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D3.2: Delineation of Business Models

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Abstract

The present deliverable contributes to advance the work on 5G-Blueprint's business-related objectives. First, it provides a market analysis for the existing market of teleoperation services. Second, it presents an in-depth analysis of the roles, interactions and potential bottlenecks within the complex value network for 5G-based teleoperation, including a discussion of the main data and liability flows. Third, it also provides an extensive business model analysis, identifying the main business model options at the levels of connectivity, logistics and TO services, discussing the feasible deployment options of teleoperation across three deployment scenarios, and delineating a series of business models. Lastly, as a basis for the entire analysis, it reviews the advantages and challenges of teleoperation and the learnings of previous European projects.

Keywords: Business models, Value network, Deployment options, Market analysis, 5G, Teleoperation

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CO	Confidential to 5G-Blueprint project and Commission Services	

* R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

The central objectives of the present deliverable are multifold. First, it provides a basis to understand the advantages and challenges of teleoperation and build on previous work in related projects. Second, it defines and studies the overall value network for cross-border teleoperated transport based on 5G connectivity, thoroughly plotting the main roles and responsibilities as well as their data and liability interactions and potential bottlenecks. Third, it delineates a series of business models for teleoperation (TO) with 5G, based on different future deployment options. Last, by thoroughly studying the underlying business model options for several key roles in the value network, this study provides a blueprint that can be flexibly re-used in and adapted to deployments of teleoperated transport solutions in other areas.

We also provide a market assessment for teleoperation as a stand-alone service, comparing the value propositions of the companies that are currently advertising their offering of remote operation services. This incipient market is dominated by young companies that have driverless software providers, logistics companies, and car owners as target customers. In general, these TO service providers aim at offering a complete solution, for instance including remote operator training, their own analytics platforms, a connectivity subscription, or even their own vehicle. In contrast, either as their main business model or as an alternative option, some companies offer more flexible options, including the provision of software only or the TO service on-demand. In addition, while some offer to install a TO station at a customer's premises, others manage and operate their own TO center. Similarly, while some companies focus on specific use cases, either related to freight or passenger transport, others target many types of use cases, with the ambition to teleoperate any type of vehicle and equipment.

In the value network analysis, we first plot the main business roles whose involvement is crucial to enable the use cases of the project, providing a comprehensive description of the entire value network. Since 5G-Blueprint covers different deployment environments (roads and waterways) and aims to explore different use cases, the relevant value network is complex. We identify six different layers, which in turn include each several specific roles and responsibilities. We also allocate these roles to those stakeholders that are potentially willing and capable to fulfill them.

Building up on the identified value network, we discuss the main necessary interactions amongst stakeholders/roles in terms of liability shifts and data flows. Since teleoperation will bring new sources of risk, for instance from the malfunctioning of software or from an unstable 5G connection, it may imply a liability shift from traditional liable actors–largely, human drivers or captains on board of a vehicle–to new ones, affecting which entities will be responsible to contract insurance to cover liability claims in case of damage to the vehicle, the cargo or third parties. Achieving an attractive business case may require MNOs, vehicle manufacturers, system integrators and TO service providers alike to assume part of the liability. However, a lot of uncertainty remains around legislative mandates as well as on multilateral agreements by market players in order to distribute the responsibilities. For instance, MNOs may assume liability, to some extent, for damages caused (indirectly) by the underperformance of their networks in terms of reliability and latency. While SLAs between TO and 5G service providers cannot guarantee the QoS required by TO with absolute reliability, they may include promises and associated penalties based on the service levels that the network can provide in each given area. In addition, regulation regarding liability will affect the resulting business models, for example if OEMs choose to integrate all the enabling hardware and software themselves–or even the TO service provision–in order to avoid assuming responsibility for damages caused by retrofitted third-party systems.

Supporting or enhancing teleoperation, several data transactions are relevant to consider, stemming from multiple sources within vehicles or their environment. We provide an understanding of the main data sources and types that need to be shared, aiming to give clarity regarding which specific actors will be responsible for providing these data. In addition, we try to highlight the main data requirements to perform several key roles in the value network. At the center are those data streams sent from transport, information and connectivity service providers to the teleoperation service provider and between the remote control station and the vehicles.

In addition, it is important to identify any potential bottlenecks to the adoption of the different value network roles and responsibilities and, consequently, to the adoption of 5G Blueprint's use cases. We discuss the challenge of providing uninterrupted high QoS connectivity, which relies on seamless session handover between a private and a public network or, when a vehicle crosses a border, between public networks of different member states. From a business perspective, this entails a coordination challenge among MNOs, and would require much more complex roaming agreements than the current available ones. Standardizing future handovers will require defining new international templates, the specifics of which remain a topic of further research.

