Clarification no. 8 to

Invitation to Tender: AO/1-9427/18/NL/MP

NAVISP Element 3

Thematic Window dedicated to "Ubiquitous PNT for Connected, Cooperative and Automated Mobility for more efficient, safe, and sustainable roads and vehicles"- Clarification

16th September 2022

Potential Tenderers are invited to take note of the following Clarification to the Standard Call for Proposal of NAVISP Element 2 and NAVISP Element 3:

In the framework of these Standard Calls for Proposal, permanently open, under NAVISP Element 2 and NAVISP Element 3, the European Space Agency (ESA) in cooperation with ERTICO-ITS Europe, a public-private partnership organisation, is opening a Thematic Window dedicated to "**Ubiquitous PNT for more efficient, safe, and sustainable roads and vehicles**", calling for proof-of-concept demonstration projects and national or cross-boundary test-beds to facilitate the development and introduction of related PNT technologies into commercial products. The activities will be funded under the NAVISP Element 2 or Element 3, aimed at supporting industrial competitiveness and national strategic initiatives respectively.

Tenderers are hereby invited to submit an Outline Proposal on this topic, preferably **by February 28 2023, within the Standard Call overall duration.** Applicants requesting funding should refer to the thematic window in their outline proposals.

Further proposals on the topic could still be submitted after that deadline. However, they may not benefit from the increased visibility and priority that will be offered during the duration of this Thematic Window.

The scope of this Thematic Window is to support and accelerate the transition to a more connected, automated and sustainable transport sector by promoting the use of PNT data in the context of Connected, Cooperative, and Automated Mobility (CCAM). It also aims to support the development and commercialization of corresponding technologies towards more sustainable forms. This is directly related to ESA's strategy to support and increase the use of space through three accelerators, one of which is focused on using space for a green future. The themes addressed in this thematic window revolve around private or public use scenarios in the CCAM domain. The following use cases center around different application areas and can include infrastructure-related advancements, cars, buses, trucks, as well as shared mobility services (for more detailed information please see ANNEX):

- **Theme 1:** Ubiquitous and High-Performance PNT for CCAM
- **Theme 2:** Perception 360 for CCAM
- **Theme 3:** PNT Monitoring and over-the-air updates for CCAM

- **Theme 4:** PNT for Clean Mobility
- **Theme 5**: Testing for CCAM related PNT technologies

All the documentation of the respective NAVISP Element 2 and Element 3 Standard Call for proposals, as updated by Clarifications, remain valid and applicable with the exception of the composition of the consortium, which shall include (one or more) members representing the stakeholders involved in the value-added chain of the application, namely:

- Car manufacturers or suppliers;
- Infrastructure developers (e.g. Road, IT);
- Public Authorities;
- Developers of PNT user equipment;
- Certification[Homologation] facilities[centers];

either as bidding team members or supporting parties with a letter of interest.

This is in order to render the results of the projects readily applicable in an operational environment. On **October 18th 2022,** the Agency organizes a webinar with interested stakeholders in order to raise general awareness about the initiative and clarify any issues potential Tenderers may have. At the webinar, the Agency will present the scope of this Thematic Window as well as the application process. During this Webinar, the general context and status of CCAM will be presented. The Webinar will also include the participation of prospective customers of CCAM products to present the market perspectives as an introduction to the presentation of the themes of this Window and how to apply. Information on how to register to the workshop will be made available through the NAVISP website (**https://navisp.esa.int/).**

The **Annex** provides further details on the background of the thematic window, its economic, societal as well as regulatory relevance, and the scenarios and application areas that it will address.

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ACRONYMS

C2V	Communication between the Vehicles
C2X	Communication between the Vehicles and Environments
CCAM	Connected Cooperative Automated Mobility
CCAV	Connected Cooperative Automated Vehicle
ERTICO	European Road Transport Telematics Implementation Coordination
ERP	Electronic Road Pricing
ESA	European Space Agency
EV	Electric Vehicle
GNSS	Global Navigation Satellite systems
HADF	Highly Automated Driving Functions
IOT	Internet of Things
LoS	Line-Of-Sight
MOD	Moving Object Detection
NAVISP	Navigation Innovation Support Programme
NR	New Radio
OBU	On board Unit
OEM	Original equipment manufacturer
OTA	Over the air
PNT	Positioning Navigation and Timing
RTK	Real-time kinematic
SAE	Society of Automotive Engineers
ToF	Time-of-Flight

1. INTRODUCTION

Vehicle automation has gained considerable momentum in recent years. The use of complementary technologies is already evident in daily life, with a clear trend toward adopting (semi-) autonomous solutions. Most of these solutions operate in a distributed and decentralized manner, so they require communication and connectivity between the elements in the system. As a result, there is an increasing demand for vehicles that cooperate and coordinate with each other and the infrastructure to perform more complex mobility tasks and thus provide a safer and more convenient driving experience.[1] As a matter of fact, all original equipment manufacturers (OEMs) and car manufacturers agree that connectivity is essential for SAE Level 4 and 5 autonomous vehicles.[2] The underlying concept is often referred to as cooperative, connected, and automated mobility (CCAM).

