Enhanced Teleoperated Transport and Logistics: A 5G Cross-Border Use Case

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***Abstract*—5G technologies promise to significantly improve the network connection with ultra-low latency communications and edge computing, enabling the delivery of groundbreaking solutions, such as autonomous vehicles and artificial intelligence (AI) based communications systems. As 5G mobile networks are still under deployment, the potential for 5G-connected AI-assisted driverless cars, drones, and vessels is still several years away. However, to realize fully connected and automated mobility (CAM), a crucial step needs to be addressed: 5G-based teleoperated transport. For this reason, the H2020 5G-Blueprint project is designing, testing, and validating a 5G-enabled teleoperated transport system and its enabling functions in both relevant and operational environments, realized through cross-border trials on the road/highways and waterways along 5G corridors that cross through Belgium and The Netherlands. The main outcome of the 5G-Blueprint project will result in a blueprint for the future cooperation between public, private, and semi-private parties (e.g., ports), empowered by 5G technologies and gaining new insights related to the architecture, governance, and relevant business models of CAM services.**

***Index Terms*—5G communications; teleoperated transport; logistics; vehicular communications; remotely operated vessels and trucks**

I. Introduction

Being the next generation of cellular network technology, 5G is considered as the mobile system that meets the stringent requirements of the ITU IMT-2020 to support enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC), massive machine-type communications (mMTC). In the 5G network architecture, several important aspects are being considered. Apart from the 5G-NR, where an enhanced new radio is being developed, many other features are essential components of the 5G architecture, such as network slicing, service-based architecture (SBA), multi-access edge computing (MEC), network function virtualization (NFV). As a successor of 4G, 5G is being standardized in 3GPP, starting from Release 15 onwards. Currently, Release 17 is under development where enhanced V2X services are being incorporated (e.g. platooning, extended sensors, automated driving, and remote driving) enabling the so-called Connected and Automated Mobility (CAM) services.

During the last 5 years, there have been a few demonstrations, trials, and pilots of CAM use cases where V2X connectivity has been envisaged by the incumbent ITS-G5 technology or existing mobile networks (4G/4G+) for connectivity purposes. Recently, C-V2X PC5 direct communication is being tested in trials in Europe as part of CONCORDA [1]. Also, some CAM trials are being demonstrated using 5G technology, as part of several H2020 projects, including 5GCarmen [2], 5G-Mobix [3], and 5GCroco [4], targeting higher level of automation of vehicles in cross-border environments using 5G technology to meet the stringent requirements.

Industry experts believe that it is just a matter of time before autonomous vehicles become part of the transportation network. The introduction of driverless vehicles is going to have a major impact on businesses and professionals [5]. Automated vehicles could replace corporate fleets for deliveries or transporting employees, while workers could gain productive hours in the day by working instead of driving during daily commutes. Though their potential may be great, fully autonomous vehicles are not readily available. Attempts at developing fully autonomous (road) vehicles have not yet led to a mature technology that would be safe enough for the public introduction.

In the meantime, many problems that autonomous driving could resolve persist. Although advanced driver assistance systems (ADAS) have managed to ease driving tasks and improve road safety, the need for a manual driver imposes a vast efficiency challenge on the transport sector. Drivers have to spend an important part of their time waiting, e.g., when (un)loading the vehicle or while administrative tasks are being performed. Additionally when the driver needs to respect their resting times, the vehicle is halted until the next day. Therefore many scarce drivers and vehicles are needed to complete transportation tasks. Teleoperation of vehicles could resolve these issues, while full autonomous functionality remains unavailable. The current state of the art already includes drive-by-wire solutions coupled with connectivity solutions that enable 'remote driving'. Though, the research found that latency in wireless connections hinders remote driving tasks