The present study also explores what would be the most economically feasible and beneficial role of teleoperation in the future, in relation to automation technology and the geographical scope of deployment. The identified deployment options relying on lesser than L4 automation (i.e., the most feasible ones to start with) were the teleoperation of cranes, reach stackers and forklifts, as well as the use of direct TO for platoon forming and for short milk runs within a logistics terminal. This would require having an advanced 5G network but only within a local area where other use cases would also use the upgraded network resources. Teleoperation for waterway transport is seen as feasible to scale up beyond port sites before upgrading in terms of automation: it would be possible to reduce the size of the on-board crew while still keeping some personnel on board of the barges for safety purposes, and the remote captain would take over for the more difficult parts of the trip. This would already allow transport companies to use the idle or resting time more efficiently.

In contrast, wider deployments of direct TO for road transport would likely only be feasible once higher automation levels are available for driving in open roads, for safety reasons. On open roads, the largest benefits may arise when AD and TO complement each other: TO can enhance safety by ensuring a human driver can take over control remotely when the AD functionality fails, while automation helps guarantee the safety of remote driving when the wireless connection is interrupted. TO would be used as a complement to autonomous driving (AD) in (a) more complex local roads, and to (b) help (semi-)autonomous vehicles get on and off highways or if they suddenly become unable to continue driving autonomously.

In line with this, we propose and quantitatively assess a business model for long-haul road freight through European highway corridors. In this model, L4 (i.e., highly but not fully) autonomous trucks are driven to a location near a highway by a human teleoperator, and then drive autonomously until they exit the highway, subject to a traffic control center giving clearance for the routes on the basis of road and weather conditions. This business model would result in benefits from higher productivity and traffic efficiency prior to the commercial readiness of full automation, while also yielding better work conditions. TO would help mitigate the negative consequences of long-haul trips, such as mental health issues from social isolation, and in turn could help reduce current labor shortages. Similarly, TO can increase safety, since fatigue from long-haul journeys is a main cause of accidents. Our cost-benefit analysis also shows there are high potential economic benefits from decreasing the operational downtime of vehicles. In turn, automation would increase the cost-efficiency of TO by lowering the ratio of required human operators per supervised vehicle.

The business model analysis also delineates a wide set of specific options regarding the following crucial roles in the value network, in the context of deploying TO solutions based on 5G:

- Commercial roaming agreements for seamless 5G service continuity.
- 5G connectivity service provision, including the provision of network slicing.
- Deployment of network infrastructure.
- Logistics services and other services intended to optimize goods transport, including automated docking, container ID recognition and VRU warnings.
- TO service provision and the management and deployment of the TO center

The discussions about discrete business model options revolve around, among others, (i) who will be the customers and providers of the services, (ii) the pricing models and value propositions offered, (iii) any specific challenges identified, and (iv) possible co-investment arrangements.

Based on possible combinations of the identified business model options per role, we also propose a series of overall business models for each deployment scenario.

- For scenario 1, consisting of a port or industrial area with numerous short distance transports, the following two business models were discussed:
    - The first one relies on a more locally-orchestrated deployment, with a private 5G network financed by a port authority. In addition, the port would also help finance the deployment of a TO center, in collaboration with local logistics companies. These logistics companies would form a joint venture to offer the TO service within the area.
    - The second model relies on attracting deployment of 5G and TO services by providers with a broader (inter)national focus. With coverage on-demand, an MNO upgrades the capacity of its public network in the port or industrial site. The TO service is done by an independent service provider. Compared to the prior model, here the site owner plays more the role of orchestrating rather than financing.
- For scenario 2, consisting of a major transport axis within a country, we focus on the use case of teleoperation of semi-autonomous barges.
    - In the third business model, port authorities as well as TO service providers lease customized network slices-as-a-service from M(V)NOs, who in turn acquire virtual network resources via a slice broker. The resulting higher flexibility can provide a quicker time-to-market. TO service provision is provided by a specialized service provider that offers an integrated service and deploys its own TO center.
    - In the fourth model, 5G network deployment is based on network sharing; MNOs densify their networks along waterways by relying on active network sharing to substantially reduce costs. Regarding the TO service, the provider would be a large transport company with a wide geographical presence and substantial volume of transports. This company would retrain their current captains to be licensed to remotely operate vehicles.
- For scenario 3, consisting of goods transport across national borders, we extend the aforementioned business model in which TO is used to support L4 trucks in complex local roads and when road and climatic conditions become unmanageable for the self-driving systems.
    - In the fifth business model, a vehicle manufacturer integrates the role of TO service provider, offering it as an added value service. In this model, the TO center would be co-located within the premises of a traffic manager, who would lease space for the TO stations. The OEM may even own its own fleet of trucks, implying that the business model of logistics service providers would become similar to that of a broker.
    - In the last model, the TO service provider is a large international match-making platform that owns TO centers across the EU but does not own the vehicles. Customers of the platform (e.g., transportation companies) would pay a subscription to access the service, complemented with additional optional fees for a priority allocation of a teleoperator in periods of high demand (i.e., to reduce waiting times).