Figure 1: Concept of Connected Cooperative and Autonomous Driving[3]

This mobility megatrend is driven to a large extent by CCAM's ability to relieve the burden on human drivers through intelligent functions such as collision avoidance, lane departure warning, and traffic sign recognition. Additionally, the use of CCAM services can directly impact society by, for example, reliably and safely transporting passengers, including the elderly and disabled, solving parking problems, and avoiding a large number of accidents previously caused by human error or poor infrastructure (more than 40 000 deaths per year on European roads, 90% caused by human error).[4] Moreover, CCAM technologies have the potential to efficiently manage traffic flow, reduce congestion, and improve fuel economy thus lowering emissions and accelerating sustainable development. [5]

[1] Malik et al. (2021)
[2] 5G PPP H2020 ICT (2020)
[3] Figure provided by adobe stock (Door Feodora), adapted based on Mertens et al (2020), Behere & Torngren (2015), Pendleton et al (2017)
[4] EC (2022), Hussein & Zeadally (2018)
[5] Liu et al. (2020)

Over the past decade, various players, including automotive OEMs, CCAM suppliers, SMEs, startups, as well as public and private research institutions, have made increased efforts to become active in this domain. Their endeavours include the development of driving assistance systems, entire CCAM vehicle prototypes, as well as autonomous driving laboratories aimed at creating realistic traffic situations for training intelligent vehicles, such as obstacle detection, autonomous braking and steering, and collision avoidance. [6,7] All these developments have in common that they rely on positioning, navigation, and timing (PNT) information and that significant efforts in research and development in this area are still required to drive this development forward, as the commercial implementation of CCAM solutions still remains a significant challenge.

To support and accelerate the transition to a more connected, collaborative, and automated society, ESA's Navigation Innovation and Support Programme (NAVISP) in cooperation with ERTICO-ITS Europe[8] , is launching a Thematic Window soliciting proposals from European industry, institutions, and research organizations to advance the use of PNT in the domain of CCAM. In addition, this thematic window helps to support technology development and commercialization towards more sustainable forms. This is well aligned with the objectives of the European Green Deal and the Sustainable and Smart Mobility policies as well as those of ESA that aim to accelerate the use of space to mitigate climate change within the context of the "Space for a green future" accelerator.[9] As the climate crisis is the most urgent challenge facing humanity, holistic and all-encompassing solutions must be found on every continent, in every region, and also in every sector of the economy. GNSS and general PNT systems have the opportunity to provide sustainable and commercial solutions for a decarbonized green economy. In this context, the transport and mobility sector is particularly important as it is responsible for around 23% of global CO_2 emissions, of which almost half (45%) are caused by passenger cars and a further 30% by trucks. Thus, road transport is responsible for almost 75% of transport emissions. [10] CCAM technologies that complement new propulsion models such as electric vehicles, offer the opportunity to make urban environments more sustainable by reducing overall fuel consumption and thus carbon emissions, air and light pollution, and congestion-related productivity losses. [11] Moreover, through the adoption of data-driven CCAM concepts, smart, sustainable mobility and land use approaches can be improved and zero-emission urban mobility facilitated.[12]

The following section summarizes the evolution and current trends of CCAM, followed by the presentation of several challenging use cases that address both the multiple requirements and challenges of CCAM and incorporate the use of the multiple capabilities of PNT data to support and promote CCAM for more efficient, safer, and sustainable roads and vehicles. To this end, the PNT requirements

[6] Kahn (2021)
[7] Examples include: ESCAPE Project, Germany's "Digital Motorway Testbed", Hi-drive project, BMW VISION iNEXT- *For more information and examples, the Transport Research and Innovation Monitoring and Information System (TRIMIS) provides open-access information on past and current transport research and innovation projects in Europe.*
[8] ERTICO, 2022
[9] ESA (2022)
[10] A. Walker (2021)
[11] Mora et. Al (2020), Chehri and Mouftah, (2019), Dean et al., (2019), Stone et al., (2020), Fagnant and Kockelman, (2015)
[12] J.Keane (2020)

and technological challenges of CCAM are explored in more detail, and possible technological extensions of current PNT technologies are presented.

2. POSITIONING, NAVIGATION AND TIME IN COOPERATIVE, CONNECTED AUTOMATED MOBILITY

Connected, Cooperative and Automated Vehicles (CCAV) can be defined as the next generation of vehicles equipped with advanced sensors, controllers, and actuators to provide intelligent driving, comfort, safety, and energy efficiency. In 2014, the Society of Automotive Engineers (SAE)[13] published a standard for intelligent and autonomous vehicles that has been adopted by companies and research institutions around the world and classifies the level of driving intelligence and automation (see *Table 1* for closer definition).[14]

The degree of autonomy and the level of intelligent driving functions is complemented or even enabled by communication mechanisms between road users and their environment. The function of CCAM systems is thus mainly based on communication between vehicles (C2V or V2V) and communication between the vehicle and the environment (C2X or V2X). In this context, technological developments benefit in particular from the latest trends and advances in 5G technologies, machine learning and artificial intelligence, which have the ability to provide and share complementary PNT information. So when it comes to the development and implementation of CCAM systems, the automotive industry is just as much in demand as the PNT community: Autonomous and connected vehicles need to be equipped with a multitude of sensors and actuators, generating a large amount of data in real-time that must be processed and analysed to make timely decisions.[15]