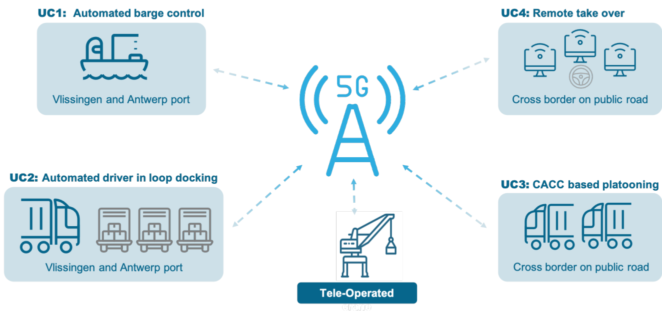

Fig. 1. 5G-Blueprint use cases

crucially, the human reaction time varies depending on the specific tasks, falling in the range of hundreds of milliseconds (ms). To not deteriorate the operator's performance, the latency of the network shall be one order of magnitude lower, i.e., in the range of tens of ms. Further requirements may include high throughput and low latency for continuous video streaming. Such various and diverse use cases put differentiated quality-of-service (QoS) requirements on the network [6]. Of course, seamless handover of wireless connections between national networks turns out to be essential under these conditions when crossing borders. Introducing any additional latency may have detrimental safety effects. The cellular network is best suited for such cross-border vehicle teleoperation as it allows to cover long distances, at acceptable cost. In addition to that, vehicle teleoperation requires a very responsive network to feed the live video and sensor stream to a control room and to communicate with the vehicle from a control room. Only 5G technology will enable latency levels that are low enough for safe cross-border teleoperation. Hence, no international teleoperation use cases have been developed to date that would truly demonstrate the impact of teleoperation on current transportation over cross-border public roads and waterways. The current state of the art only comprises local pilots who may easily assure wireless connection stability and do not require seamless connection handover.

The 5G-Blueprint is designing and validating a technical architecture and business and governance models for uninterrupted cross-border teleoperated transport based on 5G connectivity and is to explore related business and governance models [7]. The project aims to provide a blueprint for future operational pan-European deployments for teleoperated transportation solutions within the logistics sector and beyond, considering road and water transport means (i.e., cars/trucks and vessels). In this paper, we present the technical approach undertaken by the 5G-Blueprint and elaborate on an initial analysis of the risks and benefits of teleoperation resulting from the survey we conducted with the main players and actors involved in the logistics and transportation sector.

II. 5G Blueprint Concept

A. Use cases

The project is focused on implementing the 5G network thereby achieving low latency and ultra-reliable communication to develop innovative new use cases with new governance and business models. To cater to the 5G technology within the mobility domain four use cases and a series of enabling functions will be addressed in the course of the project. The following sections provide insights into the baseline functionality that is being provided by each of the use cases. One of the use cases focuses on waterway transport whereas the other three focus on roads. We also demonstrate how the combination of teleoperation and automation will be developed along with the lifespan of the project trying to bridge the gap between the human driver and autonomy.

5G-Blueprint explores the following use cases depicted in Figure 1:

Automated Barge Control

Within this use case, the channel navigation of the barges will be teleoperated along with partial automation. Cross-border passing will be given a priority whereas channel navigation, port entry, and exit efficiency will be enhanced by reducing crew requirements for barge navigation. Vessel navigation during barging will be performed entirely by the vessel captain in collaboration with a teleoperating captain in the shore control center, therefore eliminating further crew interventions. Pilots are located in the ports of Antwerp and Vlissingen (Belgian and the Dutch sites), whereas validation in the cross-border environment will be piloted near the Zelzate site. Please refer to Section II-B