Lastly, we address remaining challenges, discussing the potential role of several stakeholders in orchestrating the new ecosystem or kickstarting investments in order to help overcome the chicken-egg problem of investing in 5G network infrastructure and setting up TO control centers. Since TO requires a high network performance, especially regarding latency and uplink capacity, it will likely require the expensive deployment of dedicated networks or the densification of current ones. Such infrastructure deployments offer an unclear return on investment and exhibit a mutual dependency among multiple stakeholders. We also provide a brief discussion of business models for teleoperated passenger transport. Since MNOs indicated that they do not yet see a business case in upgrading and expanding their telecommunications networks to service teleoperated goods transport only, passenger transport use cases can provide an additional revenue source while sharing the same infrastructure resources.

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ABBREVIATIONS

AD	Autonomous Driving
API	Application Programming Interface
AV	Autonomous Vehicle
B2B(2B)	Business to Business (to Business)
B2B(2C)	Business to Business (to Consumer)
BM	Business Model
CACC	Cooperative Adaptive Cruise Control
CAD	Connected and Automated Driving
CAPEX	Capital Expenditures
CCAM	Connected, Cooperative and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
E2E	End to End
EF	Enabling Function
eMBB	Enhanced Mobile Broadband
ETA	Estimated Time of Arrival
GDP	Gross Domestic Product
GPS	Global Positioning System
HMI	Human-Machine Interface
HW	Hardware
ICT	Information and Communications Technology
ITS	Intelligent Transport Systems
JV	Joint Venture
KPI	Key Performance Indicator
MEC	Multi-Access Edge Computing
MIMO	Multiple-Input, Multiple-Output
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
NESP	Network Equipment and Solutions Provider
NFV	Network Function Virtualisation
NRA	National Regulatory Agency
NSaaS	Network Slicing as a Service
OEM	Original Equipment Manufacturer (of vehicles)
OPEX	Operational Expenditures
PNO	Private Network Operator
PT	Public Transport

PTO	Public Transport Operator
QoS	Quality of Service
RAN	Radio Access Network
ROI	Return on Investment
RSU	Road-side unit
SA	Stand-alone (network)
SIM	Subscriber Identification Module
SP	Service Provider
SW	Software
TCO	Total Cost of Ownership
TO	Teleoperation
UC	Use case
URLLC	Ultra-Reliable Low Latency Communications
VRU	Vulnerable Road Users

1 INTRODUCTION

1.1 Current problems and opportunities in the transportation sector

Several publicly available sources estimate the total global logistics market to amount to between 4 to 6 trillion euros in revenue (counting all modes of transport) [1,2]. These figures would be equivalent to approximately 5-7% of the world's Gross Domestic Product (GDP). According to Eurostat, Belgium's estimated inland freight transport in 2019 was dominated by road transport (77%), while inland waterways represented 11% of the total volume [3]. In the Netherlands, the modal split of freight transport showed a heavier weight of inland waterway transport: the equivalent numbers were 51% and 43% for road and waterways, respectively.

Belgian and Dutch ports and cross-border areas are characterized by very intense daily transport flows. Due to their geographical location, Flemish and Dutch ports are a main entry way to continental Europe for goods transported internationally by sea. According to Statbel, the official statistics bureau of Belgium, in 2020 inland vessels transported about 156 million tons of goods through Belgian inland waterways [4]. Globally, the annual volume of goods transport in ports was more than 11 billion tons in 2018 [5]. In Europe, 74% of the imported and exported goods are transported by ship, and most of this transport is based on containers [6]. Therefore, enhancing the efficiency in managing container terminals in ports is crucial to help avoid the present issues of congestion and long waiting times at container terminals.

Current problems in the sector are not limited to goods transport by water. A considerable challenge in the European transport sector is that of structurally unfilled vacancies. A fifth of truck driver positions were expected to be unfilled before the COVID-19 pandemic [8]. This is largely due to the professions involving long working hours and social isolation. Drivers and captains must be away from home for a long period of time, which makes it difficult to find new personnel, especially among younger demographics. By allowing to operate driverless vehicles from an office in the long term, teleoperation (TO) can make the job more attractive.

Teleoperation can also increase the operational efficiency of goods transport by enabling remote operators to take control of a different vehicle or machine while the current one must remain idle. A teleoperator can also take over control of a vehicle from another operator or driver while the latter needs to rest, thereby also increasing productivity and operational uptime.

However, TO also imposes stringent requirements on the network, especially on latency and uplink capacity. 5G networks can alleviate this problem, but their pervasive deployment is expensive. Yet another challenge is guaranteeing service continuity with seamless cross-border roaming. Business models need to consider all these challenges, as well as the feasible deployment scenarios and areas.

