly from European road authorities and road operators, but also from private actors and the European Root CA provider. Furthermore, we have organized two expert workshops in collaboration with the other project partners, in which a total of 12 informants engaged in PKI related discussions. The total number of informants was 18, as some participated in both activities.

The interview and workshop findings show that the roll out of PKIs for C-ITS in Europe is currently limited, however, Austria and Germany have managed to establish a significant C-ITS road infrastructure. National Road Authorities (NRAs) are expected to play a key role in the establishment and operation of PKIs, but the service will likely be outsourced to specialist companies.

C-ITS service providers will need to work closely with car manufacturers, as the performance of integrated C-ITS functions will directly influence user experience and the manufacturer's reputation. There are already several providers of C-ITS PKI services, including OEMs like Volkswagen.

Operating a PKI requires specific competence and resources, leading many C-ITS stakeholders to outsource their PKI needs. Lessons from other industries highlight the need for operational practices to reflect organizational structures and the importance of minimizing complexity.

2 Introduction

2.1 About TIARA

The objective of the TIARA project (*Trusted Integrity and Authenticity for Road Applications*) is to provide the National Road Authorities (NRAs) with an increased understanding of what is required to achieve a trustworthy and secure data infrastructure. The availability of data has allowed road users and NRAs to benefit from new business models. To deliver these benefits, the data infrastructure must be trustworthy and trusted, i.e., secure, with assurances that it is managed to achieve privacy for all stakeholders.

As more Cooperative Intelligent Transport Systems (C-ITS) services develop in Europe, and road users access and share more C-ITS data through open border countries, NRAs will need to ensure greater interoperability through common approaches to connected systems. Data trust is therefore paramount.

CEDR is undertaking a series of projects to research how NRAs can maintain and share the digital road infrastructure data and improve the use of third-party data by NRAs. The C-Roads platform (se section 3.1.1) has provided an overview of such projects(C-Roads, 2023), most of which involve CEDR members. C-Roads has also provided a roadmap(C-Roads, 2024), presenting a timeline of past, present and future initiatives.

Since the C-Roads Platform has started, several ITS programmes have been rolled out and it has been identified that there are key elements that the NRAs will need to understand before implementing these systems more widely. The TIARA project has been designed to address the two key areas of Trust and Privacy in C-ITS applications. The first subject Trust concerns an understanding of the implementation of trust models that could protect C-ITS data. The second subject Privacy concerns an understanding of the impact of processed user personal data, including location.

Three broad research areas have been identified:

- Trust for C-ITS applications to develop practical guidance for the implementation of Public Key Infrastructure (PKI) for C-Roads,
- Legal and ethical ramifications for NRAs when making use of C-ITS data, and of how these change the role of the NRAs,
- Privacy impact of the processed road user location data, and recommendations to improve the location privacy-preservation for NRAs.

An experienced team of European research organisation have gathered under the coordination of AESIN/Techworkshub, the UK-based member trade association. To address this complex topic, we recognise that the best approach will be through network engagement with many organisations and individuals with experience and technical expertise, preferably independent of any specific solution vendors.

AESIN/Techworkshub belongs to the Techworkshub organisation, through which it has access to member experts in both transport and Internet-of-Things (IoT) security sectors.

SINTEF, as an independent and non-profit research organisation, has independent technical expertise and deep experience from PKI deployments in multiple sectors.

Traficon has longstanding experience of independent work with NRAs, specifically legal and ethical expertise of particular relevance to this project.

TML, bridging the gap between university and private sector, is an independent open and transparent organisation with extensive experience of data analyses and privacy ramifications.

Linking the three broad research areas identified to expertise of these organisations provides a natural project delivery structure, which will benefit CEDR and all the stakeholders involved.

A key TIARA objective is to deliver the project in close liaison with CEDR and its members, as well as the two research projects funded in the CEDR 2022 Research call on Data, Topics A (DROIDS[1]) and B (PRESORT[2]). The liaison ensures that results are fully compliant with CEDR and Programme Executive Board (PEB) expectations. The liaison also guarantees that the DROIDS and PRESORT projects have the possibility to utilise TIARA results and vice versa.

2.2 Purpose of this document

The primary purpose of this document is to provide a comprehensive overview of the ongoing roll-out of the C-ITS PKI within the European NRAs. In addition, this document offers an overview of both commercial entities and public organisations that are currently providing “X.1609 PKI” functionality. This information is crucial for stakeholders interested in the broader adoption and application of C-ITS PKI technology. Finally, this document presents lessons learned from the operation of PKI and identity governance in other adjacent sectors. These lessons provide valuable insights and best practices that can guide future implementations and operations of PKI systems.

Below is a list of the expected outcomes for the PKI related deliverables in the TIARA project. Those marked with bold font are the main objectives for this document, but the remaining objectives will also be addressed to some degree and will receive further attention in a later deliverable.

- **EO1 Review of the current stake of PKI roll-out in European NRAs (State of the art)**
- EO2 Analysis of the issues and problems that NRAs will encounter when developing PKI infrastructure.
- EO3 Advice for building the organisations required to run a nationwide PKI infrastructure that is interoperable with Europe, and advice on outsourcing PKI services.
- **EO4 Lessons from other industries (finance, healthcare, etc.) on operation of a PKI infrastructure.**
- **EO5 Lessons from other industries (license plate registry, etc.) on governing of identities.**
- EO6 Guidance on the use of role-based and identity-based PKI.

[1] https://www.droids-project.eu/
[2] https://www.cedr.eu/call-2022

- EO7 Analysis resources required to run C-Roads PKI infrastructure, including how the cost and computational requirements scale, and the administration required for certificate and key management.
- **EO8 View of commercial and public organisations offering X.1609 PKI functionality**
- EO9 Advice for developing PKI systems that provide trust across multiple parties, for example extending the trust infrastructure to road workers or maintenance companies.

2.3 Structure of this document

This document is structured as follows: Section 3 provides the background for the deliverable and introduces relevant C-ITS initiatives and organisations. Section 4 presents the methodology used, and in section 5 we present our findings. Finally, the deliverable is concluded in section 6.

2.4 Acronyms

AA	Authorisation Authority
ACARS	Aircraft Communications Addressing and Reporting System
ARINC	Aeronautical Radio, Incorporated
ATA	Air Transportation Association
ATM	Air Traffic Management
C2C-CC	Car 2 Car Communication Consortium
CA	Certificate Authority
CDMA	Code-Division Multiple Access
CEDR	Conference of European Directors of Roads
CEO	Chief Executive Officer
C-ITS	Cooperative Intelligent Transport Systems
CL-PKC	Certificateless-Public Key Cryptography
CPA	Certificate Policy Authority
CPOC	C-ITS Point of Contact
CRL	Certificate Revocation List
DG MOVE	Directorate-General for Mobility and Transport
DoRN	Description of Research Needs
EA	Enrolment Authority
EC	European Commission
ECTL	European Certificate Trust List
eIDAS	electronic IDentification And trust Services
ENCAP	The European New Car Assessment Programme
ETSI	European Telecommunications Standards Institute
EU	European Union
EU CCMS	EU C-ITS Security Credential Management System
EUDI	European Digital Identity

GmbH	Gesellschaft mit beschränkter Haftung (company with limited liability)
GSM	Global System for Mobile Communications
IBC	Identity-Based Cryptography
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet-of-Things
ITS	Intelligent Transport Systems
LTE	Long-Term Evolution
NAP	National Access Point
NRA	National Road Authority
OCSP	Online Certificate Status Protocol
OEM	Original Equipment Manufacturer
OPEX	Operational Expence
PEB	Programme Executive Board
PKI	Public Key Infrastructure
RCA	Root Certification Authority [remove, and stick to "Root CA"?]
RTTI	Real-Time Traffic Information
SRTI	Safety-Related Traffic Information
SSP	Service Specific Permissions
TIARA	Trusted Integrity and Authenticity for Road Applications
TLM	Trust List Manager
TRA	Transport Research Arena
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VW	Volkswagen
WP	Work package

3 Background

3.1 Relevant C-ITS initiatives and organisations

The following sections present a selection of the most relevant initiatives and organisations, along with relevant documents for communication and information security in European C-ITS systems.

3.1.1 C-Roads

The C-Roads Platform is a cooperation of member states and road operators, working towards harmonized and interoperable C-ITS services in Europe. C-Roads is co-funded by the European Union.

The main goals are to link C-ITS deployment across Europe, to develop, share and publish common technical specifications, and to test and verify interoperability between deployments and nations. These efforts aim to enable coherent C-ITS deployment in European Union, for both long-term and large-scale roll-outs.

The C-Roads steering committee consists of representatives from the member states and infrastructure operators, and provides an interface to all internal and external stakeholders. The steering committee receives decision support from various working groups and task forces. The C-Roads organisational and operational structure is illustrated in Figure 1.