Automated driver-in-loop docking functionality

This use case has been divided into two subcases namely, a) Automated docking and b) Teleoperated crane. The first subcase propounds on the idea of a driver assistant system for docking articulated vehicles within warehouses and distribution centers by integrating 5G technology. The focus of this subcase is to develop a bi-directional controller to control the vehicle along the desired reference path. This is carried out in two steps, the first being the forward (preparation) maneuver and the second being the reverse (docking) maneuver, by controlling the vehicle autonomously along with the teleoperator overseeing the operation and taking control if necessary. Trucks will be equipped with standardized 5G connectivity solutions for an optimized docking operation with respect to time and space requirements. The positioning of these trucks will be performed via a stationary camera and an RTK GPS-based RTLS. Within the second subcase, a mobile harbor crane will be retrofitted with teleoperation functionality, so that it can be operated from a remote-control center by a teleoperator. Communicating optimal driving paths to the tractor and maneuvering the crane in safety-critical situations will be highly time-critical. At first, the cranes will be teleoperated for loading and unloading only.

Cooperative Adaptive Cruise Control based platooning

Platooning of trucks has been a widely discussed topic in the area of logistics for a while now. A platoon of trucks happens when two or more trucks follow one another in close proximity to each other on dedicated stretches of the highway. This is achieved by using a combination of adaptive cruise control, lane-keeping system and V2V communication, the cost savings due to the reduced aerodynamic drag leading to lower fuel costs and lower emissions have been established by many studies in the past. However, most companies failed to demonstrate a clear business case with this technology as the following of trucks still requires a driver on board ready to take over at any point in time. This use case revolves around the fundamental strategy of platooning by relying of 5G, while the driver is removed from the cabin of the truck and placed in a remote location from where they can control the vehicle. The system is aimed at being partly automated wherein the lead vehicle can be driven by a driver in the cabin or a teleoperator and the following vehicle(s) can be automated.

Remote takeover operations

Remote takeover defines the process in which a remote operator takes control of a distant vehicle. To enable remote takeover, it is necessary to monitor and adjust the vehicles to steer and drive remotely from the control center. Subsequently, the vehicle must be equipped with an onboard unit and cameras providing teleoperation functionality. Another essential component is the teleoperation center, which must provide the technical means to manage vehicles, remote operators, ensure connectivity, and control vehicles' access. Remote takeover operations are integration tests verifying the function of all major components (vehicle, remote station, teleoperation center) of the teleoperation solution. Remote-takeover operations will be tested as one of the crucial activities of a real deployment of teleoperation. The tests will verify both static (stationary vehicle) and dynamic (vehicle in motion) scenarios. As the name suggests this use case provides the teleoperation functionality to the first three use cases.

The process flow between these use case can be interpreted in the following way, Firstly the port entry/exit of the barge is teleoperated from which a teleoperated crane lifts the container and loads it onto the truck. These trucks will then form a platoon and drive to the nearby distribution centre by using the CACC technology that will be adopted in this project. Once the truck arrives at the DC the autodocking system helps dock the trailer in the designated location. Figure 2 presents the process flow of teleoperation from port entry to distribution centre, thus interleaving the four use cases into one comprehensive enhanced teleoperated transport and logistic solution.

B. Pilot sites

Described use cases will be validated and tested within the three different pilot sites, see Figure 2 for the 5G-Blueprint project, such locations are strategic logistic-related sites located in Belgium and The Netherlands (Figure 3 depicts the pilot's sites):

- Vlissingen (North Sea Port Area)
- Cross border area in Zelzate (North Sea Port Area)
- Antwerp (Port of Antwerp Area)

On the Belgian side, in Antwerp, automated barge control will be validated by considering navigation in a busy port and performing loading/unloading operations. In addition, the land-site component of this pilot area provides room for assessing co-existence between C-V2X and ITS-G5 (within the platooning use case) and remote takeover operations.