1.2 Deliverable objectives, methodology & structure

The overall objectives of the 5G-Blueprint project are to design and validate a technical architecture, and define business and governance models for cross-border teleoperated transport based on 5G connectivity. Although focusing on Belgian and Dutch ports, roads and cross-border areas, the project's outcome should be usable as a blueprint for subsequent cross-border deployments of teleoperated transport solutions across Europe.

The project's objectives consist of technological, regulatory, and business objectives. Building on 5G-Blueprint's D3.1 [8], the present deliverable focuses on the latter, aiming to address the following business-related objectives:

- Providing a market analysis of existing teleoperation solutions.
- Defining business models for teleoperated transport based on 5G connectivity.
- Positioning the role of teleoperated transport based on 5G connectivity in the transition to autonomous driving.

- Providing a better understanding of the roles, relations and responsibilities of market players and public authorities within the complex Connected, Cooperative and Automated Mobility (CCAM) ecosystem.

To accomplish these objectives, this deliverable has relied on both desk research and input from project partners. The business-related findings of previous CCAM projects are adopted as a basis for the present work. Moreover, through interviews, workshops, and structured collaborative written templates, the consortium's expertise has been extensively used as input to the present deliverable, and will continue to be used in the following ones, which will validate and extend the results of the present study. Recognizing the complexity of the value chain corresponding with 5G and CCAM, the project's consortium includes the following stakeholder types: national, road and port authorities, research institutes, mobile network operators, infrastructure providers, vehicle OEMs, TO tier 1 suppliers, information service providers, and logistics companies.

The present deliverable consists of several interconnected types of analyses, which complement each other. Providing a basis for later sections to build upon, we start by reviewing the challenges and opportunities that teleoperation brings and, considering its role in relationship with autonomous driving, we identify the scenarios where it is more sensible and realistic to deploy teleoperation solutions. Throughout the entire deliverable, the learnings of previous CCAM projects are also used as a basis and as inspiration. To be able to assess the economic impact of teleoperation in cross-border logistics settings, as well as to draft sensible business and governance models, we need to understand the entire value network. Building upon the value network analysis, we present business model options for the crucial roles and responsibilities within it. In addition, the business model analysis relies on the assumed deployment scenarios to assess the feasible deployment options for teleoperation and provide a set of complete business model examples. Finally, the business model analysis also uses the findings of the market assessment to understand the possible value propositions and business models of teleoperation services. Figure 1 shows, graphically, the relationship among the different parts of the deliverable.

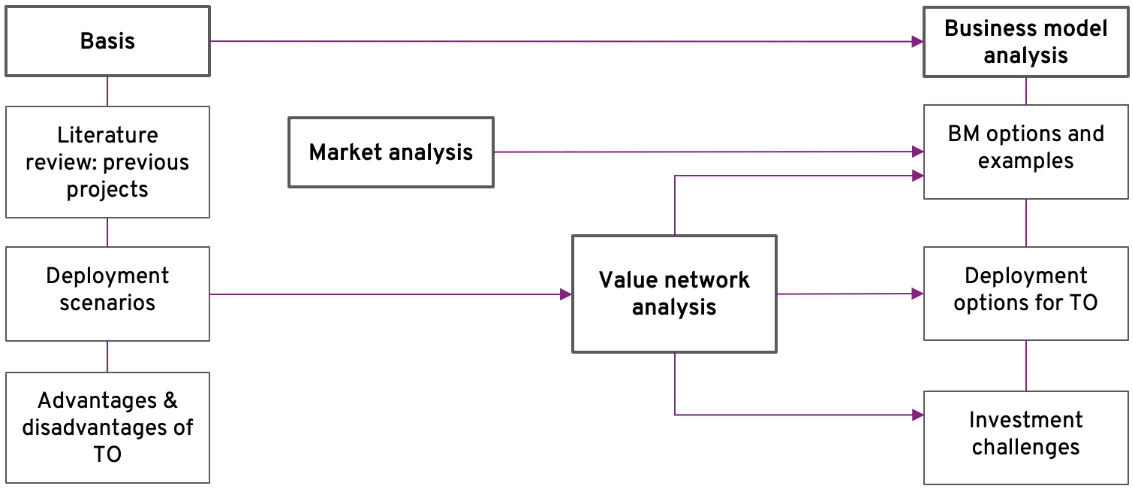

Figure 1. Relationship among the different types of analyses in the deliverable.

More precisely, the present deliverable is structured as follows. Section 2 provides a basis for the entire analysis, investigating the advantages and challenges of teleoperation technology, reviewing the relevant literature, and identifying three potential deployment scenarios. Section 3 provides a market analysis for the current market of standalone TO services. Section 4 presents an in-depth value network analysis, identifying the main different roles, responsibilities and bottlenecks, and discussing and plotting the main flows of data and liability. Section 5 provides an extensive business model analysis, identifying the main business model options at the levels of connectivity, logistics and TO services, discussing the feasible deployment options of TO across scenarios, and delineating a series of business models for teleoperation with the use of 5G. Lastly, section 6 recaps and provides the conclusions of the study.