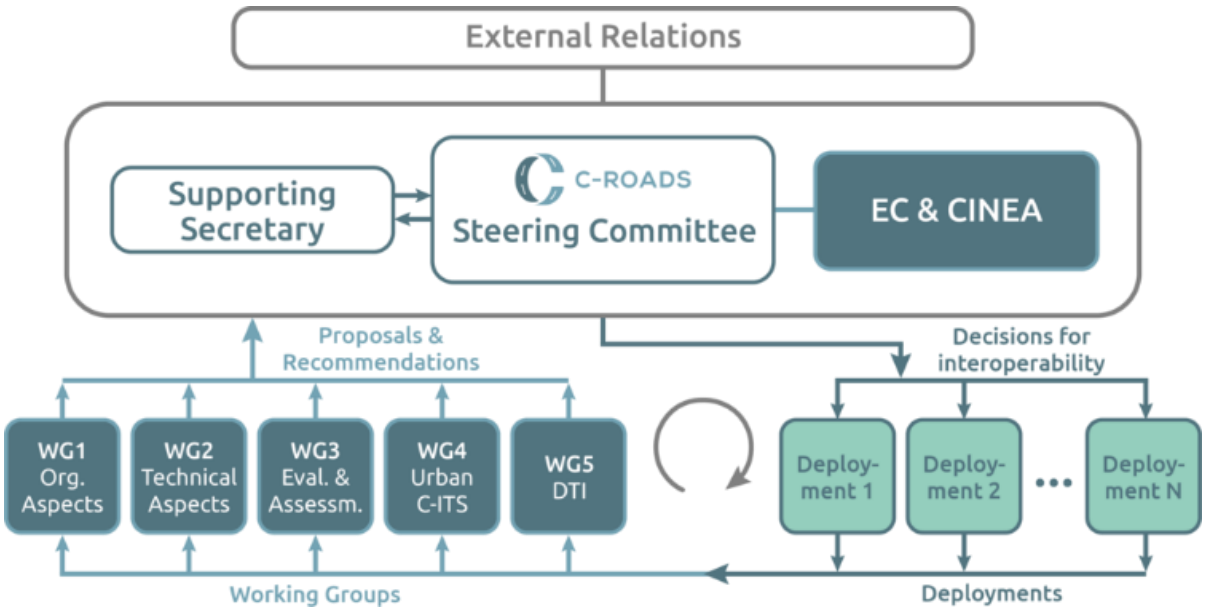

Figure 1: C-Roads organisation and operation (https://www.c-roads.eu/platform/about/about.html)

More information, including various relevant reports and other documents, can be found on the C-Roads homepage (https://www.c-roads.eu/platform.html).

3.1.2 Car 2 Car Communication Consortium (C2C-CC)

The CAR 2 CAR Communication Consortium is a group of vehicles manufacturers, equipment suppliers, engineering companies, road operators and research institutions which have joined forces to enhance road safety and traffic efficiency through research and development of C-ITS solutions. Their work focuses on interoperability across vehicle classes and borders, leveraging V2X communication for safer, cooperative driving.

C2C-CC was founded in 2002 and aims for global standardisation and the promotion of C-ITS to achieve a vision of zero road accidents. The C2C-CC organisational structure is illustrated in Figure 2.

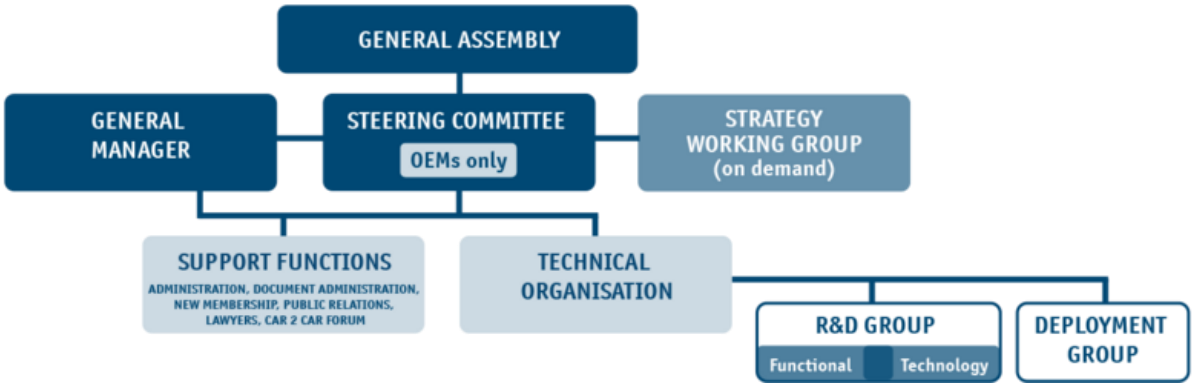

Figure 2: C2C-CC structure

More information can be found on the C2C-CC homepage (https://www.c-roads.eu/platform.html).

3.1.3 NAPCORE

NAPCORE (National Access Point Coordination Organisation for Europe) is an initiative aimed at harmonizing mobility data across Europe. It was established in response to the ITS Directive 2010/40/EU, which mandates that each European Member State must set up a National Access Point (NAP) for mobility data. These NAPs serve as repositories where mobility-related data is published and made accessible, primarily for use in travel information services. The NAPCORE project seeks to improve the interoperability of these NAPs, ensuring consistent and coordinated access to mobility data used for travel information services. NAPCORE is co-funded by the European Union.

More information can be found on the NAPCORE website (https://napcore.eu/)

3.1.4 EU CCMS

The European Union C-ITS Security Credential Management System (EU CCMS) is a framework set up by the European Commission. It relies mostly on two main documents[3], the Certificate policy (Joint Research Centre, 2024) and the Security policy (Joint Research Centre, 2023).

[3] Updated versions of the EU CCMS policy documents can be found at https://cpoc.jrc.ec.europa.eu/Documentation.html

The European Commission aims to offer support for European C-ITS deployment with three different levels of TLM services. The first level, L0, is used for testing and pilot purposes. L1 is the intermediate level, where stations and use cases are in operation, but with some exceptions regarding regulations. The final level is L2, and here the stations and use cases need to be fully compliant with the regulation. L0 only requires a self-declaration, whereas L1 and L2 entail a regulation assurance process.

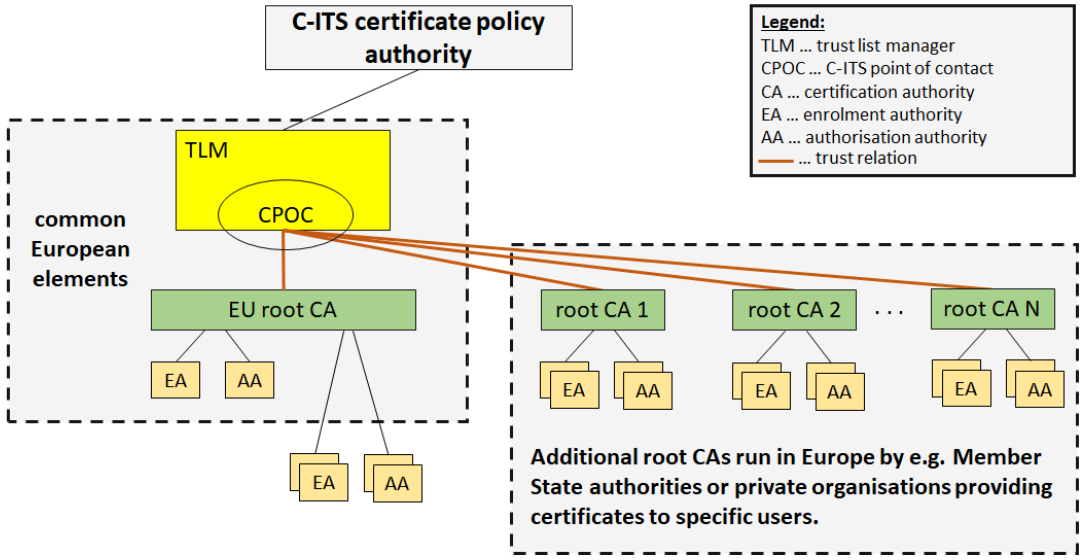

Figure 3: C-ITS Trust model architecture (Joint Research Centre, 2024)

3.1.5 ETSI

The European Telecommunications Standards Institute (ETSI) is an independent standardization organization focused on the telecommunications sector. Established in 1988, ETSI is involved in the development and testing of technical standards for ICT systems and services globally. Recognized by the European Union as a European Standards Organization, ETSI's work supports EU regulations and policies through the creation of harmonized standards.

In addition to working with mobile communications such as 3G, 4G and 5G, ETSI has also developed what is commonly referred to as the "ITS-G5" standard which is highly relevant for short-range C-ITS communications. The ITS-G5 standard is using already existing standards for communications, and the document that defines the access layer technology for ITS-G5 (ETSI, 2020) refers to several specifications and standards from IEEE and ETSI.

When discussing technical standards such as those defined by ETSI, it is also relevant to mention standardization bodies such as ISO, IEC and SAE. In this context, however, the ITS-G5 standard has received particular attention, and we have therefore highlighted ETSI. A more comprehensive overview of safety, security and privacy standards can be found in deliverable D10.2(Shan, 2019) of the SECREDAS project, funded by the EU's Horizon 2020 programme.

More information can be found on the ETSI home page (https://www.etsi.org/)

4 Methodology

This deliverable presents our findings gathered from multiple interviews, two workshops conducted with domain experts, and a literature study of PKI operations from other sectors.

4.1 Interviews

Interviews have been conducted with various C-ITS personnel, mainly from European NRAs. The interviews were conducted in the period from 2024-03-08 to 2024-05-31. In total, 7 interviews with 10 domain experts, were conducted. These experts were selected based on a contact list including NRAs, PEB members, and individual experts. The list has been populated both by project participants, and also extended and approved by PEB members. We refer to these interviewees as *informants*, since they have *"specialist knowledge about other people, processes or happenings that is more extensive, detailed or privileged than ordinary people, and who are therefore particularly valuable sources of information to a researcher"* (Payne & Payne, 2004). The informants have provided information from countries with varying maturity levels on C-ITS PKI deployment, and we therefore consider our findings to be relevant for the whole Europe.

The interviews were semi-structured, allowing for open discussions and giving the informants the opportunity to address topics or questions not raised by the interviewers. The interview guide can be found in 0 and an overview of the affiliations and roles can be found in Table 1.

Table 1: Overview of interviewees

Organisation role	Affiliation	Informant roles
NRA for Norway	The Norwegian Public Roads Administration (Statens vegvesen)	• Senior engineer • Solution architect • Senior engineer
NRA for Denmark	Danish Road Directorate (Danske Vejdirektoratet)	• Special consultant
Consultancy company based in Norway	Mobilits AS	• CEO/consultant
Automotive engineering and development consultancy company based in the UK	Horiba Mira	• Senior Functional Safety/ Cyber Security Engineer
NRA for Germany	BASt	• (Dipl.-Phys) Research Assistant
NRA for Austria	ASFiNAG	• Expert in Cooperative, Connected and Automated Driving

EU Root CA provider, based in France	Eviden	• Head of Engineering • V2X & IoT Security Business Manager

All interviews were recorded and automatically transcribed. The recording and automatic transcription was done using the Microsoft Teams recording and transcription functionality. All informants have signed a consent form, informing them about how the data will be processed and stored during the project, and what will happen with the data after the project ends. All informants have also given their consent to include their affiliation and role/title in the report.