SAE Level	Name	Dynamic Driving Task	Importance Ubiquitous PNT	PNT accuracy
0	No automation	Human Driver	Low	~1m
1	Driver Assistance	Human Driver		
2	Partial Automation	Human Driver		
3	Conditional Automation	Human Driver		
4	High Automation	System		
5	Full Automation	System	**High**	**<10 cm**

Table 1: Role of PNT per SAE level

There are different scenarios of how these types of vehicles will be integrated into the transportation sector, but the main ones are either fully autonomous, independent, self-driving vehicles that can work with existing infrastructure, or a simplified version, CCAVs, that are fully autonomous only where the road infrastructure allows, and switch between different levels of autonomy.[16] The higher the level of automation and the more independent the execution of dynamic driving tasks, the more important PNT information becomes to enable real-time environmental awareness and decision making. This leads to a

[13] SAE 2014
[14] Yang te al. (2018)
[15] Hussain & Zeadally (2018)
[16] Johnson, RAC Foundation (2017)

wide variety of technological possibilities for CCAM systems, depending on for example the degree of autonomy, the objective, the sensors used, or the capabilities required.

Figure 3 contains the taxonomy related to CCAM, including different technological needs and opportunities, objectives as well as required capabilities.

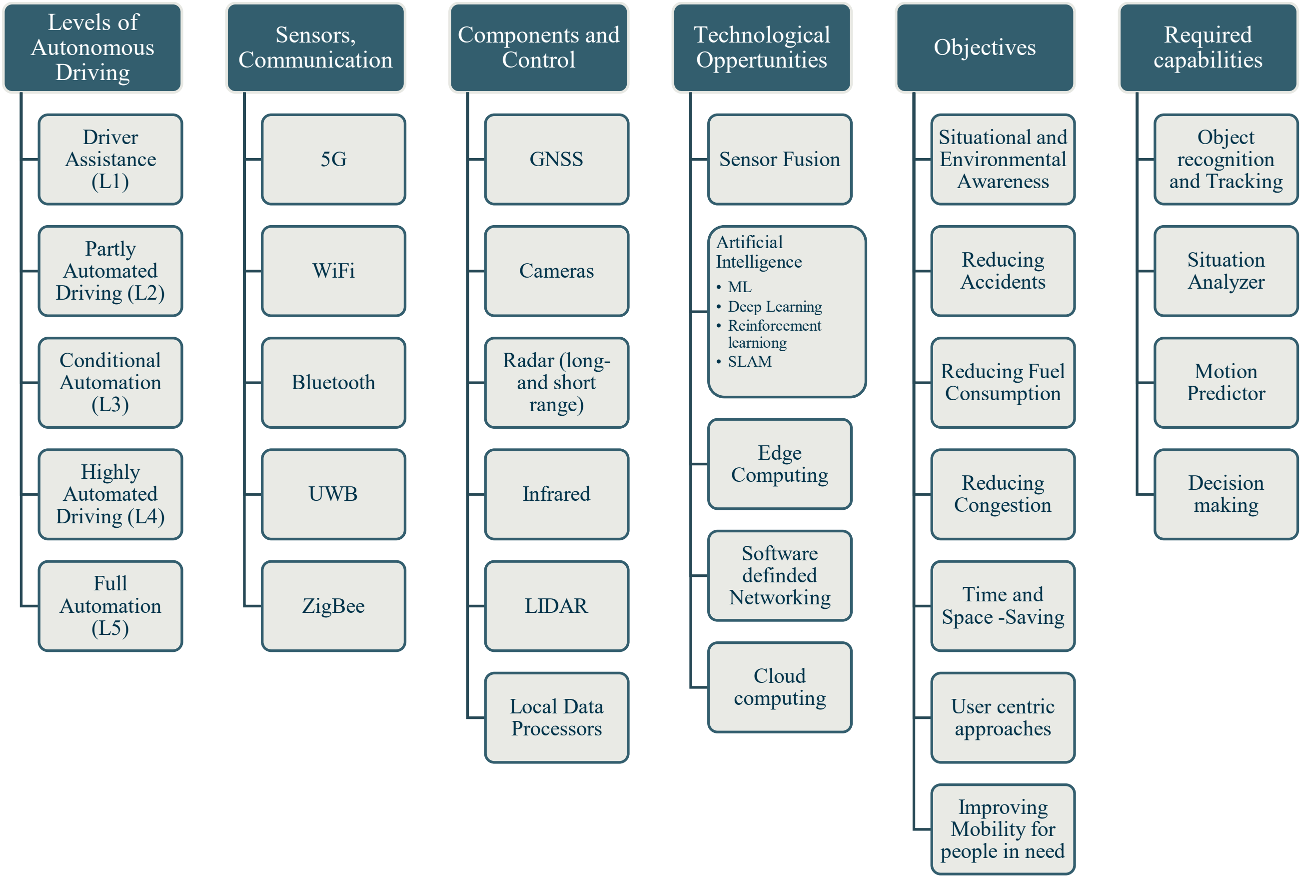

Figure 2: Different Classifications related to CCAM[17]

Different technical solutions entail very different requirements that have to be met in order to counter current and future challenges and enable the safe, accurate, and reliable use of CCAM systems. For autonomous and connected vehicle operation, the technical foundation must first be established, especially in urban situations with unpredictable traffic, including the collaboration of multiple real-time systems, such as environmental awareness, localization, planning, and control. In addition to these challenges, environmental factors, such as real-time traffic analysis and weather conditions, as well as road infrastructure, including traffic signs, road markings, accidents and road works, pavement, road structure, and available parking spaces, must be considered and integrated into the system.[18] This must be combined with a robust vehicle platform with appropriate sensors, computer hardware, networks, and software infrastructures that are able to consider the volume, speed, quality, heterogeneity, and real-time nature of data.[19]