2 BASIS

2.1 Advantages & challenges of teleoperation

Deliverable D3.1 [8] showed that teleoperation (TO) can offer a positive business case for logistics service providers. Focusing on road transport, it developed a simulation model to compare the costs of traditional transport with teleoperated transport. The main benefits of direct TO arose from the opportunity to deploy a driver onto another vehicle once a vehicle comes to a standstill, i.e. from the ability of each remote operator to support more than one vehicle. Reducing the teleoperator-per-vehicle ratio would depend on (i) the percentage of the time vehicles come to a standstill, (ii) the waiting times for a remote driver to be assigned to a truck, which were assumed to be agreed with logistics service customers (shorter response times would require more remote drivers), and (iii) the size of the fleet: larger fleets require fewer remote operators per truck, implying that larger companies will be more cost-efficient when exploiting these economies of scale.

TO can bring value in different ways, from supervising limited functions like docking to enabling the direct remote operation of vehicles for a full trip. More realistically, most benefits may arise through supporting autonomous driving in complex traffic situations, as both technologies complement each other. A certain degree of automation may be required to guarantee safe teleoperation on public roads, for instance in case the wireless connection is interrupted. For passenger and goods transport alike, TO can also support AVs when the autonomous driving functionality fails, thereby guaranteeing service continuity. In addition, automation helps lower the ratio of human operator per teleoperated or supervised vehicle.

On the other hand, teleoperation can be an intermediary step in the evolution towards autonomous driving, enabling a gradual implementation of autonomous transport solutions, as well as help support citizen acceptance of driverless vehicles by providing initial exposure to them. In addition, it can help achieve the benefits of CAD sooner, while full autonomy remains unavailable. With these premises in mind, we review the benefits of teleoperation as well as of autonomous driving, as these are interlinked and the latter represent the full potential extent, in the long-term, of the cited benefits.

Connected and automated driving (CAD) promises to bring substantial economic and societal benefits both for road and waterway transport. CAD can increase traffic efficiency and reduce congestion and fuel consumption [9,10]. Furthermore, by aiding or substituting human drivers, autonomous vehicles (AVs) can mitigate or eliminate those accidents that are caused by human errors, and therefore save lives. In long-haul road freight, fatigue is a main cause of accidents [11,12]. This is due to the truck driver profession being a straining one, involving long working hours and social isolation [13], a fact that in turn underlies the increasing problem of labor shortage in the sector [14,15]. Besides helping reduce such shortage, substituting human drivers will reduce operational costs from wages and increase the total time vehicles are operational. However, while AVs will provide cost savings from higher fuel efficiency and productivity, the potential negative societal impact of job losses must also be considered. Moreover, CAD will likely require a large operational scale (in terms of the volume of transported goods to deliver this higher uptime) and thus reduce Total Costs of Ownership (TCO) of AVs.

The impact of teleoperation and CAD will depend on the future business models that companies adopt. Betting for high (L4) or full (L5) automation entails a trade-off. On the one hand, L5 can enable more pervasive use cases and reap the potential benefits of automation to a fuller extent. On the other hand, L5 requires far more technical complexity and when —or if— the technology will be available is still uncertain. L4 would enable CAD in fixed, low-complexity routes in the open road, and enable some of the aforementioned benefits sooner. Complementing automation, teleoperation would enable driverless services in more complex environments. In addition, having a human ‘in-the-loop’ can add safety for certain tasks in the logistics chain. A caveat of L4 is the required complexity to implement it, since it involves transfers of control between human operators and autonomous systems, which entails not only technological but also legal challenges.

However, teleoperation also entails several challenges on its own. Therefore, after reviewing its potential advantages, this section also discusses the technical and economic challenges of teleoperation, as well as some possible solutions used in the 5G-Blueprint project.

2.1.1 The role of teleoperation and autonomous driving

Connected and automated driving, as well as teleoperation, have the potential to add substantial economic and societal value. Remotely operated and autonomous vehicles can bring benefits in terms of safety, cost efficiency, fuel consumption and road congestion, as well as relieve the problem of labor shortage. However, their overall impact on the economy and on working conditions will depend on the future business models used to exploit these innovations.

2.1.1.1 Safety

Road traffic accidents claim about 1.35 million human deaths worldwide each year, representing the leading cause of death amongst children and young people [16]. While road fatalities decreased by 21% on average between 2010 and 2018 in the EU [17], in 2017 there were still almost 25 thousand road deaths in the region [18]. In the US, 11% of all motor vehicle crash fatalities in 2018 occurred in large truck crashes [19]. Besides human and psychological suffering, road accidents have an economic impact, involving medical, property and administrative costs, and production and consumption losses derived from the disability or fatality of the victims [20]. On average, the societal costs of road accidents in high income countries are estimated to be 2.7% of GDP [20].