When post-processing the automatically generated interview transcripts, AI chatbots (Microsoft Copilot and Open AI's Chat GPT) were used to generate summaries and identify main topics (using queries such as "based on the following interview transcript, please write a summary of the interview and highlight the main topics which were discussed" and "what were [interviewee]'s opinions on the matters discussed?"). To prevent unwanted use and sharing of the interview transcripts, only paid subscriptions were used to access the mentioned AI chatbots. Due to text length limitations in the query fields, the interview transcripts were split into parts before they were shared with the chatbots. The summaries and thematic overviews generated were then used in combination with the transcripts and human-written notes to extract the main findings, which are summarised in section 5.

4.2 Workshops

In addition to the interviews, two expert workshops were held. In total, 26 informants participated in the workshop, along with 8 representatives from the project. Among the informants were mainly NRA representatives, consultants, researchers and representatives from different ITS stakeholder organizations. Both expert workshops started with an introduction to the TIARA project, followed by a summary of all work packages and the initial findings. After that the informants were divided into two break-out sessions based on their interests and competence, and one of those sessions covered the C-ITS PKI topic of WP2. A total of 12 informants participated in the PKI breakout sessions.

The goal of the workshops was to present our initial findings, and to get more information on specific topics based on our previous findings. An interactive workspace for collaborative work, or a virtual whiteboard, was used in the workshop to present the discussion topics and allow informants to write down their input. When facilitating the discussion, we also ensured to write down the points that were not already written down.

The data from the workshops have been analysed and are presented in section 5.

4.3 Literature study

We believe that many sectors have faced many of the same challenges of PKI operations as C-ITS. Hence, we conducted a study of academic literature and publicly available reports on lessons learned on a selected set of sectors. The sources were identified using a combination of traditional keyword search (such as “PKI” + “lessons learned” + [SECTOR])

using Google Scholar, and Microsoft Copilot, which is an AI companion that combine technology such as GPT-4 and Bing (using queries such as “what are the lessons learned from academic literature on operating a PKI in the [ZZZ] sector?”). The sources were filtered, read and synthesized according to relevance by human researchers. The results are presented in section 5.3.

5 Findings

Since the identified and available literature provides insufficient information for answering the DoRN questions related to C-ITS PKI, the majority of this report is based on input from interviews and workshops with relevant C-ITS actors (including representatives from various European road authorities).

The following subchapters present findings from the interviews and workshops, as well as a summary of lessons learned from PKI operations in other sectors.

5.1 Interviews

5.1.1 Germany

Our informant from Germany comes from the *Federal Highway Research Institute* (BASt, *Bundesanstalt für Straßenwesen*) in Germany. BASt is a part of the Ministry of Transport, and are involved in standardisation, contribute to regulation and are actively involved in research projects related to C-ITS.

The informant explained that in Germany, the first operational deployment of a federal Root CA has been the responsibility of the Autobahn GmbH, which has been used for piloting e.g. services for road work warning trailers. This PKI is offered to other parties as well, but with some limitations. Currently, Autobahn GmbH is financing the root CA on behalf of the public bodies. They are also closely aligned with their Austrian counterpart. There are also examples of more local pilot sites that operate their own PKI, such as in the city of Hamburg. Both Autobahn GmbH and the city of Hamburg have contracted private companies to operate their PKIs. Though this is the current situation, Germany is still figuring out what the long-term PKI structure should be. There is an ongoing analysis looking at the needs in terms of the number of road stations, number of different services and number of different actors that need to be registered in the PKI.

The informant's further opinions can be summarized around the following key points:

- **PKI implementation challenges**: The informant acknowledges the complexities and challenges of implementing and managing PKI systems, particularly in terms of regulatory and operational requirements. He recognizes that managing a PKI system requires strict processes and significant expertise, which are often challenging to maintain consistently over time.

- **National vs. European PKI**: The informant discusses the advantages and disadvantages of maintaining a national PKI system versus using a European-wide system. The informant suggests that while a national system offers more control and customization, a European system could be more cost-effective and reduce redundancies across member states. Also, in Germany, there are 16 federal states that operate more or less independently. These could set up their own PKIs, but that would probably not be very efficient. Related to financing, the national level would not be paying for several PKI infrastructures in the individual federal states. The Federal Office for Information Security in Germany have created a set of national guidance documents and argue for a national root CA rather than at EU level in order to be independent of other actors and able to modify the PKI if considered necessary.

- **Cross-border data sharing**: The informant is supportive of enhanced data sharing capabilities across borders within the C-ITS framework, acknowledging the technical potential and the benefits of interoperability. A concrete example is that the Austrian road operator can subscribe to German the information stream on road work for certain corridors close to the border and vice versa, thereby improving cross-border traffic management. However, he also notes the current limitations and the need for improvements in system integration.

- **Technological challenges**: The informant expresses concerns about the impact of patents and proprietary technologies on the accessibility and cost of communication technologies, particularly how these might affect the broader deployment of C-ITS technologies.

- **Workforce and expertise**: The informant is candid about the difficulties in finding and retaining the right talent to manage a PKI system. He stresses the niche nature of the expertise required, which is not commonly taught in traditional educational settings, making it a significant bottleneck.

- **Future regulations and standards**: The informant is optimistic about the future developments in regulations and standards, particularly those being considered by the European Commission, since a very stable basis has already been established. The informant hopes for a more streamlined and integrated approach to C-ITS security, ideally simplifying the current complex landscape.

- **Collaboration and knowledge sharing**: Throughout the interview, the informant advocates for greater collaboration and knowledge sharing among countries and experts in the field. He believes that learning from each other's experiences and challenges can lead to more effective and efficient PKI and C-ITS implementations.

All in all, the informant’s opinions reflect a thoughtful consideration of the operational, technical, and strategic challenges involved in PKI and C-ITS. He emphasizes the need for adaptability, collaboration, and expert knowledge to navigate the evolving landscape of transportation technology and infrastructure security.

5.1.2 Austria

Our informant from Austria is an expert in cooperative, connected and automated driving, representing ASFiNAG.

Austria is one of the early adopters of C-ITS and the country that has come the furthest with regards to deployment of operative C-ITS stations. For them, it is therefore paramount to have a safe and secure system that people trust.

ASFiNAG is a roadside operator and therefore does not have a high number of C-ITS units compared to vehicle original equipment manufacturers (OEMs). Thus, establishing their own PKI was not deemed as the most practical or cost-effective solution. The possible solutions at hand were the following: the first option was to go with the EU Root CA, which is financed by the European Commission. The second option was to use the existing PKI of another

operator, and the third option was to operate their own PKI. They decided to use an existing PKI solution for the start of operations.

To have an operational system, they needed to be able to reach their users/customers inside the cars. This required a common trust with the OEM that is deploying this kind of technology, and in 2019 when the decision was made, Volkswagen was the only OEM that had the technology built into operational vehicles. Volkswagen then granted them access to one of their own project PKIs, which has a direct bilateral trust with their vehicles. By using this PKI, their messages are displayed in operational vehicles.

In the process of selecting which communication protocol to use, Austria has chosen the short-range communication protocol, ITS-G5. ITS-G5 has undergone extensive testing and is considered a stable solution. When implementing the system inside vehicles that are operational for 10 years or more, it is important that the solution is stable and does not change for the lifetime of the vehicle.

The C-ITS messages sent from their stations are broadcast and sent to any receiver in the area using ITS-G5. The messages are signed using the PKI offered by Volkswagen, so anyone that trusts this PKI can receive and validate them. However, currently there are no other OEMs than the Volkswagen group that have deployed C-ITS in their vehicles.

In the future, the goal is to be part of the European credential management system so that everybody can trust each other. They are considering partnering up with the German Autobahn GmbH and make use of their PKI. Today, it does not make any sense to go onto the EU Root CA under the European Certificate Trust List (ECTL) level 1 (L1) if they are there alone and then their messages are completely secure, but these are not processed and displayed because they are not trusted by the receiving systems. Therefore, in the near future, the goal is to be part of the European credential management system either using the German "Autobahn GmbH" PKI or preferably the EU Root CA, so that everybody can trust each other.

Austria has had quite a lot of research projects with the industry, more information about such projects can be found in the C-Roads pilot overview report (C-Roads, 2023). These projects have allowed for testing of the system and building up specifications which further were used for the tendering system. They received high maturity of the specifications of the solutions offered by the industry through all those years of running those projects.

The informant's further opinions can be summarized around the following key points:

- **C-ITS deployment:** The informant believes that Austria’s early adoption and deployment of C-ITS have positioned the country as a pioneer in this field. He emphasizes the importance of operational systems and the need for high-quality, timely, and geolocated data about road events.
- **PKI implementation:** The informant supports the decision not to operate Austria’s own PKI, instead opting to use Volkswagen’s PKI and partnering with the German Autobahn GmbH. He sees this as a practical and efficient solution given the low number of certificates required by their roadside units.
- **EU trust Model:** The informant is hopeful about the move to the EU trust model in the near future, which would allow all systems to trust each other. However, he

acknowledges that this would require concerted action where multiple parties move to the EU trust model together at the same time.

- **Challenges:** The informant acknowledges the challenges faced during implementation, particularly the need for high-quality, timely, and geolocated data about events on the roads. The informant sees the digitalization of this information as a significant task that goes beyond C-ITS.
- **Future plans:** The informant hopes that more OEMs will start deploying CITS in their vehicles, which would necessitate a move to the EU trust system. He also hopes that Volkswagen Group will move to the EU trust system in the near future.
- **Communication technologies:** The informant supports Austria's strategy to deploy C-ITS based on ITS-G5, a short-range communication based on Wi-Fi. The informant believes this technology is stable enough to be deployed in vehicles and is expected to be operational for at least 10 years.
- **National and European projects:** The informant values the importance of Austria's involvement in various research projects and field tests to develop and refine the specifications for C-ITS. The informant believes these specifications form the basis for the future C-ITS delegated act.
- **Trust model:** The informant supports the European trust model developed to allow for multiple root CAs while maintaining trust across all systems. The informant sees this model as a practical solution that respects the sovereignty of Member States in Europe.
- **Quality of information:** The informant emphasizes the importance of providing high-quality information to users. He believes that both false positives and false negatives can erode user trust in the system, and therefore, maintaining the quality of information is crucial.