[17] Based on Yaqoob et al. 2019, SAE International 2022, Liu et al. (2020)
[18] Liu et al. (2019)
[19] Levinson et al. (2011)

Although many demonstration CCAVs have been developed to prove the concept of connected and autonomous driving and the possibility of improving traffic efficiency, there is still a large gap that needs to be closed before high-level mass production of CCAVs can be achieved. This gap reflects the discrepancy between the focus of the various actors involved. On the one hand, the automotive industry focus on the development of key technologies, mostly hardware, including high-value electronic components such as sensors, control units, and actuators. On the other hand, researchers focus on developing reliable algorithms to perform driving tasks such as perception, decision-making, and control. However, high-level interaction and cooperation between the two appear to be limited. [20] The interaction between the automotive industry and research as well as the integration and complementation by the PNT Industry can provide confident solutions to the problem.

3. CHALLENGING PNT USE CASES

The provision of ubiquitous positioning, navigation, and timing information as well as the full situation awareness of vehicles in the system belong to the main challenges, that need to be countered in the future. Possible PNT solutions for CCAM are as diverse as their application areas and offer technological opportunities not only for passenger cars but also for buses, trucks, and entire infrastructures. This allows for more customized applications such as advanced traffic and parking management and traffic pricing systems. Thus, the integration of complementary and alternative PNT technologies in CCAM systems from tomorrow can reduce congestion, increase efficiency, minimize energy consumption, reduce emissions, avoid accidents, and thus provide more sustainable modes of transportation overall.

Accordingly, a variety of stakeholders is addressed, from private car users to car manufacturers and suppliers, to public authorities, municipalities and city planners. All will benefit from better connected, cleaner, and more automated traffic development. And although the development of fully automated vehicles (SAE Level 4-5) has still major challenges to overcome, the road ahead is described by innovative CCAM solutions, enabled by PNT data that, step by step, will enable the automotive sector of tomorrow. The following section describes different potential application areas in form of five themes, all related to the integration of PNT information but all with different goals and addressing different challenges, to serve as illustration for what the market is currently looking for:

- **Theme 1:** Ubiquitous and High-Performance PNT for CCAM
- **Theme 2:** Perception 360 for CCAM
- **Theme 3:** Monitoring and over-the-air updates for
- **Theme 4:** PNT for Clean Mobility
- **Theme 5:** Testing for CCAM-related PNT technologies

[20] Pereira et al. (2019), Yang te al. (2018)

3.1. Ubiquitous and High-Performance PNT for CCAM

To ensure the reliability, accuracy, coverage, and safety of CCAM, continuous, trustworthy and real-time PNT information is critical. This is even more challenging when considering that highly automated vehicles require, depending on the application scenario, real-time accuracy of less than 10 cm, while also requiring a high level of integrity in any environment (in particular challenging in urban environments).[21] GNSS alone is not able to meet all of these stringent requirements due to signal attenuation and potential interferences. To obtain accurate location information, various solutions need to be combined, including GNSS-based solutions that enable accurate outdoor location and 5G-based technologies such as angle-based solutions (Downlink Angle of Departure *DL-AoD*, Uplink Angle of Arrival *UL-AoA*), and time-based solutions (Downlink Time Difference of Arrival *DL-TDOA*, Uplink Time Difference of Arrival *UL-TDOA*, and Multi Round Time Trip *Multi RTT*).[22] In addition to on-board sensors, concepts such as smart roads, Highway 4.0, and other intelligent transportation infrastructures that have recently gained momentum in the scientific community[23] can be used to increase the accuracy and reliability of PNT data. Unlike conventional roads, smart roads interact dynamically with drivers, using active perception and automatic differentiation to provide real-time information about traffic, accidents, and alternative routes in emergencies.[24]

Detailed use case examples here include for example the development and use of combined 4G/5G/satellite architectures to utilize the advantages of satellites and complement them with 4G and 5G technologies to enable ubiquitous connectivity, and thus to realize the always-connected aspect of CCAM. Various tests are already underway to design and develop level 4 or higher autonomous vehicles, and external wireless connectivity, in particular, is a powerful extension to the integrated sensors already used in vehicles.[25] Compared to 4G, 5G offers a variety of benefits including added bandwidth, reliability, low end-to-end latency, and enhanced 5G New Radio (NR) capabilities.[26] With these features, 5G has the opportunity to enable seamless and ubiquitous value-added positioning. However, these possibilities still need to be exploited to realize positioning functions in connected, cooperative and autonomous driving.