The driver is estimated to be the main cause of car and truck crashes in the overwhelming majority (almost or above 90%) of cases [21–23]. More specifically, error, distraction and emotional state are amongst the chief factors behind driver-induced accidents [21,23].

For long-haul road transport, a main behavioral cause of accidents is fatigue [11,12,24,25]. Fatigue impairs drivers' efficiency, performance, attention, and reaction times, and can lead to them falling asleep while driving [11,12,26]. Several empirical studies report the prevalence of fatigue and fatigue-related accidents in the trucking industry. For instance, Häkkänen & Summala [27] report that around a fifth of long-distance truck drivers in their survey had dozed off at least twice while driving, while in McCartt et al. [28] almost half of the surveyed drivers reported having fallen asleep at the wheel of the truck. Moreover, in Boufous & Williamson's [26] study, fatigue levels were reported in 28% of fatalities, while Akerstedt [11] claimed fatigue was behind between 15 to 20% of accidents. In addition, data from the European Commission & IRU [22] estimated that fatigue was the main cause in 6% of the accidents, and 37% of those were fatal. Finally, a more recent survey of long-haul truck drivers showed that 7% of them believed sleepiness influenced them to cause an accident [29].

In long-haul road freight, fatigue is caused by, among other factors, inadequate rest and prolonged and irregular working hours [11,12,24,26,28]. Current European legislation, specifically 'Regulation (EC) No 561/2006' [30] mandates that workdays should not exceed nine (exceptionally ten) hours of driving, with a weekly limit of 56 hours, besides frequent breaks and rest periods. Most of the reviewed studies show that practices exceeding these limits were common across different regions, whether in Japan [31], the United States [29], Argentina [25] or Europe [27], often infringing regulatory limits. While recent data suggests that, overall, regulatory requirements are met in the EU, detected manipulation of tachographs and driving time records rose in recent years [32].

In addition, even though more advanced tachographs have been mandatory in new vehicles since mid 2019, there exist other worrying factors intrinsic to the industry. In their literature review, Crizzle et al. [33] show that besides fatigue, long-haul truck drivers are more likely to experience health problems such as obesity, diabetes and lower back pain, as well as mental health issues like depression, loneliness and family stress. The job of truck driving is associated with stress and anxiety due to its working conditions, involving long driving shifts, disrupted sleep patterns, and social isolation from being long periods away from home [13]. As mentioned below, these issues are contributing factors behind the structural problem of labor shortage in the sector.

With the use of advanced artificial intelligence systems, which constantly interpret data from radars, cameras and other sensors in real time, the use of automation for the driving task can enhance safety. This applies not only for trucks but for barges as well.

While remote driving does not remove the risk of human error, it can enhance road and navigation safety. If teleoperators can work in less-straining work shifts with a better work-life balance, they would be less susceptible to driver fatigue. Besides reducing the risk of being involved in a traffic accident, working remotely also increases the safety of drivers or equipment operators who deal with dangerous materials in port sites, warehouses or other logistics centers. Similarly, reducing the amount of people physically present among the cargo, machinery and vehicles in harbors, distribution centers and warehouses can also make the work environments safer.

2.1.1.2 Labor market

According to a forecast by the International Road Transport Union, 36% of road freight driver vacancies in Europe were unfilled in 2020 [15], up from about a fifth the previous year [14]. This is distant from the current overall job vacancy rate in the EU of 1.9% [34]. In 2008, the estimated number of heavy truck drivers in the EU was almost 2 million, and while the shortage ratio was just 3.8%, a trend of increased labor demand in the sector was already identified [35]. A similar trend has been present in the US, where it is forecasted that the shortage could triplicate before the end of the decade [36].

Two crucial factors behind the shortage of drivers are (i) the difficulty of attracting women and young people, and (ii) the working conditions, in particular regarding the health- and safety-related issues mentioned above [14,35]. Underlying both factors is the need to spend long, uninterrupted periods on the road, which has a negative impact on the health and social life of long-distance drivers.

The actual impact of AVs on the labor market is unclear, as it will depend both on their adoption rates and the resulting business models. Removing the need for a human driver would avoid the problem of unfilled vacancies, but business models leading to a pervasiveness of AVs would result in substantial job losses. Moreover, while freeing workers from the driving responsibility during parts of the trip could be a source of stress relief, it would not solve the issue of social isolation. Therefore, business models need to take these aspects into account.