In summary, the informant's opinions reflect a pragmatic and forward-thinking approach to the implementation of C-ITS and PKI in Austria. He acknowledges the challenges but also sees the potential benefits and future possibilities of these technologies. He emphasizes the importance of cooperation, high-quality data, and user trust throughout the conversation.

5.1.3 Denmark

Our informant from Danmark is a coordinator in the traffic center of the Danish Road Directorate.

Denmark currently does not have a C-ITS deployment decision nor a deployment strategy. Recently, they have decided to go ahead with a very small demonstration project with the implementation of two use cases. The first use case is road works warning (RWW) demonstrating static roadworks warnings at the E45 in Jutland. The second use case is emergency vehicle interventions (EVI) and emergency vehicle approaching (EVA). Their greatest barriers are the PKI, the software systems, data flow, working processes, operational set-up and managing the roadside units.

Denmark is currently in the process of considering "PKI as a service". The likely goal is to be able to operate some of the systems from the Danish Road Directorate., The intention is for the Danish Road Directorate to act as the enrolment authority and the authentication authority. However, they have not taken a formal stand about if and how to move along with

C-ITS. They are preparing a decision basis for the management to be presented by the end of 2024.

They understand that there is a bit of competition between short-range and long-range communication standards, and therefore the informant believes they will go for a hybrid solution where both standards will be used. The informant also believes there will be parallel PKI systems for different kinds of services.

The informant mentioned that it is difficult for them to get funding and make a choice when things are not set in stone, and they are therefore waiting for things to be ready, among others from the EU side. They are waiting for more information on how the implementations should work in the optimal set-up and how to ensure interoperability in a European context.

Another reason for holding back is that the solutions are still expensive, and the informant said that they expect that this will be much cheaper in just a year's time or so. Today there are not many vendors selling the hardware and software solutions needed, and they expect that more vendors will come into the market as has been seen with ITS equipment in general. They are aware that the solution will cost money, but they accept the costs if it can balance the investment in relation to safety out on the road. Now they must prove that the solution is safe and that it provides safety for their colleagues working on the roads and for the road users.

Denmark collaborates with other European countries as part of the C-Roads platform and was also a partner in the NordicWay projects[4], where NordicWay3 finished by the end of 2023. The NordicWay project had a lot of sub-groups working on different topics, and one of the groups worked with security and certifications. Additionally, Denmark is part of the National Access Point Cooperation (NAPCORE), where they are working on e.g., the interchange solutions between the national access points.

The informant's further opinions can be summarized around the following key points:

- **CITS implementation in Denmark:**
  - Denmark focuses on safety, data quality, and collaboration with other countries.
  - Denmark aims to provide traffic information via a hybrid approach using both long-range and short-range communication where relevant.
  - Use cases include emergency interventions incl. emergency vehicle approaching, and road works, incl. static road work warnings.
  - Challenges include PKI implementation and balancing technology excitement with safety considerations.
- **Collaboration and data sharing:**
  - Denmark collaborates with C-Roads and NAPCORE; and further with Nordic countries and Germany on C-ITS.
  - NAPCORE focuses on coordination and harmonization of mobility data platforms in Europe, including interchange solutions for sharing data between national access points.

[4] https://www.nordicway.net/

- **Data quality:**
  - Denmark wants to ensure safe implementations and small-scale demonstrations before widespread adoption.
- **Political considerations and funding:**
  - Denmark has not yet formally presented C-ITS decisions to top management or politicians.
  - Funding challenges exist, but a common European vision is crucial for success.
- **Future directions:**
  - Balancing technology rollout with safety and scalability is essential.
- **Challenges and excitement:**
  - Denmark faces challenges related to manpower, communication, system and organizational integration, governance, and political support.
  - The team is excited about making C-ITS information available and ensuring safety.

Overall, Denmark's cautious optimism and commitment to safety provide valuable insights for ongoing CITS research and implementation efforts.

5.1.4 UK

Our informant from the UK is a chief engineer for cybersecurity at Horiba Mira which is a consultancy and test service company delivering services for the automotive industry.

Horiba Mira have been involved in collaborative programs within the UK on C-ITS pilots. They are waiting to see whether C-ITS will be adopted in the real world, and starts to become fitted to vehicles, however, this seems to be a little way in the future.

They have observed some challenges around which technologies to be adopted, and it is still unclear whether the ITS-G5 or the cellular V2X solution will be the preferred solution in Europe. Another challenge is the monetization of the application, and who will benefit and who will pay for these kinds of services, and this is probably the most challenging part. The informant believes that the UK will go for a hybrid solution with a combination of ITS-G5 and V2X, but that this also could make it more challenging for implementers.

The informant expects that the PKI solution will be outsourced to a subcontractor responsible for implementation and operation, but he also assumes that the UK government will be the owner of the solution, however, no official announcements have been made.

The informants' further comments are summarised in the following key points:

- **Introduction to C-ITS:**
  - C-ITS involve direct communication between vehicles and road infrastructure.
  - Goals include enhancing road safety, improving traffic flow, and providing real-time information to drivers.
  - Services cover various aspects, including traffic management, emergency response, and driver assistance.
- **European Commission's Strategy:**

    - The European Commission adopted the C-ITS strategy in 2016.
    - Aims to align investments and regulatory frameworks across EU member states.
    - Mature C-ITS services were expected to roll out from 2019 onward.
    - Legal Frameworks are necessary for harmonization and interoperability of the services.
    - EU Funding to support research, development, and deployment of C-ITS services.
    - The European Commission encourages collaboration across countries and regions.
- **Responsible Organizations:**
    - UK Department for Transport:
        - Responsible for C-ITS matters in the UK.
        - Collaboration with the National Cybersecurity Centre ensures security aspects of the C-ITS.
        - National Highways (operating motorways and major roads) may also play a role.
- **Challenges:**
    - Interoperability: Ensuring seamless communication across different systems and brands.
    - Cross-Border Information Exchange: Managing transitions between different PKIs (Public Key Infrastructures) when vehicles cross borders.
    - Security: Balancing robustness with security measures.
    - Political Barriers: Differing views and priorities among stakeholders.
- **Trials and Practical Experience:**
    - Most practical experiences are related to trials rather than full-scale operations.
    - Trials focus on functionality but often overlook security aspects.
    - Questions remain about the need for continuous trials and bridging gaps.
    - Security Considerations:
        - Security should be a significant focus in future trials.
        - Ensuring robustness while maintaining interoperability is critical.
- **Future Directions and Research:**
    - Need for standardized use cases and message formats.
    - Questions about how different PKIs interact internationally.
    - Consider more continuous field trials beyond isolated events.
    - Explore long-term deployment challenges.
    - Investigate sharing information across vehicle brands and national boundaries.
    - Address privacy concerns and anonymization of data.

In conclusion, C-ITS faces multifaceted challenges, but efforts continue to advance this transformative technology across Europe. The need for collaboration, standardization, and security remains paramount.

5.1.5 Norway

Two different Norwegian C-ITS stakeholders were interviewed. In the first interview, the Norwegian Public Roads Administration participated with 3 representatives, and in the second, a C-ITS consultant participated on behalf of his company Mobilits AS.

5.1.5.1 The Norwegian Public Roads Administration

Regarding PKI rollout and ongoing initiatives, we were told that there is very little C-ITS hardware in the Norwegian road infrastructure. The Norwegian Public Roads Administration currently has three mobile radio devices. On the vehicles side, Volkswagen (VW) has come a long way compared to other manufacturers and delivers all their new cars with C-ITS capability built in. Until recently, however, radios from VW were geofenced and inoperable in Norway. Although Norway currently lacks operational C-ITS services, there have been some work and discussions regarding safety related applications and smart traffic lights. Traffic safety implementations are of particular interest.

When discussing the technology, two main types of C-ITS communication were mentioned, namely ITS-G5 which is a short range (essentially Wi-Fi) communication, and an ad hoc version of cellular communication commonly referred to as C-V2X. Each has certain advantages over the other and the choice of communication technology depends on the use case and other factors. The informants expect to see both technologies being widely used within C-ITS, so the service providers will need good solutions for how these technologies should coexist and interact in the C-ITS domain. The complementary use of ITS-G5 and C-V2X is commonly referred to as hybrid communication, and many countries now seem to opt for such a solution. Even Austria, which has been a significant ITS-G5 advocate, has shown interest in hybrid communication.

Several car manufacturers have chosen C-V2X communication for their vehicles, while others, such as VW, have chosen ITS-G5. There is an ongoing "competition" between the two approaches, where the final outcome is still undecided. The lack of a widely adopted solution is considered a barrier for C-ITS implementation, as it makes various stakeholders (such as infrastructure providers) reluctant to invest in solutions whose relevance is still uncertain.

The informants are currently aware of one C-ITS PKI for Norwegian services, which is provided by TeskaLabs[5] and included in the ECTL. This was developed under the C-ITS delegated act[6] and has been refined and modified in recent years. The delegated act was not approved.

Regarding data sharing and traffic safety, it was mentioned that different car manufacturers currently do not share data from each other's vehicles, but there is sharing of data within each manufacturer's "fleet". The ITS directive[7] encourages more sharing (to improve safety), but such sharing is not required.

[5] https://teskalabs.com/
[6] https://www.europarl.europa.eu/cmsdata/161226/Delegated%20Regulation%20C-ITS.pdf
[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0040

The interviewees envision that Norway will have its own root CA in the EU CCMS trust hierarchy in the future. This will require resources (either in-house or outsourced) to manage policies, enrollment, etc. In such a system there can be different types of users, e.g. police cars, ambulances, maintenance vehicles, repair shops, etc.