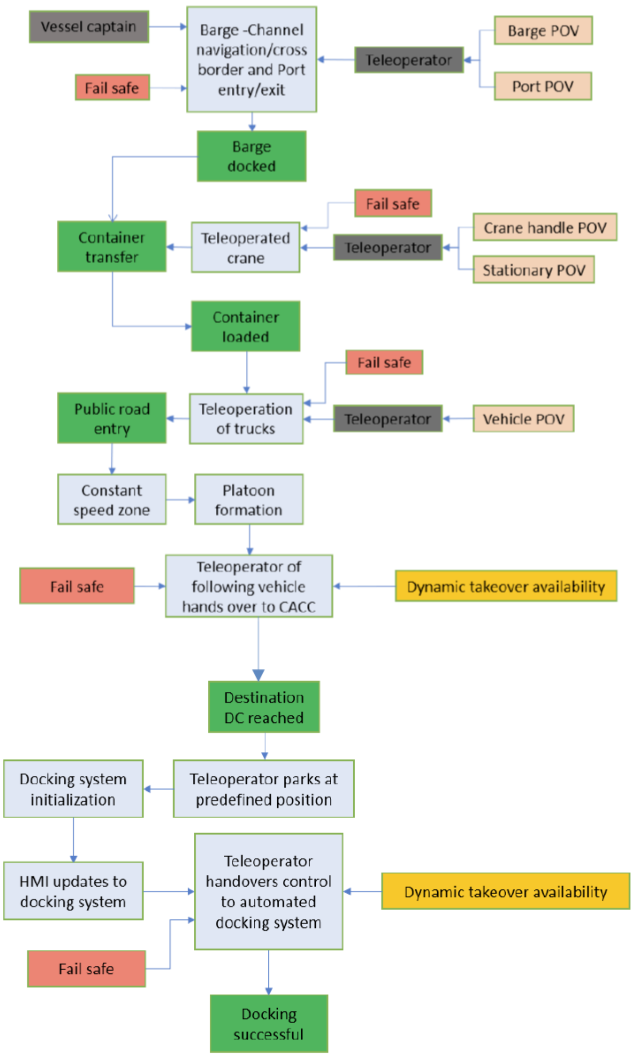

Fig. 2. Teleoperation flow: From port to distribution centre

In the cross-border scenario, in Zelzate, three use cases will take place. Both car-based connectivity and barge control using long-range 5G connectivity will be assessed. In addition, a remote takeover operation use case will be considered in a scenario where the seamless handover takes place on a public road.