Another example is the development of next-generation on-board units (OBU) that enable highly automated driving, such as the development of a precise positioning system for the high levels of automated driving according to SAE-L4 and L5 for many different types of vehicles such as cars, buses or trucks. New on-board units are central to the future of the automotive sector as they can integrate a wide range of different services, such as next-generation electronic road pricing (ERP) systems, real-time road traffic updates, and notifications of nearby school and environmental zones to alert drivers to children and senior citizens. [27] They can also collect and share vehicle-specific data with other road users

[21] Reid et al. (2019), Rehrl & Groechening (2021)
[22] Dwivedi et al. (2021), ESA (2020): PNT in 5G, Thematic Call,
[23] e.g.: Pratico et al. (2022), Garcia et al. (2022), Mazzola et al. (2021)
[24] Garcia et al. (2022)
[25] 5G PPP H2020 ICT (2020)
[26] ESA (2020): PNT in 5G, Thematic Call
[27] Kamil & Awang (2021), Todayonline.com

in the network to enable connected and cooperative mechanisms. This data is also of big interest for OEMs and municipalities in order to adjust and monitor vehicle movements and road infrastructures.

3.2. Perception 360 for CCAM

A key requirement for more automated traffic is the full situational awareness of the vehicles in the system. Connected, cooperative, and automated vehicles require information from a variety of sensors that perform tasks such as sensing, navigating, and communicating with other vehicles, and the environment.

One important task is the detection of moving objects (MOD) in order to achieve robust autonomous driving. Thus, multiple sensors, including cameras, LIDAR sensors, and speed detection systems must cooperate for the perception of the surrounding environment. However, a challenge connected to this is the position of the respective vehicle itself. Cameras for example do not offer the capability to cover objects at all distances and speeds, in particular, if the ego-vehicle itself is moving. Moreover, cameras are informative systems, that are dependent on visibility conditions. Therefore, it is necessary to merge the information of cameras, as well as Radar or LIDAR sensors with PNT information in real-time, so the decision-making can be supported.

However, combining this information and producing a meaningful, timely evaluation is difficult due to the latency of the transmitted data. Only if vehicles and objects that are in the same location have the same situational awareness at the same time within a very narrow time window, collision avoidance can be dramatically improved.[28] Thus, if a vehicle is moving, solutions must be in place that can model the predicted position of the moving vehicle.[29] Artificial intelligence and machine learning play an important role in evaluating the image and sensor data and correlating them with the actual or foreseeable position. Another perception issue concerns the development of suitable algorithms capable of detecting the environment with a high degree of reliability in all operational areas and distinguishing, for example, a stationary motorcycle from a cyclist riding on the side of the road.[30]

A detailed Use case example includes the use of vehicle cameras and intelligent image processing algorithms, as part of an integrated multi-camera system –to provide an all-around view (360-degree visibility) of the vehicle environment from a bird's eye perspective. Together with integrated PNT information, the 360 perception could enable vehicles to identify an object approaching rapidly from behind and the system could warn the driver or prevent the vehicle from changing lanes as planned.[31]

3.3. PNT Monitoring and over-the-air updates for CCAM

CCAM comprises all digital services and functions necessary to commercially realize automated driving to SAE Level 4 or higher in Europe, which includes a wide range of technologies and services. One of

[28] Neil et al. (2020)
[29] Almutairi et al. (2022)
[30] Botte et al. (2019)
[31] Still a major perception issue to read the surrounding environment (including complex object analysis) with a high degree of reliability in all operational domains (Botte et al. (2019)

the most important components of connected, cooperative, and autonomous vehicles is the software and firmware. It is the foundation of every vehicle in the system and thus constant validation and update mechanisms need to be in place to ensure safe and reliable traffic behaviour. Instead of going to the garage, however, so-called over-the-air updates enable the remote management and update of the software and firmware in the car via various over-the-air (OTA) interfaces such as Cellular, Wi-Fi, and Bluetooth.[32] This makes the rollout more convenient not only for the driver but also for the automotive OEM itself, as the introduction of OTA updates brought high-cost savings in the billions of dollars.

OTA updates, especially of the software, are already common practice at many OEMs and include, for example, the regular updating of map material. The updates have become more and more sophisticated in the last 2 to 3 years, including for example the infotainment system and adaptive cruise control. However, with the transition to electric vehicles, these updates are becoming more regular, more complex and therefore more necessary. Some OEMs already offer OTAs to update the battery control module, or more generally to optimize the charging capability in all-electric vehicles.[33] Still, there is much room for improvement as the adoption rate is still relatively low due to the complexity of the process and the need for high reliability of the update functionality.

In addition, recent technical developments related to autonomous vehicles allow highly automated driving functions (HADF) to be updated over the air. This increases the need for highly secure development of these updates, as a threat in certain scenarios can lead to functional failures and thus greater damage. HDAFs rely on a scenario-based threat analysis, which enables us to develop a secure information management system and provides valuable analysis data for future risk estimation.[34] This data needs to be evaluated and updated regularly, thus it requires the OTA transmission of diagnostic and position data between the vehicle and the OEM in order to analyse and evaluate the vehicle's behaviour and the traffic situation. Therefore, a scenario-based threat analysis process for highly automated driving functions is an important part of OTA updates and needs to be aligned with stringent cybersecurity requirements.[35]

The proposed use case, therefore, comprises the development of a networked system, in particular the development of update solutions, of vehicle sensors networked with the OEM to transmit and exchange data and monitor vehicle parameters with a focus on the above-presented challenges. One specific example is the exploitation of blockchain technologies within OTA updates as blockchain databases offer the ability to store proof of location and other forms of 5G usage of network resources, traffic flow, and billing details, enabling a new form of mobility management for OEMs or perhaps even municipal services.[36]

3.4. PNT for Clean Mobility

[32] Khurram et al. (2016)
[33] Rahman et al (2020)
[34] Kim& Cha (2011), Glazia et al (2018)
[35] Khatun et al. (2021)
[36] Rahman et al (2020)

In order to comply with the Paris Agreement and reach the net zero goal by 2050, sooner or later petrol vehicles will be replaced by electric vehicles. The adoption of electric vehicles (EVs) has the potential to reduce pollutant and greenhouse gas emissions currently cause by road transport (approximately 25% of global CO2 emissions[37]). The development of electric vehicles and associated infrastructures is closely linked to the adoption of CCAM technologies, which can help accelerate the transition to more sustainable modes of transport.