The informants did not have specific opinions regarding certificate validity and revocation in C-ITS, as there has so far been very little discussion on these topics in their organization. The choice of validity management (revocation or short-lived certificates) will depend on the type of application/service.

The Norwegian Public Roads Administration currently has very little experience with costs related to PKI operations, but the interviewees expect that there will be significant costs related to operation (OPEX), including support, maintenance and certificate management). Any functionality or service which utilizes wireless communication will have to be included and managed.

Regarding the way forward, the informants have the impression that several of the applicable standards are not sufficiently understood and applied, such that there is currently a "learning phase" among many C-ITS actors. There is a concern that we will see an "over-engineering phase" before the application of the standards has "normalized". As with various other services, there is a need to move from a "shell-based" protection approach to a transaction-based system, and this applies to the entire value chain.

The Norwegian Public Roads Administration is eager to learn from the experiences of other NRAs (and vice versa). As specific partners/sources, Denmark and the Netherlands were mentioned. The informants believe in small and agile initiatives, to allow "failing fast" and identifying pitfalls such that the consequences of failures and bad choices are minimized while the technology matures.

5.1.5.2 Mobilits

To provide a bit of history/background, Mobilits mentioned the Directorate-General for Mobility and Transport (DG MOVE)[8] early in the interview. DG MOVE was created in 2010, and their work with cyber security for C-ITS has played and still plays a big role when it comes to topics discussed in this project. In the early stages (from 2013-2014), C-ITS was "synonymous" with short range car-to-car communication.

For short range C-ITS communication (commonly referred to as ITS-G5), IEEE p1609.2[9] is the main certificate standard. To address privacy issues in automotive applications, pseudonymous certificates is a common approach. In today's C-ITS services (which are mostly safety related), a lot of data is broadcast openly, but anonymously, from C-ITS enabled vehicles. These messages have no confidentiality, only anonymity and integrity (via signatures and certificates). According to the informant, there are currently about 15000 to 20000 such cars in Norway, using 1609.2 certificates. The majority of these are from VW.

[8] https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/mobility-and-transport_en
[9] https://standards.ieee.org/ieee/1609.2/10258/

At present, only VW has a significant number of operational cars with p1609.2 capabilities. Among road operators, there are a few which have rolled out a significant number of roadside stations, most notably Austria. There are also many roadside and mobile work zone stations along the German Autobahn which use p1609.2.

The p1609.2 certificate structure is based on X.509, but with modifications to meet C-ITS specific needs (such as pseudo-anonymization). Such certificates have embedded "service specific permissions" (SSP) and can be issued based on the "role" of a vehicle.

The *C-ITS delegated act* was stopped in 2019, after several member states and stakeholders objected to a lack of technology neutrality, claiming that the act favored ITS-G5 technology. Today there are two main communication technologies for C-ITS; ITS-G5 based on Wi-Fi technology, and C-V2X which is currently not part of C-ITS standards, but work is ongoing to provide C-ITS standards over Internet. The first cybersecurity standard based on the C-ITS certificates is available as ISO 21177.

To achieve interoperability between the various C-ITS services in Europe, a common trust system and standard protocols are needed. Proper anonymization of data is also crucial. The European Commission (EC) has the role as central trust provider (CPOC and TLM).

There are three levels of ECTL certification: L0, L1 and L2. L0 is intended for pilots and testing and does not have strict security requirements. L1 and L2 are now ready for deployment, and the EC intends to go live from November 2024. The lack of L1 and L2 accreditation until now is likely one of the reasons why VW provides their own root CA which is currently not in the EU CCMS hierarchy.

Parallel PKIs is a complicated matter. The p1609.2 certificates have embedded, service specific permissions, so the certificates themselves are service specific. This means that there will generally be different root CAs for different services. There are some discussions (both national and trans-national) regarding "service groups" and how these should be handled in terms of certificates.

It is not easy to say which actors are natural root CA candidates for different services. The different providers in the trust list (ECTL) will also be service specific, and a C-ITS station (e.g. a car) can potentially have certificates from dozens of root CAs.

Regarding ongoing initiatives in Norway, the informant mentioned that the Norwegian NRA has an ongoing project to get a better overview of the PKI "status" in Europe and provide a roadmap/plan for future C-ITS activities. It is likely that the public sector in Norway will take the role as domestic trust anchor.

Norway is one of the countries opting for a hybrid communication technology, since it is not considered feasible to cover all C-ITS needs in Norway with short-range ITS-G5 alone. The expectation for Norway is a hybrid solution with ITS-G5 stations in certain locations (such as intersections with smart traffic lights) and relying on cellular technology elsewhere to prevent an unnecessary myriad of roadside stations.

The interviewee did not highlight specific challenges related to trans-national C-ITS services, and pointed out that there will likely be many C-ITS services in the future, where some will be international and others national or regional. There will likely be a wide range of "service

types" in the future, and handling the many service types may be just as challenging as handling trans-national challenges.

When discussing certificate revocation, two main approaches were mentioned for C-ITS. One is to perform revocation based on revocation lists which have to be managed and distributed, and the other is to have short-lived pseudonym certificates which expire frequently. The "break even" between these two options is essentially when the distribution of a revocation list requires the same amount of time as the lifetime of a short-lived certificate. According to the informant, a revocation approach has been chosen in the US, while European solutions rely on short-lived pseudonym certificates.

5.1.6 France

The responsibility of operating/offering the EU Root-CA service was put out to tender by the EU commission in April 2019[10], and in the process of selecting a provider, the French company Eviden (Atos) was chosen in December 2019[11]. Eviden is now responsible for the operation of the EU Root-CA, enrolment authority and authorisation authority.

Currently, more than 40 actors are connected to the EU Root-CA solution. The group of actors represent a wide range of European countries and sectors and comprises manufacturers who develops C-ITS stations and operators of C-ITS stations. According to the interviewees, actors from Germany, France, Italy, Netherlands and Austria are considered most active. During the interview the interviewees provided an overview of the largest station providers connected to the EU Root-CA (see Table 2), however, they could not share the full list with us, as they are only operating the EU Root-CA on behalf of the EC.

Table 2: Some station providers connected to the EU Root-CA

Station providers:
Hyundai
Fiat
Bosch
Qualcomm

In addition to the station providers listed in the table above, there is also quite an extensive list of Italian companies, mostly small R&D operators, connected to the EU Root-CA.

The level of maturity amongst the European countries varies greatly. Some countries have a strong PKI policy and are willing to invest and deploy national systems, whereas others are not that involved and prefer the market to decide what it will do. In Germany, Austria and France there is the will to deploy actively, and they have a proactive strategy.

[10] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=4701
[11] https://www.car-2-car.org/fileadmin/press/pdf/2020_06_18_EU_Root_CA_Webinar_Presentation.pdf

Maturity and coverage do not only depend on technical maturity of the solutions provided today, but there are also several elements that can interfere or accelerate the deployment of C-ITS. First, there is the regulation. Today there is no delegated act, so it is not compulsory to deploy C-ITS services, but when the delegated act enters into force, it will accelerate the deployment. Second, there is the Euro NCAP[12] test for cars, which is a common safety rating system for new cars in Europe. The score in this test has a high impact on the sales of cars. Five stars is the best score, and if a car receives perhaps only three stars it is a bad publicity for the brand and the sales will decrease. So, including C-ITS services and their interoperability as a part of the test will ensure that car manufacturers implement these services. A third point that was mentioned was that today there is only the Volkswagen group who has integrated and deployed C-ITS PKI. If another large car manufacturer, such as Stellantis or Renault also releases such solution, it could make others follow.

Administratively connecting to the EU Root solution at L0 is a simple and streamlined process. At L1, the procedure remains relatively uncomplicated, however, it does require verification of certain compliance factors. The technical integration of C-ITS stations is also regarded as straightforward. Among the 40 actors connected to the solution, only a few of them needed technical support.

Several factors can impact the decision to adopt the EU solution or opt for a private alternative. Primarily, the choice depends on the specific use case scenarios. For instance, France has decided to maintain sovereignty of their cryptography solution for the security of the C-ITS services delivered in the country. They have decided to invest in the PKI and maintain independence from decisions made at the European level. Another consideration is the need for a specific service that is incompatible with the use of the Central European PKI because it is a shared service, and they want to have some specific use cases only for themselves. If, for example, a city wants to give some specific permissions to busses so that they can request the traffic light to remain green to move forward and not having to stop they can do so at the central European PKI level, but then this applies to all busses. If you want to give that right exclusively to the busses of your city, and not to the city that is close by, then you need a private PKI to differentiate your messages or your certificates from those of other cities.

In the standard you have some technical aspects that are covered, but at the usage level you also need harmonisation, so this is what the car2car consortium and C-Roads platform are using. They are defining the harmonisation of some specific use cases[13]. Today we do not have enough harmonisation to provide common solutions for similar use cases. This is where you would have to opt for a private PKI.

The main challenge is not related to the PKI itself, but to the hardware deployment and installation on the roads. It is complex and has a high cost, which can make the public administration reluctant to accelerate their C-ITS deployment. For example, L2 PKI can only accept L2 stations on the PKI side. It is relatively easy to be audited and to maintain this level of security for many years. However, on the hardware side, you must be compliant with

[12] https://www.euroncap.com/en

[13] https://www.c-roads.eu/platform/about/news/News/entry/show/c-roads-publishes-harmonised-c-its-specifications.html

some protection profiles that are evolving, and the regulations will also be evolving. At some point, you might have stations that have been produced in 2024 that are not valid anymore in 2029.

The informants' further opinions are summarized around the following key points:

- **European C-ITS PKI deployment:** The informants discussed the current state of European C-ITS PKI deployment, mentioning that they have over 40 actors connected to their solution, including manufacturers and operators from various sectors and countries.
- **Challenges and solutions:** The discussion covered challenges organizations face when connecting to C-ITS solutions, such as technical integration and administrative processes. They highlighted the ease of onboarding for L0 on the European Root CA and the open criteria for companies to comply with regulations.
- **Technical support and standardisation:** The importance of technical support for actors and the role of standardisation bodies like ETSI in ensuring interoperability was emphasized. Plug tests were mentioned as a key activity for verifying standards implementation.
- **Private vs central European PKI:** Reasons for choosing private PKI solutions over the central European PKI were discussed, including sovereignty, specific use cases, and the critical mass justifying investment.
- **Hardware deployment and privacy concerns:** The conversation touched upon the complexities of hardware deployment and installation, the evolution of protection profiles, and the need for hardware to be compliant with changing regulations.
- **Future predictions and strategies:** The participants speculated on future requirements for C-ITS services, the potential need for hardware updates, and the impact of second-hand car markets on PKI management.
- **Closing remarks:** The interview concluded with acknowledgments of the usefulness of the discussion and a request to share the presentation and any other relevant materials.