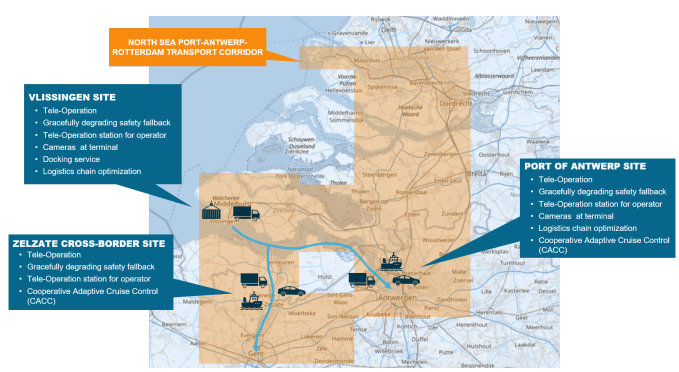

Fig. 3. Pilot sites located in Belgium and The Netherlands

III. 5G Blueprint enhanced technologies

A. 5G connectivity for teleoperation

The 5G network that we are implementing in the context of 5G-Blueprint will give an opportunity to explore innovative solutions that can overcome several issues that Mobile Network Operators (MNOs) are confronted with, when supporting advanced CAM use cases both in an inland and cross-border context. Within Blueprint two types of use cases have been chosen that are not only very promising for logistics but also challenging in respect to the demand on the mobile network. For teleoperations both bandwidth and latency are of importance. With CACC (or platooning), the latency is even more straining. For both types of use cases the robustness is of utmost importance, what may be challenging, especially in cross-border areas. Focus is needed on i) providing performance guarantees (e.g. with 5G slicing), ii) predicting when the performance will get too poor such that preventive measures can be taken while maneuvering and how the performance guarantees can traverse the border to the other operator (e.g. by dynamically allocating the resources and providing the slices at the other operator). Currently, the focus in cross-border areas is on minimizing connectivity interruptions when crossing borders and during hand-overs among operators. There is an ongoing discussion in Europe on the frame type selection for the 3,5GHz band. Since currently discussions are mostly based on theoretical models, testing these in a real live situation will be of value to further improve the coverage in our border areas. Existing 5G Core standards do not support handovers between operators at this moment. 4G technology should support handovers between operators but this has never been implemented in real operations. Work is needed to design and test out possible handover relations between cross border mobile infrastructures. This needs to cover both the technical issues as also the governance issues to keep the implemented solutions in a working condition. 5G Blueprint will study whether hybrid communication (5G-NR CV2X long- and short-range communication) can be used to enhance specific CAM use cases. Moreover, coexistence among 3GPP based CV2X (PC5) and IEEE ITS-G5 communications will be explored concerning short-range communications. Also, the use of public/private fiber infrastructure in a 5G landscape will be technically investigated, targeting the reduction of deployment and operational costs of 5G networks.

B. Enabling functions

Enhanced functions enable teleoperation in two important ways. First, they help to resolve key safety and security challenges related to physically removing the operator from the vehicle: a teleoperator will not have the same situational awareness as an on-board operator, and the interaction between the operator and its environment may be hindered, in particular when when a transfer of control is necessary. Second, enabling functionalities support unlocking the business potential of teleoperated transport.

Eight Enabling Functions are being developed and demonstrated within the project to help resolve key safety and security challenges related to physically removing the operator from the vehicle. Some of these will also contribute to unlocking the business potential of teleoperated transport. The business case for teleoperated transport lies mainly in the more efficient use of scarce operators but may also be supported by emerging innovative business models, e.g., building on opportunities for robust 24/7 operations. Assessing the good functioning and value of enabling functions are therefore a first step towards increasing operator efficiency, through providing better and up-to-date information, reducing operator waiting times and enhancing effectivness of operations.

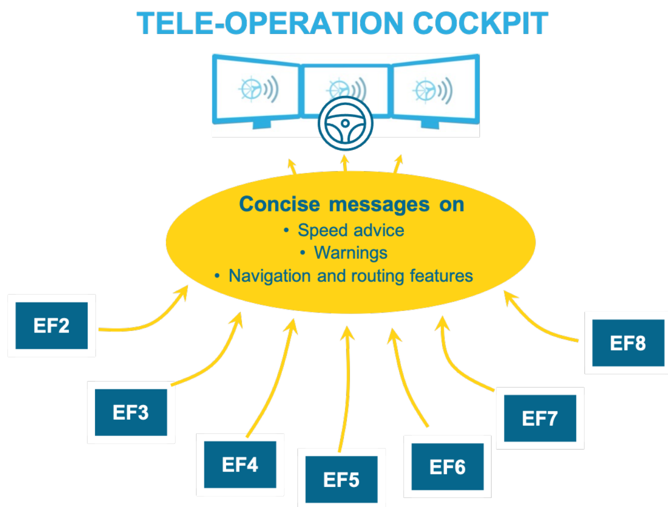

Fig. 4. 5G-Blueprint enabling functions

The following enabling functions are being developed to support the use cases:

- **EF1 EAD**: Enhanced awareness Human Machine Interface foresees in clear and concise on-trip information about the situation on the road ahead to the teleoperator via a dashboard. This will present a consolidated view of all safety-related information to the teleoperator, increasing his/her situational awareness without creating information overload.
- **EF2 VRU**: Vulnerable Road User (VRU) interaction provides warnings to the teleoperator and vulnerable road users (e.g., pedestrians or cyclists) about likely and impending conflicts between them.
- **EF3 iTLC**: Time slot reservation at intersection ensures a conflictless crossing of intersections by teleoperated vehicles by providing a timeslot for "green-lighted" passage. This will reduce the likelihood of collisions on intersections, as well as ensure smooth navigation of the intersection (which is particularly important for truck platoons – see UC3).
- **EF4 DP**: Distributed perception extends the perceptive range of the teleoperator (currently limited to cameras and sensors installed on the teleoperated vehicle) by making use of cameras and sensors on other vehicles or roadside units. This should lead to safer transport as the

teleoperator can be made aware of obstacles not picked up by the teleoperated vehicle's own sensors.