The deployment of EVs still struggles with various challenges such as long charging times and limited range. Moreover, the nationwide or regional introduction of electric vehicles depends not only on the public acceptance of the vehicles themselves but also on the development and expansion of the corresponding supportive infrastructure. Charging vehicles at home is obviously more convenient for owners in rural areas, but the majority of people live in cities, and the trend is growing. Here, access to the user's own garages is limited and public charging stations are needed. While home charging takes about 6 hours, public fast-charging stations take about 30 minutes, which has a greater impact on power grids.[38] If the energy is purchased on the wholesale electricity market, the prices for charging at public charging stations can be even lower due to the corresponding lower tariffs. [39]

Given the huge investment effort required for these infrastructures, this is a challenge for many countries and regions. Thus, in addition to the provision of charging stations, the integrated provision of information for vehicles but also for the energy provider must be taken into account. Route planning and optimization, including the integration of the consideration of charging points and times, are important cornerstones when it comes to the wider use of electric vehicles.

Considering this context, two detailed use cases are proposed. The first use case addresses the challenges related to infrastructure planning and optimal routing of battery electric vehicles. Due to the limited range, energy-efficient route selection (eco-routing) is of particular importance and very complex. Challenges include on the one side the currently often underdeveloped infrastructure, but also the dynamic energy pricing, optimization constraints that include road topography, dynamic speed limits, and regenerative braking systems that enable energy recovery during braking, which is affected by route selection. PNT plays a critical role in this context, as a vehicle needs to communicate its position and routing to the grid and other participants in the transportation network while regularly updating environmental information quickly, reliably, and accurately to enable the dynamic responses to changing environmental conditions to optimize routing and extend battery life. Moreover, this information can be used not only for route optimization, but also to support infrastructure planning and services such as traffic information and management.

The second use case revolves around the integration of EVs into smart grids. Smart grids offer the possibility of dynamically controlling demand and supply at the local level, thus enabling greater flexibility of the energy system.[40] Daily charging of e-vehicles, especially fast charging, which is expected to increase immensely in the next few years, impacts power systems, especially during peak

[37] According to European Environment Agency (2021), A. Walker (2020), United States Environmental Protection Agency (2022)
[38] Zishan et al.2021, Levin (2022) in Business Insider
[39] Tan &Wang (2017)
[40] Zishan et al.2021

hours, and the impact can occur in different locations as traffic conditions change. Thus, when integrating electric vehicles into smart grids, the impact on both the energy grid and the transportation system must be considered, as intermittent charging, for example, can place additional stress on the power grid by overloading distribution transformers and transmission lines. On the other hand, by using bidirectional charging stations, electric vehicles can also provide services to the grid, often referred to as vehicle to grid (V2G), including price arbitrage, demand side response, and energy trading as well as frequency and load control.[41] Timing information is very important in this context, as is time synchronization between the grid and the vehicle, since it enables accurate localization of power line faults, synchronization of distributed control processes and load flows, rerouting of power flows during transmission outages, and balancing of energy supply and demand through precise time stamping of end-to-end grid data sets.[42]

3.5. Testing for CCAM-related PNT technologies

All the technological opportunities described above, such as digitalization, 5G and IOT (Internet of Things), and their combination with common or new PNT technologies, open up new ways to improve road safety, develop sustainable infrastructure and increase mobility. However, in order to fully exploit the potential of these technological opportunities, various CCAM innovations need to be tested and, if necessary, improved and further developed. Testing new technologies is particularly important, as errors or inaccuracies can lead to the damage of vehicles, infrastructures, or even to the loss of life of road users. Therefore, the standardization of technologies in road traffic is indispensable to make the public space safer, avoid possible errors, but also to create legal certainty in case of unexpected problems. The validation of alternative or complementary PNT technologies and their impact, or linkage with other elements in the system, be it the environment or the ego-vehicle itself, plays an important role in supporting the certification process. Testing and validation also build trust in society, which affects adoption rates, and is an important component of each country's national strategy to fully implement CCAM.

To this end, there are several initiatives, such as testbeds, developed by the academic community, research institutions and public authorities but also private companies that, while not widely promoted or advertised, are proving to be noteworthy and particularly relevant for moving forward in connected, cooperative and automated driving tasks.[43]

Testbeds can be designed differently, with different scope and characteristics, including data plane.[44] In other words, the testbed can be characterized at the network level with a server centralizing the information, or at the perceptual level providing the information sources, including GNSS raw

[41] Ravi et al. (2022), Frankland (2018), Heilmann & Friedl (2021)
[42] De Falcis, 2022
[43] Botte et al. (2019)
[44] A list of different test beds in Europe can be found here

measurements, Wifi roundtrip measurements, or at the application level focusing on the users themselves, as well as at the geographic level, e.g., national or cross-border testbeds.[45,46]

The more detailed use case focuses on the development of a national or cross-border test bed to provide testing capabilities, particularly with respect to connected, cooperative, and automated mobility technologies, with components to test the real effectiveness of vehicle-to-vehicle and vehicle-to-infrastructure communications for autonomous driving level 4 or higher and their interaction with PNT information (including the use of resilient, accurate, real-time dynamic PNT data).