Key take-aways:

- There is a growing network of actors connected to the European C-ITS PKI, indicating progress in deployment.
- Technical and administrative ease of integration is crucial for expanding C-ITS services.
- Private PKI solutions are chosen for reasons of national strategy, specific use cases, and when the scale justifies the investment.
- Future-proofing C-ITS services against evolving regulations and ensuring interoperability are ongoing challenges.
- The interview highlighted the dynamic nature of C-ITS PKI deployment and the various factors influencing decisions at the national and organizational levels.

5.1.7 Summary of key inputs

In the following, a selection of key topics and challenges from interview discussions are summarized.

Trust hierarchy, roles and accreditation

The informants were reasonably acquainted with the EU CCMS trust model, but most were uncertain about how roles and responsibilities should be distributed between the various stakeholders. The trust hierarchy “picture” is expected to get clearer as C-ITS services become more widely adopted and more mature.

There is a general lack of PKI expertise and resources in the C-ITS community, and many of the needed PKI services are expected to be outsourced to private companies.

For a trust provider (root CA) to be included in the ECTL, it has to be audited and approved by an independent party according to the accreditation scheme defined by EU CCMS (Joint Research Centre, 2024). There are three different security levels for accreditation: L0, L1 and L2. L1 and L2 have recently become ready for deployment (EU CCMS policy documents were finalized in 2024), so we should expect to see L1 and L2 certifications in the near future.

Trans-national compatibility

Based on workshop and interview discussions, we expect a C-ITS ecosystem with multiple services and multiple PKIs, where some need to operate across borders while others don't. Any C-ITS functionality related to traffic safety should be managed such that messages can flow easily between the involved vehicles and roadside stations, regardless of which country a given vehicle or roadside station "belongs" to. In addition to safety related services, C-ITS services which involve for example customs information or payment solutions may also require trans-national cooperation and harmonization. Most existing C-ITS services currently operate within rather than across country borders, so there is very limited operational experience regarding how to manage cross-border challenges.

Communication technology

There are two main types of communication technology which enable C-ITS services, each with their pros and cons.

- ITS-G5: Short range communication based on Wi-Fi technology. Mainly uses the IEEE p1609.2 certificate standard. ITS-G5 is a well-defined and open standard which can be applied by any provider with relative ease and high compatibility with other ITS-G5 solutions. This technology allows for very fast (but local) communication and is well suited for time-critical services involving fast-moving vehicles, such as smart traffic lights.
- C-V2X: Long range communication based on cellular technology such as LTE and 5G. C-V2X also enables vehicles and other C-ITS stations to communicate directly with each other. At present, C-V2X is not included in the C-ITS standards, but work is ongoing to provide C-ITS standards over the Internet. Since it involves several different cellular technologies, C-V2X is less standardized and involves proprietary protocols, but the certificates used generally follow the X.509 standard. C-V2X is significantly slower than ITS-G5, but greatly reduces the need for roadside C-ITS stations since it relies on mature infrastructures which already have good coverage in large parts of the EU.

The C-ITS delegated act, which was proposed by the European commission and aimed to set a legal framework for the use of C-ITS in the EU, was stopped in 2019 due to objections from several member states and stakeholders. The opponents claimed that the principle of technology neutrality was violated because the proposed act favored ITS-G5 and included requirements which would effectively exclude C-V2X from C-ITS applications. The idea of a "hybrid communication" approach, where ITS-G5 and cellular technology can complement each other, has since gained momentum, as evidenced by initiatives such as the C-Roads hybrid communication task force[14].

There is an ongoing competition between ITS-G5 and C-V2X among car manufacturers, as some have chosen ITS-G5 for their vehicles, while others have opted for C-V2X. This competition is hampering C-ITS implementation, since stakeholders are reluctant to invest in technologies and solutions with such uncertain prospects.

Several informants and workshop participants claim that there is still too much focus on short-range ITS-G5 communication and would like to see more guidance for how to implement C-ITS services with C-V2X communication.

Past (and ongoing) discussions regarding long-range vs short-range communication have been complex and involved a wide range of political, economic and technological considerations. Based on the interviews and workshops, it seems that most member states are now opting for a hybrid approach.

Cost

There are various types of costs to consider for providers of C-ITS services and their PKIs, which can influence the plans and strategies of NRAs and other stakeholders. In the interviews and workshops, a few types of cost considerations were mentioned which we would like to highlight:

- Cost expectations as incentive to delay C-ITS adoption: Since C-ITS involves relatively new technologies which are rapidly evolving, several stakeholders will be tempted to "sit on the fence" and let other actors (the early adopters) bear the costs while the technology matures and becomes cheaper. The fear of "not keeping up" with technological advancements seems quite insignificant.
- Cost related to obsolete hardware: Since C-ITS capabilities are integrated in vehicles which may have a lifetime of up to several decades, there are some concerns that the C-ITS infrastructure will evolve "too fast" compared to the lifespan and future proofing of today's vehicles (and other C-ITS hardware currently in operation). Such obsolescence concerns are much less common when it comes to e.g. general IT hardware which has a much shorter lifespan. If C-ITS hardware becomes obsolete prematurely, it will either trigger replacement/upgrade costs, or lead to a reduction in available services for the outdated devices.
- Cost of PKI operation: Interview informants and workshop participants seem generally more concerned with operational costs (OPEX) than initial investments (CAPEX), as the former is much harder to get approved in the respective

[14] https://www.c-roads.eu/platform/activities/tf-hybrid-communication.html

organizations. As mentioned in sections 5.3.7 and 5.3.9, the cost of support services is one of the biggest operational costs, and we don't expect the cost picture for C-ITS PKI operation to be much different.

User adoption

Most new technologies (including C-ITS) depend on significant user adoption to become successful. Unless providers see good opportunities for commercialization and profit, they will be reluctant to make the necessary investments. On the other hand, end users are much more willing to embrace a product or service if it is already well-functioning and mature. This "chicken-and-egg" challenge is highly relevant for C-ITS as well.

For private individuals who purchase modern cars, the C-ITS services will generally be perceived as a property or functionality of the car itself, and the user's experience with the C-ITS functionalities will directly influence customer satisfaction and reputation for car manufacturers. For this reason, car manufacturers are expected to have strict requirements for the C-ITS services which they choose to integrate in their cars.

5.2 Expert workshops

This section presents the results of the two expert workshops held in the project. Initially, the expert workshop was planned as an in-person event at the TRA conference in April 2024. However, it was decided to replace it with two online events to allow more people to join and avoid the risk of not being able to recruit enough experts at the TRA conference. In total 26 informants participated in the workshops, and 13 of them joined our breakout sessions. The results from both workshops have been combined and are presented in the following paragraphs.

(Joint Research Centre, 2023, 2024)The European Commission aims to offer support for European C-ITS deployment with three different levels of trust list management (TLM) services. The first level, L0, is used for testing and pilot purposes. L1 is the intermediate level, and here, stations and use cases are in operation, but with some exceptions regarding regulations. The final level is L2, and here the stations and use cases need to be fully compliant with the regulation. L0 only requires a self-declaration, whereas L1 and L2 entail a regulation assurance process.

When implementing a C-ITS PKI solution, there are three different approaches to take. The first approach is for the organization to take care of all the tasks and responsibilities themselves. The second option is contracting each part of the system, and the third option is to buy everything as a package.

There are multiple use cases for C-ITS PKI, and the service is offered by several providers, although none are currently operating at large scale. Workshop participants mentioned that it is important to identify the providers of the Root CAs. TeskaLabs[15] was mentioned as one of the providers, and it was also mentioned that car brands explore the opportunities of offering

[15] https://teskalabs.com/

their own PKI. Volkswagen (VW) is one of the car brands offering their own PKI, which is currently being used in Austria and Italy. The VW PKI is operational and at the L1 stage. Other Root CA providers mentioned were Microsec, Saesol[16], Autocrypt[17] and Greenhills[18]. One of the informants said that in Europe we should only focus on the providers of the Root CAs because the EC takes care of the PKI CCMS management and governance.

The EU Root CA has more than 40 registered actors on L0. The solution is free of charge, and this will also be the case for L1 and L2. One of the informants, who had experience with both the EU Root CA and the solution from a different provider, mentioned that connecting with the EU Root CA had been more challenging than connecting with the other provider. They faced several challenges during the implementation phase, including in the administrative process. However, the informant was not familiar with the entire situation and could not provide more details on this matter.

The timeframe for setting up the solution and having something that works depends on several factors. First, the procurement and tendering process takes time. You need to decide if you want to do it yourself or if you want to contract it to others. Further, you need time for the enrollment of the stations. There are many intermediate steps, and it is difficult to set an upper time limit. One of the informants reported that it took longer than expected.

The informants briefly discussed the costs associated with C-ITS PKI. They mentioned that these costs play a role and that from an NRA perspective, justifying the operating expenses is more challenging than advocating for the initial setup costs of the solution.

5.3 Lessons learned from PKI operations in other sectors

The lessons learned from operating Public Key Infrastructure (PKI) can be drawn from a wide range of sectors. These include, but are not limited to general information technology, healthcare, finance, government, telecommunications, manufacturing, education, maritime and aviation. Selected publications that provide relevant challenges and advice on these are summarised below.