- **EF5 ACA**: Active collision avoidance provides safety measures that actively protect teleoperated vehicles from colliding with other road users. This will further ensure the safe deployment of teleoperation in a production environment.
- **EF6 CID**: Container ID Recognition provides the capability to identify the unique shipping container ID number on the basis of camera images. This will allow for visual confirmation of the container ID in the absence of the operator, increasing efficiency and reducing the risk of errors.
- **EF7 ETA**: Estimated time of arrival (ETA) sharing provides real-time ETA and routing information to the teleoperator and other relevant parties, as well as sets up an exchange of data with terminal systems to dynamically organize the container pick-up or drop-off time at the terminal.
- **EF8 SA**: Scene analytics foresees in continuous monitoring of several key areas relevant to teleoperation. Based on available data streams (camera, sound, text) and using machine learning techniques, anomalies to the normal operation of the vehicle and its surroundings can be detected, which can then be communicated to the teleoperator or other relevant parties. This should increase the safety and efficiency of teleoperation.

IV. Risks, Benefits and requirements for teleoperation - An initial survey study

Driven by shared mobility, connectivity services, and autonomous driving, new business models are to expand automotive revenue pools byup to 30 percent, adding up to $1.5 trillion [8]. For several new mobility services, business models exist for the interaction between companies and end users. The car industry primary service delivery might be altered, from a purely product business model towards a service-oriented business model. More attention will be given on usage models (shared mobility), and after sales models, as well as to maintenance and repair. User habits will change, as a larger percentage of the mobility use will be shared and autonomous. This will result in a higher usage rate of cars (in shared vehicles), as it will be cheaper, easier and safer to be on the road. This however might result in a higher personal mileage, which might increase by 23% by 2030 according to PWC Autofacts [9]. This might go along with a lower possession level of cars, if fewer people will purchase a personal car, utilizing more shared mobility services, especially in urban areas. Thus, the overall car inventory sold globally might be lower, while the cars might need to be replaced faster, as more wear might occur. Thus, new recurring revenues may emerge, going together with "as-a-service" business models (shared mobility, ride hailing, data connectivity services with applications, safety services and software updates)- that all need better, continuous monitoring and anhanced interaction with a service center. McKinsey [10] expects this market to grow by 2030 from $2.750 trillion towards $4.000 trillion in one-time vehicle sales. According to the same source, the aftermarket will almost double from $720 trillion to $2,200 trillion dollars and the recurring revenues will boom from $30 trillion to $1.500 trillion.