[45] See ESA Hansel Project (2020), Testbed for Navigation and GNSS in Smart Cities
[46] Example P-Car: NAVISP EL3 012 ongoing Project- Testbed in Italy for autonomous driving

4. ADDRESSED TECHNOLOGIES AND CHALLENGES

4.1. Exemplary technologies to support PNT in CCAM

A large number of technologies are possible to realize different application cases, as already mentioned in the previous chapters. The following table contains a non-exhaustive list of currently investigated technical solutions that may be considered to address CCAM related challenges through different approaches. Examples of utilization of these technologies in the context of CCAM can be found in the public literature.

Technology	Short Description	Goal
Variety of sensors		
5G New Radio	Global standard for unified, higher performance 5G wireless air interface: improves positioning performance by exploiting high bandwidths for precise timing, new millimetre-wave frequency bands, Massive MIMO for accurate angle-of-arrival estimation, and new architectural options to support positioning.	PNT information, Communication functions
6G	Next Generation Cellular Network. 6G wireless uses higher frequencies compared to 5G, with higher capacity and lower latency. Higher Degree of freedom related to different environments such as terrestrial but also underwater and aerial communication (3D connectivity)	PNT information, Communication functions with higher reliability and lower latency
Inertial Navigation System (INS)	Navigation technique independent from GNSS, providing measurements by accelerometer and gyroscope, widely used for automated vehicles.	High autonomy, concealment, continuum, and the successive supply of position, velocity, and attitude
Odometer	Measures the distance traveled by the vehicle by integrating wheel's rotations and overlays the position of the autonomous vehicle at the previous time to calculate the current position.	Higher resilience of PNT information
Barometer	Collects pressure data: By correlating pressure time series data with topographic elevation and road maps, a computer can estimate a vehicle's path.	Alternative/ complementary PNT method at low power to analyse driving patterns
Magnetic Sensors	Estimating the position of a vehicle by measuring the magnetic field after placing magnetic markers on a moving path or the vehicle itself.	Alternative/ complementary PNT method at low power
Visual Sensors	Cameras can be classified as visible (VIS- 400 to 780 nm), Near-infrared (IR- 780 nm–3 mm) or Mid Infrared/ Thermal cameras (3–50 mm) .	Perception of Environment
Ultrasonic Sensors	Based on the principle of measuring the Time-of-Flight (ToF) of sonic waves between transmission and reception. Relies on sonic transducers to transmit and receive sonic waves in the range of 40 kHz to 70 kHz for automotive applications.	Close Object Detection

Radio Detection and Ranging technology (Radar)	Uses radio waves to detect objects within a specific area: When the transmitted waves encounter an object on their propagation path, they are reflected from its surface, where the RADAR antenna picks up the backscattered signal (echo) in its field of view (operates at 24, 74, 77, and 79 GHz).	Provides a precise determination of the object's distance and velocity from the vehicle
Light Detection and Ranging (LIDAR)	Measures the time it takes for a light pulse in the infrared or near-infrared range emitted by a laser diode to be received by the system's receiver (Wavelengths 905nm and 1550 nm).	Gives accurate depth information; Creating a 3D profile of the environment surrounding the vehicle
GNSS related Approaches		
High Accuracy Corrections (PPP, RTK)	Precise Point Positioning and Real Time Kinematic (PPP and RTK) are methods that provide GNSS corrrectionns to user receivers and have the potential to meet the requirements of accuracy, availability, continuity and cost. The correction data (whether system related or local environment related) is received from an operator or a fixed reference station via e.g. satellite/mobile communication.	Enables new form of High accuracy positioning systems for coordinated and automated mobility by sharing sensor data and combines GNSS and 5G
New Receiver & Antenna techniques	Receiver & Antenna design play a key role in mitigating interference effects. Different techniques like vector tracking, Kalman-filtering, digital beam forming or supercorrelation can help to increase the performance in degraded environments and mitigate intentional and unintentional interference.	Higher resilience against jamming and spoofing, higher performance in degraded environments
3D Mapping–Aided GNSS	These projection techniques give information on the terrain hight and they can predict which satellites are directly visible at multiple locations. Moreover, they can give predictions on which signal will be reflected including the path and delay. Ray-tracing techniques can predict the path delay of Non-Line-of-Sight (NLOS) signals, enabling correction of NLOS errors, and predict which direct Line-of-Sight (LOS) signals may be subject to severe multipath.	Communicates to the users the satellites that should be directly visible and avoid the non-line of sight which would be affected by multipath.
GNSS Proxy Canopy	Deploying GNSS "relays" or pseudolites at rooftop or street level (at very low altitude) to remove urban canyon problem.	Provision of ubiquitous, precise, reliable PNT information
Computer Methods		
Blockchain	Blockchain is a shared/distributed database with pieces of data stored in data blocks. Blockchain is an important link between IoT devices, vehicles, and people, providing CCAM stakeholders with the necessary level of trust and effective management of the underlying CCAM systems.	Secure PNT Data transmission and real-time applications
Computer vision,	Machine learning and artificial intelligence can support and enhance a variety of PNT technologies	Analysis of data from different sensors and merging of information into meaningful output