Finally, policymakers must take into account the potential impact on the job market due to job losses if the task of current manual drivers becomes redundant with the advent of higher autonomy. However, for the foreseeable future, especially in complex settings, AVs are not expected to be able to drive themselves everywhere. During this transition period, policymakers must allow the business case of remote operation by adapting legislation so as not to mandate an operator to be behind the wheel all the time, as soon as it is objectively proven safe. In addition, it is important to avoid future labor market disruptions once full self-driving technology matures. To this end, it is important to already invest in planning to anticipate the future labor demand for these professions. Remote operation can help achieve a smooth transition by supporting an evolutionary approach to reap the long-term benefits of automation in a fair way for all the main stakeholders involved. By improving work-life balance, teleoperation can increase social inclusion. The regular working hours and the option to work part-time can also increase interest in the driving job by those demographics that are currently difficult to attract.

Similarly, these benefits are also relevant for water transport. Captains will no longer need to leave their homes for multiple days. TO and automation will allow to reduce the crew needed on board of vessels, resulting in less unfilled vacancies as well as yielding cost savings. Lastly, autonomous and teleoperated shipping will also allow captains to control or supervise multiple vessels at the same time.

2.1.1.3 Traffic efficiency and environmental impact

Through more efficient driving, autonomous vehicles are expected to help reduce fuel consumption and carbon dioxide emissions [10]. Smoother driving can also reduce congestion, which in turn reduces fuel consumption. In their simulation, Hartmann et al. [9] concluded that AVs have the potential to increase freeway capacity by 30%.

With regard to road freight, an important way to improve traffic flow is via autonomous truck platooning. Truck platooning refers to when a convoy of vehicles travels together leaving a very short distances between them. In such a setting, trucks follow each other and automatically and cooperatively adapt their longitudinal (e.g., speed, accelerating and braking), and lateral (e.g., steering, changing lanes) operational functions to the driving behavior of the platoon leader. The reduced inter-vehicle distance lowers air friction and thus fuel consumption. For instance, Al Alam, Gattami and Johansson [37] found that truck platooning can reduce fuel consumption up to 7.7% for two trucks, depending on the time gap and the relative size of the lead vehicle.

However, a couple aspects challenge the cost-efficiency of platooning. First, since such driving maneuvers must be made simultaneously and safely while maintaining the small time gaps between the vehicles, truck platooning relies on ultra-low-latency inter-vehicle communication, and thus may require deploying additional roadside telecommunications infrastructure. Moreover, it follows that for substantial benefits to arise there must be multiple trucks travelling the same route at the same time, which calls for enough demand and coordination of trips without limiting the idle time of trucks and drivers.

To a lesser extent, teleoperation can already provide some of these benefits. For instance, it can reduce road congestion by making it more cost-efficient to drive trucks at night only, since an office job is more flexible in terms of work schedules than traditional manual driving can be, at least for the long-haul.

2.1.1.4 Economic efficiency and Total Cost of Ownership (TCO)

In the trucking industry, customer (i.e., truck owners and operators) willingness to pay for self-driving trucks is driven by the total cost of owning a truck over its life span and financial return indicators like payback time. To achieve break-even, future business models must yield a more efficient use of trucks.

Besides lowering fuel consumption, self-driving systems promise to reduce operational costs of freight by removing the responsibility of the driver to actively perform driving tasks and monitor traffic. Not having a human driver on board of the vehicle would, all else equal, lower overall wage expenses, which are the largest element in current operational cost structures [38]. If a driver were still present, AVs would still result in less operational downtime and enhanced productivity, as it would allow drivers to perform other tasks or rest while a truck is driving autonomously.

However, achieving high autonomy levels also entails higher capital expenses from state-of-the-art hardware. More specifically, a main source of increased CAPEX is sensing components, such as LiDAR, radars, cameras, etc. While all these elements help portray a detailed picture of the vehicle’s environment, they perform different functions and are not single-handedly sufficient [39]. On the other hand, AVs and teleoperation can reduce some of the costs from manufacturing from reducing the need to build a cabin in trucks or to build other facilities in ships (e.g., kitchens, accommodation, etc.).

Teleoperation can already yield an enhanced operational efficiency. TO will increase productivity by increasing vehicle uptime and reducing idle, waiting times for drivers and captains, for example during loading cycles. For road transport, TO will enable longer uninterrupted driving journeys compared to manual truck driving, as a different teleoperator could take over after the previous one’s shift ends, thus avoiding that driver resting times result in idle time. For both road and barge transport, TO can increase efficiency by allowing a remote driver or captain to supervise different vehicles at the same time. Remote drivers or captains may constantly switch their attention to remotely operate the vehicle that needs it at a certain point in time, for instance when a barge is waiting to moor or to be (un)loaded, while remaining less active when automation can handle the navigation, e.g. during straight stretches of a waterway without overtaking ships or bridges. The described enhanced operational efficiency will consequently increase operating margins; in turn, higher operating margins could be passed to workers or customers in the form of higher wages or lower delivery costs.