A first survey round amongst the use case owners has provided a starting point for the analysis of the business case for teleoperated road and barge transport, including an overview of the alleged benefits and risks. The recognized benefits can be split into three categories: **i) cost decrease, ii) safety increase, and iii) job market compatibility**. Cost decrease would be established by a significant reduction of waiting and resting hours as the teleoperator will be able to switch from one to another vehicle/vessel that requires assistance. Fuel consumption would go down due to the smart dashboard that will provide a recommended speed that will allow the vehicle/vessel to keep moving continuously as much as possible. Payload capacity may be increased as driver cabins would no longer be required. There is some disagreement on the alleged decrease in human capital cost. The question at hand is if the cost for a teleoperator desk job with increased complexity will be lower than that of a driver whose job might be less complex, but who needs to be paid travel expenses, overtime, and overnight allowance. And if not, whether the costs will be compensated by the reduction of the aforementioned cost elements. Additional sensors on vehicles and vessels, e.g., radar, lidar, and others will be able to perceive and process more situational information than the human eye and hence may help to respond more pro-actively hence increasing the safety of other road users. Also, the safety of drivers and shippers could be increased as they can be taken away from a potentially dangerous situation when transporting dangerous goods or having to rest at remote locations. Fewer people on site will decrease the risk of accidents, as well as ensure an easy handover of control from one teleoperator to another in case one is not feeling well. When it comes to the job market and current shortage of drivers, the development of teleoperation is believed to provide more predictable working hours and align better with the preferences of young people who are used to work with computers and screens and prefer an 8-hour shift close to home, rather than staying away for days or weeks at a time. As the importance of work-life balance continues to grow, all indicated elements will grow in importance and contribute to a more sustainable future. Lower costs will make room for investments in new sustainable vehicles and vessels. The smart dashboard can control fuel consumption and teleoperators will work closer to home than drivers, hence reducing their carbon footprint. Innovation generates a wide variety of questions to be answered and challenges to be solved. To enable proper risk mitigation in advance, the use case owners (part of the project) were asked to highlight the risks they foresee in regard to regulations, organization, operation, safety, and technology. The biggest risk and showstopper for teleoperation identified so far is the absence of a legal framework, which means it is not yet allowed to drive teleoperated vehicles on public roads or waterways, except for smaller experiments like the pilots under work package 4 of the 5G Blueprint project. Moreover, the advantage of job market compatibility could also be a big risk. Whereas the driver/shipper shortage is one of the main motivations for this project, it could also lead to fear among the current drivers, fear for job loss, fear for the changing job environment, and increased complexity. This fear could lead to union protests and strikes. It may put even more pressure on an already tight job market. Finally, there is a risk that the teleoperator jobs might be outsourced to non-EU countries where the cost is lower, hence increasing unemployment within the EU. When it comes to technology, it is apparent that one will require the support of OEMs in the development of teleoperation kits that are compatible with external software that connects the teleoperator with the vehicle or vessel. It also requires a 5G connection at all times, with the projected bandwidth and latency at even remote locations and across borders. It may be clear that without proper connectivity, there is no control of the vehicle and the vehicle will be required to stop, herewith increasing the risk of accidents. The challenge for 5G providers is to commit to the required service level. Should the connection fail, this would lead to an increased risk of incidents on the road. Taking the driver out of the vehicle will most likely create additional communication layers in the human-machine interaction hence lengthening the communication process and causing an increased safety risk. It is also believed that sensory deprivation of the teleoperator, by not being present inside the truck and for example not hearing a flat tire or ambulance, could lead to more and/or different incidents. Community acceptance will be directly impacted by the level of safety that can be guaranteed, therefore these risks need to be mitigated first in terms of actual and cost-effective deployment of teleoperation. Based on this initial survey, the project aims to create a business case for logistics end-users, where all requirements in relation to safety, technology, operations, finance, and regulations are explained and a basic calculation model is generated to assess the financial impact of teleoperation in different scenarios.

V. Conclusions

5G-Blueprint focuses on door-to-door teleoperated transport - an approach towards CAM presenting a lot of business potential in the short term, especially in the logistics sector where it provides a response to the pressing issues of labor market shortage and economical loss caused by waiting times. This approach would not be possible in the 4G context since the corresponding connectivity requirements are too stringent. 5G-Blueprint intends to validate latest 5G technologies' fit for purpose to enable and facilitate door-to-door teleoperated transport, both from a functional and non-functional perspective. The project does so in a context covering the overall architecture to realize various use cases and by bringing together all needed technical components to realize an exhaustive validation. Moreover, the project intends to validate both business and governance models and provide clear lessons learned to the appropriate standardization bodies since this is considered crucial for enabling large-scale international deployment.

VI. Acknowledgments

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