5.3.1 Information Technology (IT)

The IT community is well-known for using PKI for services such as secure email, trust in websites, identification of users, establish session keys for secure communications, and software verification through code signing. Notably, web browsers come pre-installed with X509 root CA certificates issued by a number of trusted Certificate Authorities (CAs). This collection of self-signed certificates serves as the root of trust. When a browser connects to a secure website, the server sends its SSL/TLS certificate to the browser. The browser checks if the certificate was issued by one of the trusted CAs. This is done by comparing the signature on the TLS certificate with the public key of the CA. Although the browser does not need to contact the CA to validate the signature, it does need to contact the CA to verify that

[16] https://www.saesol.tech/
[17] https://autocrypt.io/
[18] https://www.ghs.com/

the certificate hasn't been revoked. This is typically done using base and delta Certificate Revocation Lists (CRLs), the Online Certificate Status Protocol (OCSP), or OCSP Stapling.

A diverse range of security companies and non-profit organisations operate as CAs, such as Comodo, Let's Encrypt (free), DigiCert, GoDaddy and Globalsign (McKinnon, 2022). Many of these operate in industry specific sectors as well.

When it comes to lessons learned on operating PKIs in this environment, there are some dated publications on this matter ((Ellison & Schneier, 2000; Guida et al., 2004; Gutmann, 2002)), emphasizing:

- A general problem with PKIs is the hierarchical structures, while in the real world there may be non-hierarchical organisations. Therefore, the recommendation is to design the PKI according to the real world, rather than constraining the real world to match the PKI.
- Certificates and PKIs specifically designed to address a particular problem are much easier to work with than a one size-(mis)fits-all PKI design.
- Identities should be locally meaningful and globally unique.
- There are several challenges related to CRLs, including how frequent these should be published (distribution is expensive, checking is time-consuming and subject to denial-of-service attacks). The recommendation here is simply to design the PKI so that it does not require certificate revocation, thus avoiding many of the problems.
- Users need to know how their environment will change when introducing a PKI.
- Try to estimate how many uses will need support services.
- Design processes that allow identity credential changes, this is bound to happen.
- Avoid language barriers, do not restrict to English as the information management language.

In addition to the above, general PKI advice can be provided by national cyber security bodies, such as NCSC[19].

5.3.2 Healthcare

PKI is used in the healthcare sector for many different purposes, including, but not limited to secure access to electronic medical records and ensuring the integrity of transmitted medical data. A study (Mantas et al., 2012) looking at the open issues of PKI security in large-scale healthcare networks identifies the choice of trust model as the main issue for inter-organisational PKIs. Furthermore, the complexity of certificate path processing is another critical factor that affects the efficient adoption of PKI technology. A recommendation from the authors is that end-entities should be provided with information about the CA liabilities and the quality-of-service parameters of the issued certificates. They also recommend the use of trust lists to determine whether end-users making request for healthcare services should be considered.

[19] https://www.ncsc.gov.uk/collection/in-house-public-key-infrastructure/pki-principles

5.3.3 Finance

Financial institutions use PKI related to for example secure online banking, cardholder authentication, and secure email. The international standard *ISO 21188:2018 - Public key infrastructure for financial services — Practices and policy framework* (ISO, 2018) sets out a framework of requirements to manage a PKI through certificate policies and certification practice statements and to enable the use of public key certificates in the financial services industry. The recommendations from this standard are:

- A PKI should be managed through certificate policies and certification practice statements. These are essential for defining the different levels of trust within a PKI and for detailing the procedures that a Certification Authority (CA) will employ in issuing and managing certificates.
- To manage risks, the standard states that control objectives and supporting procedures should be defined.
- Operational practices relevant to the financial services industry and their information systems should also be defined. These practices are important for ensuring the effective operation and management of the PKI.
- To ensure flexibility and scalability of the PKI, the PKI should support practices that allow for multiple certificate policies.

The standard also draws a distinction between PKI systems used in closed, open, and contractual environments. This implies that the implementation and operation of PKI may vary depending on the specific environment, which can pose challenges.

5.3.4 E-government

PKI is used in e-government solutions, including secure email, virtual private networks, and digital signatures for e-services. The paper titled “A good-practice guidance on the use of PKI services in the public sector of the European Union member states” (Gritzalis, 2005) provides several lessons learned from operating a PKI in the government sector. However, the current situation described in the paper is very much dated (2005), so it is difficult to assess the relevance of these recommendations today. The main challenges mentioned here were flexibility, scalability and interoperability.

More recently, the *electronic IDentification and trust Services* (eIDAS) (EU, 2024a) regulation has set out to facilitates secure cross-border transactions for the EU internal market by establishing a framework for digital identity and authentication. It came into effect between 2016 and 2018 and has enabled electronic signatures, digital certificates for natural persons and Websites, electronic seals and trusted timestamps. In 2021, the European Commission proposed new qualified trust services for electronic archiving, electronic ledgers and the management of remote signatures and seals. A comprehensive set of guidelines, which include technical requirements, formats of trusted lists and procedures, have been instrumental in harmonization and interoperability across the national electronic ID systems across Europe. Still, there were shortcomings identified from a consultation with various stakeholders, which has led to a new proposed regulation on *European Digital Identity* (EUDI) (EU, 2024b). Large-scale pilots are going to test the technical specifications and software prototypes for the European Digital Identity Wallets.

5.3.5 Telecommunications

Telecom companies use PKIs for secure administration of distributed networks, secure VPNs, and protection of infrastructure.

A study from 2021 (Hadan et al., 2021) from the telecom domain describes a gap between security and policy experts' perceptions of PKI failures and real-world PKI incidents between 2001-2020. The study found that experts identified weak cryptography and software bugs as the major and well-known sources of error. In reality, the primary cause of certificate failures is CAs' misinterpretation of baseline requirement, meaning the policies and processes used to determine which CAs should be trusted. This suggests that understanding of PKI operation and its challenges needs to be grounded in practical, real-world experiences, not just theoretical knowledge. The same study also found that systematic weaknesses in organisational practices can create risks for all who rely upon PKIs. On a positive note, the study identified organisational and configuration choices that could avoid or mitigate some of the risks associated with PKIs. This suggests that proactive planning and strategic decision-making can enhance the effectiveness of a PKI.

A survey paper (Ramadan et al., 2016) on PKI for mobile communication systems describes latest proposed works on the security of GSM, CDMA, and LTE cellular systems. It presents the security issues for each generation of mobile communication systems, studies and analyses the latest proposed schemes, and gives some comparisons. Though the paper concludes that public key cryptographic approaches are good from a security point-of-view, they are also computationally extensive and have more signalling overhead compared to symmetric key encryption. A solution to this could be to use efficient lightweight schemes such as *identity-based cryptography* (IBC) and *certificateless-public key cryptography* (CL-PKC). These do not require a CA, and this leads to lowering the processing time (delay) and handshaking processes.

5.3.6 Education

Educational institutions use PKI for secure access to digital resources, secure email communication, and identity management. A publication (Linden et al., 2002) with pilots from Finnish institutions focus on the applicability of PKI and smartcards. The authors come to the conclusion that it is really the user administration of the institute that needs focus in order to modify existing services and implement new ones. A too technology-oriented view to the problem should be avoided.

Another paper (Hermann, 2001) recommends to facilitate interoperability between organisations through so-called bridge-CAs. A bridge CA determines the policy mapping between the bridge's participants.

5.3.7 Maritime

The paper "PKI vs. Blockchain when Securing Maritime Operations" (Rødseth et al., 2018) compares the two technologies, indicates strengths and weaknesses of each, and gives some examples of typical applications where each of the technologies can be used. These applications include updates of nautical safety information to the ship, port state reporting from ship to shore, and approval letter for ship building process. One key challenge at sea is finding a neutral root CA that different flag states can accept. Furthermore, connectivity

could be an issue as ships could be on open seas for days or weeks. This limits the capabilities of renewing certificates or revoking certificates. All CA certificates should be downloaded and stored locally before setting sails (Frøystad, Bernsmed, & Meland, 2017).

The Norwegian project CySIMS-SE conducted a study (Frøystad, Bernsmed, Meland, et al., 2017) which included the PKI implementation process and costs for the Norwegian Maritime Authority. A premise here was that international shipping is dependent on maintaining a reasonable and normally relatively low cost on its business operations and this imposes limitations on which PKI solutions could be acceptable to the industry. The project also analysed the pros and cons of outsourcing of the PKI service versus inhouse ownership and management. The cost of implementing PKI obviously varies with each installation, but there are some common expenses that occur, such as planning and assessment, facilities, hardware and software, installation and configuration, disaster recovery, backups, root key generation, audits, and maintenance and operations. The price per user decreases as the number of certificates increases, but it is really the personnel cost that is the main driver. In that sense, it does not matter so much whether you are managing 10 000 or 50 000 entities, having staff available 24/7 is a much harder requirement. Having such support services can overshadow most of the other costs, as these can often be automated.

5.3.8 Aviation

The aviation sector has many commonalities with maritime, as connectivity can be limited and with international operations. As presented by Patterson (Patterson, n.d.) in an *International Civil Aviation Organization* (ICAO) information paper, PKIs are being used in various aspects of air transport, including Secure ACARS, Gatelink, Field Loadable Software, Electronic 8130 Airworthiness, Electronic Flight Bag, Signed Flight Plans, Manifests, weather reports, maps, etc. A major challenge is that setting up a CA is expensive, and unless there is convergence on a single policy, there will be no providers willing to set up those CAs. Moreover, key management is still a work in progress. According to Patterson, it is important for there to be only one PKI standard for the industry. A cross-certified environment makes it less expensive to set up a CA.

Bernsmed et al. (Bernsmed et al., 2017) provide a set of recommended security requirements for datalinks enabling future air traffic management services. These are derived from the needs of future ATM services and can be a useful source for defining similar requirements in C-ITS, e.g. related to integrity protection, data-origin authentication and overhead of cryptographic protection. At the same time, the authors emphasize the results from a security analysis may have a very short lifetime as *"threats that are relevant today may be irrelevant tomorrow and new threats that cannot be foreseen may appear in the future"*.