ML & AI	and applications, e.g., in the detection and classification of GNSS jamming and other threats. In general, there are different models and methods to fill different measurement gaps, simplify the analysis of data, or merge different data sets.	
Combination of Approaches, Sensors,…		
Simultaneous localization and mapping (SLAM)	Technique of building a map of the environment and estimating the state of the vehicle in the map in which it is moving, at the same time. The vehicle may reset its measurement error using static landmarks and dead reckons between them using on-board sensors e.g. by tracking vehicle dynamics, using inertial sensors and GNSS (see Map Matching).	Enabling Collaborative Positioning using GNSS and V2V communication
Map Matching	Procedure for matching objects to geographic positions on a digital map. Using a map matching procedure, the CCAV can be precisely located on the map. Static parts of the environment, such as buildings, roads, traffic lights, traffic signs, lane markings, barriers, etc., can be accurately determined and recognised, e.g. by using LIDAR. In turn, the absolute position of the CCAV can be estimated by combining the relative position of CCAV with the absolute position of the landmarks.	Combining geographic coordinates to a model of the real world

Table 2:Exemplary Technologies supporting PNT technologies for CCAM[47]

4.2. Risk & Challenges

For the successful deployment and commercialization, different challenges, including barriers to adoption (see *Figure 4*), need to be addressed by various stakeholders such as automotive manufacturers, software developers, hardware engineers, academia and policymakers. Such challenges include technical concerns such as sensor management, decision making, reliability, and security threats. But non-technical challenges, including social and regulatory challenges, must also be overcome to ensure the successful deployment of a technical solution.

[47] The list is only a first selection and not to be considered as complete.

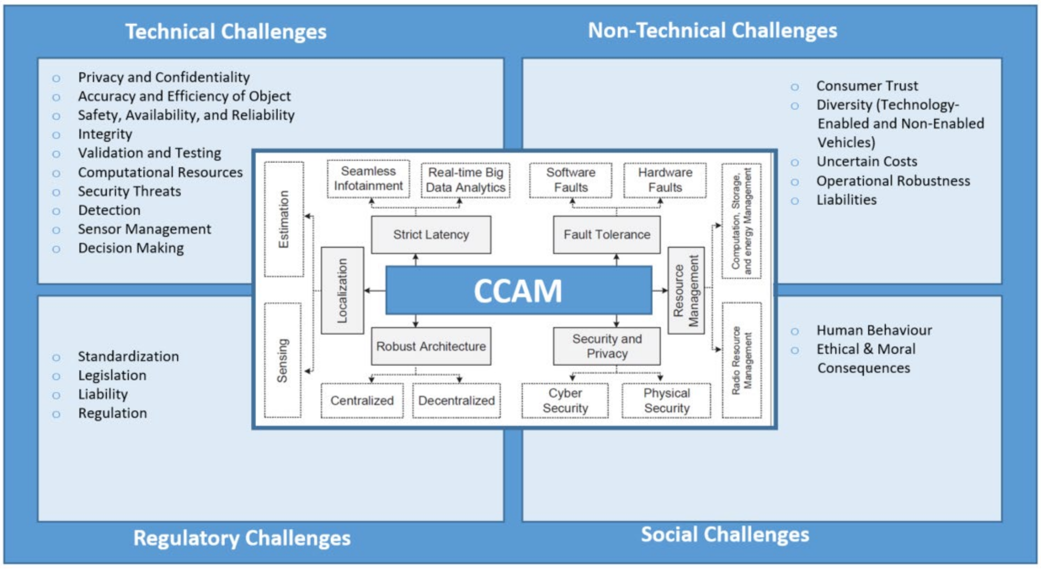

Figure 3: Challenges and related Requirements CCAM[48]

The structure of this thematic window is therefore specifically designed to address not only technology development challenges but also barriers to adoption including regulatory and non-technical challenges. *Table 3* shows that all use cases focus on the technical challenges. At the same time, however, benefits are created for the stakeholders involved, from the manufacturer to the user. On the one hand, this is achieved through improved efficiency, but the suggested themes/use cases also aim to ensure safe driving and traffic. In addition, the increase in efficiency and the transition to e-vehicles will also reduce emissions and thus accelerate the sustainable development of the transport sector.

Use Case 4, which explicitly deals with technology development for increasing the sustainability and safety of the automotive sector, focuses precisely on this objective. To address regulatory challenges, the development and use of adequate test facilities is of enormous importance. These are represented in Use Case 5, and have the goal of enabling standardization and validation while building trust in the end-users, which in turn affects the acceptance and adoption rate of the population.

Use Case	Risks & challenges			
	Technical	*Non-Technical*	*Social*	*Regulatory*
1	✓	(✓)	✓	
2	✓	(✓)	✓	
3	✓	(✓)	✓	
4	✓	✓	✓	
5	(✓)	✓	✓	✓

Table 3: Addressed challenges per use case

[48] Ilustration based on Hussain & Zeadally (2018), Gao et al. (2021), Barabas et al. (2017)