Relevant standards that come from the aviation industry include ARINC 842-1 (ARINC, 2018) on life-cycle management of asymmetric keys that are used to secure interactions among systems. This standard complements ATA Spec 42 (ATA, 2020), which specifies a digital identity management framework and standard digital certificate profiles recommended for use across the air transport industry. ARINC 835-1 (ARINC, 2014) provides guidance for security of loadable software parts using digital signatures.

5.3.9 General challenges and lessons learned

Looking across sectors, we can see that there are many of the same issues that emerge. Especially the choice of trust model is a commonality when dealing with inter-organisational PKIs. Furthermore, operational practices should be designed to reflect existing organisational structures, as these are more difficult to change. Focusing on mostly technology, and not sufficiently on the organisational aspects, can easily lead to an expensive and unsuitable PKI design.

Another general advice is to keep the complexity as low as possible. For instance, cross-certified environments are difficult and expensive to manage. Avoiding CRLs is another approach to reducing complexity, though this might make the system more vulnerable in case of key compromises. Support services is seen as a major cost driver in several sectors.

There are some sector specific challenges, such as limited connectivity or low bandwidth, that require special considerations related to e.g. cryptographic overhead. However, this is less of a challenge for C-ITS which can benefit from terrestrial communication infrastructures.

We have also seen some PKI advice that are collected from several sectors. A survey (Ponemon, 2020) conducted by the Ponemon Institute in 2020 with responses from 603 IT and security professionals revealed some of the fundamental problems in PKI management:

- There are often insufficient skills and resources to operate a PKI. Only 38% of respondents stated that their organisations have enough IT security staff members dedicated to their PKI deployment.
- There is a lack of investments in modern PKI infrastructures. Manual and outdated methods are used to deploy and manage PKIs.
- Emerging connected devices (e.g. IoT devices) present a significant challenge for enterprises. Attackers seek to exploit weak credentials to steal data, disrupt services or distribute malware.
- Failed audits due to insufficient key management practices and compromised or rogue certificate authorities (CA) are the most frequent and most serious problems faced by organisations when it comes to managing PKI and cryptography.
- Less than half of respondents (44%) are confident in the security of their root CA.

Additional PKI pitfalls mentioned by the PKI provider Sectigo (Callan, 2021) include the use of too weak keys, unnecessarily long certificate lifespans, improper protection of private keys, lack of policy consistency.

In order to address these problems, the respondents from the Ponemon survey prioritised the following four strategic priorities for their enterprises:

- Authenticating and controlling IoT devices.
- Knowing the expiration date of certificates.
- Reducing complexity in their IT infrastructure.
- Reducing the risk of unknown certificates in the workplace.

The first three of these should be just as relevant for C-ITS.

6 Conclusions

6.1 Overview of PKI roll-out

The current status for PKIs for European C-ITS services is that most countries have a very limited rollout. Although many countries' NRAs have conducted pilots and testing of new concepts, only a few (most notably Germany and Austria) have established a significant C-ITS road infrastructure. There is general consensus that the respective NRAs will have an important role regarding the establishment and operation of PKIs for public C-ITS services, but the PKI service itself will likely be outsourced to specialist companies in many cases. Although there seems to be a wide selection of private companies who can provide PKI services, it is important to ensure that C-ITS specific needs are properly identified and met. PKI expertise and resources are scarce among many C-ITS stakeholders, so there will be a need for guidance when establishing and applying best practices.

The C-ITS services which are currently available are mainly public services related to traffic safety and road work information, but many other C-ITS services are expected to be offered in the future. As the number of C-ITS services increase, so will the number of PKIs. The various PKIs will need proper accreditation in order to be included in the ECTL, such that they can operate within the EU CCMS trust hierarchy.

It is expected that providers of C-ITS services (including NRAs) will have to cooperate closely with car manufacturers in order to get their C-ITS services "approved", since the performance of integrated C-ITS functions will directly influence the user experience and the car manufacturer’s reputation. Manufacturers are therefore likely to demand high performance and reliability in the C-ITS services which they integrate in the vehicles.

6.2 Multiple PKIs

Even though C-ITS is at an "early stage" and the informants predict a strong increase in the number of services, there is already a significant number of providers which currently offer C-ITS PKI services. For the most part, these providers have information security as (part of) their core business, but there are also a few actors from the automotive industry, such as Volkswagen, who have decided to establish and operate their own PKI.

Operating a PKI requires specific competence and resources, and many C-ITS stakeholders therefore choose to focus on core business and outsource their PKI needs. According to most of the informants (mainly representatives from NRAs) their organizations did not have the necessary competence and capacity to operate their own PKI.

Several providers of C-ITS PKIs have been identified in the interviews and workshops; these are listed in Table 3.

Table 3: Overview of identified C-ITS PKI providers

PKI provider
Eviden/Atos (EU Root CA)
Microsec

Telefonica (This PKI is operated by Criptographic Services - Cybersecurity Deparment under Telefonica Digital Security Unit using 5G Telefonica network capabilities)
Swarco[20]
TeskaLabs[21]
Autocrypt[22]
IP Telecom, Serviços de Telecomunicações S.A.
CTAG
ETAS GmbH / ESCRYPT GmbH
Integrity Security Services LLC[23]
Volkswagen AG[24]
BOSCH
Saesol
Greenhills

6.3 Lessons from other sectors

One general lesson from other industries is that operational practices need to reflect organizational structures. Too much technology focus can often lead to an expensive and unsuitable PKI design. In that respect, the EU CCMS appears to be a good foundation for the European C-ITS architecture, provided that the various stakeholders are assigned appropriate roles and responsibilities.

Another general advice from other sectors is to minimize complexity, for example by avoiding CRLs. Various C-ITS services are already avoiding CRLs (with the use of short-lived pseudonym certificates), but the main motivation for this seems to be response time (and privacy considerations).

Limited PKI expertise and resources is a challenge in various sectors, and as discussed in 6.1, this is the case for C-ITS as well.

[20] https://www.swarco.com/solutions/connected-driving/c-its-ready-hardware
[21] https://teskalabs.com/solutions/seacat-cits-security
[22] https://autocrypt.io/products/pki/
[23] https://www.ghsiss.com/wp-content/uploads/2023/03/ISS_Root_CA_Certificate_Policy_v1_4.pdf

[24] https://certdist.volkswagen.de/faces/components/viewCert_CP.xhtml

Limited connectivity and low bandwidth are significant challenges in certain other sectors, but for C-ITS these will be mostly avoided by the use of terrestrial communication infrastructures. There are, however, particularly high connectivity demands for certain C-ITS services, as they need to reliably and efficiently transmit safety-critical (and time-critical) information, often in challenging circumstances such as high traffic density and poor weather conditions. Despite the robust terrestrial infrastructure, there may therefore still be significant connectivity challenges to manage.

Lastly, in addition to the lessons discussed above, we can repeat some of the generic challenges mentioned in 5.3.9, which were identified by the Ponemon survey (Ponemon, 2020):

- There is a lack of investments in modern PKI infrastructures. Manual and outdated methods are used to deploy and manage PKIs.
- Emerging connected devices (e.g. IoT devices) present a significant challenge for enterprises. Attackers seek to exploit weak credentials to steal data, disrupt services or distribute malware.
- Failed audits due to insufficient key management practices and compromised or rogue certificate authorities (CA) are the most frequent and most serious problems faced by organisations when it comes to managing PKI and cryptography.
- Less than half of respondents (44%) are confident in the security of their root CA.

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Interview Guide

Time frame:
1 hour

Introduction: 10 min
Short round of introductions

Introduction to the project and the purpose of the interview (this includes information regarding data collection and handling/management) – Clarify what we mean by PKI if that is unclear (maybe "certificate policy" is a better term)

Any questions regarding the project or the interview?

(Questions marked in yellow are most important)

Main part: 45 min
Organizational:

- General status on PKI in [country]?
  - Are you operating your own national root CA or using the European Certificate Authority (EU root CA)?
  - Who is the Enrolment Authority?
  - Who is the Authentication Authority
  - Are there parallel PKIs in your country? (private/public)
  - Number of C-ITS Stations
  - Type of information and messages (roadside, aggregated, broadcast, V2V)
- View on the European level?
- Which paths have you chosen to implement C-ITS Delegated regulation? (Not a regulation!)
- How to connect with the European solution?
- Are you in contact with other NRAs? Which?
- What are the agreements and disagreements?
- Current operations in [country]
  - Who is managing the PKI (issuing certificates)?
  - Reasons for this choice?
  - Tender/competition? Costs public information? Can we get access to this (at a later stage)?
  - Alternatives?
  - Permanent?
  - Problems/challenges with this solution?
- How is enrollment (and revocation) managed?
  - How is the process of enrolling new devices/stations in the security "ecosystem" (PKI)?
- Pilots in [country]?
  - Include certificates and signed data?
- Have you had pilots with other countries?
  - Cross-border
  - Data sharing?
- Conflict of interests?
  - Car manufacturers

  - Telco operators
  - countries

- What is your organization's "role" regarding PKI in C-ITS applications?
  - What roles and responsibilities belong to other organisations?
- PKI competence and resources
  - Support: Are any PKI related responsibilities outsourced, or is everything handled by "in-house" resources?
  - How many people are responsible/working with PKI?
- What have you learnt about operating a PKI?
  - What issues and problems have you encountered when developing and implementing the PKI?
  - What has worked well in your case?
- What actors are involved, and which role do they have?
  - Political, supplier, telco operators, police, etc.
- Politics:
  - What are the challenges? What are the discussions about?

Compatibility and collaboration:

- Are they aware of the situation in Europe? Do they collaborate with other countries?
- How is the compatibility between bordering countries?
- How is the collaboration between countries and road authorities?
  - (Agreements on what certificate standards and key lengths to use?)
  - Agreements regarding roles and responsibilities, including Certificate Authority (CA) role(s)?
- Other things?

Costs:

- Can you say something about the resources required to run a PKI infrastructure?
  - How do the cost and computational requirements scale?
  - What are the resources required to run the administration for certificate and key management?
  - Costs related to customer/user support?
- Any known or expected technological developments which may render present solutions obsolete and introduce extra cost?

Conclusion: 5 min

Thank you for participating in the interview.
Any final questions or remarks?