In addition, teleoperated CACC-based platooning can lead to labor cost reductions, compared to the case of platooning with manual driving, where the benefits were limited to reducing fuel consumption because a human driver cannot take control of a different vehicle during the idle time in which the vehicle automatically travels in a platoon as a follower; hence, remote operation of trucks can foster the adoption of truck platooning.

2.1.2 The role of 5G networks

A main challenge behind the safe operation from a remote location is related to telecommunications network requirements. These requirements include the following:

- **Low latency**. Put simply, latency refers to the time required for data to travel from one point of origin to its destination and vice versa, for instance between a vehicle and a teleoperation center. Particularly concerning are peaks of delay that may be caused by network congestion or by entering locations with lower network capacity such as cross-border areas. For safe TO, such latency can only measure a few milliseconds, since this time lag is added to the human driver's own reaction time before a driving action is performed. Therefore, ultra-low latencies are necessary to ensure remote operators have enough time to detect obstacles or other events and are able to act in time.
- **High reliability**. The constant communication between vehicles and remote operators requires a stable, continuous connection. Reliability can be measured in the proportions of packet losses and coverage interruptions. A common issue related to reliability is reduced network performance in periods of peak usage and congestion. Having highly reliable networks therefore requires high network density and seamless coverage throughout a teleoperated vehicle journey, including when crossing borders. However, handovers between operators for vehicles crossing borders often result in connections being interrupted.
- **High throughput**. Challenging the adoption and scalability of teleoperation is the required uplink capacity, especially in situations where multiple vehicles are streaming video from their respective multiple HD cameras.

5G networks are expected to enable teleoperation by meeting these stringent requirements. 5G offers the much faster data speeds needed for high throughput and also promises to offer much lower latency. Different telecommunications technologies related to 5G help deliver these improvements. For instance, Massive MIMO can improve spectral efficiency, meaning that more throughput can be delivered with the same amount of spectrum [40]. In addition, network slicing, combined with traffic prioritization, can reduce end-to-end latencies for teleoperation [41]. By bundling similar traffic, 5G network slicing can also lead to cost savings [42]. Recent tests in the H2020 5G-Mobix project show that the teleoperation of vehicles via 5G networks is technically feasible [42].

However, many economic challenges remain with regard to 5G deployments and their associated needs in terms of financial resources. For seamless teleoperation, 5G infrastructure will need to be deployed along roads and waterways, as well as in ports and cross-border areas. Such large-scale deployment implies huge investments in network densification; more specifically, this means upgrading core networks, densifying the RAN, deploying small cells and in turn the fiber backhaul to support them, etc. This may require finding alternative revenue sources or co-investing to find a suitable return on the investment. This is a reason why deploying 5G infrastructure in cross border areas is especially challenging, since the fact that these areas often have a low population density makes it more difficult to find alternative revenue streams.

2.1.3 Other challenges of teleoperation

Teleoperation can increase the safety of driving and navigation from avoiding crashes of vessels and trucks. The remote driving of vehicles enhances a human driver's vision (e.g., from better night vision or avoiding dead angles), since it relies on the instinctive use of multiple inputs, including camera streams, sensor data, and additional traffic-related messages displayed in the TO station's dashboard. However, it also causes a certain loss of sensory perception and thus situational awareness. This can be from road sounds, noises from vehicle parts that enable quick diagnostics, a natural feeling and vision of the road environment, etc. An additional risk of a reduced situational awareness could be that a remote operator has the perception of being 'gaming', which would lead to a less risk-averse behavior. At the same time, there is also the risk that a remote operator suffers from sensory overload, due to the mental processing of all the mentioned inputs. Therefore, training and certification of remote drivers is considered a key requirement prior to the actual deployment of teleoperation services. Moreover, adverse climatic and lighting conditions can affect the safety of remote driving: heavy rain or winds, fog, icy roads, etc. all pose a challenge. Relatedly, since cameras are sensitive to lighting conditions, some real-time processing will be involved (e.g., to adapt the images to night vision), which will increase the need for higher processing power and time, in turn increasing latency.

In addition, there are a series of business model challenges that can act as a barrier to the adoption of teleoperation. These relate, chiefly, to uncertainty, such as uncertainty regarding the legal framework for teleoperation on public roads, uncertainty regarding liability and insurance claims, and uncertainty concerning the adoption of the different necessary roles within the complex value network.

TO can also bring new sources of risk. Such risks can arise from a system malfunctioning or being hacked, or from faulty connectivity (for instance, due to a loss of signal when roaming or due to an unstable connection). This may imply a liability shift from traditional liable actors–largely, human drivers or captains on board of a vehicle–to new ones, affecting which entities will be responsible to contract insurance to cover liability claims.

Another economic challenge for deployment relates to stakeholder involvement, since enabling teleoperation requires multiple business roles and investment in multiple elements. As the business case for many individual actors and customer willingness to pay remain unclear, this leads to uncertainty about the benefits of investing in deploying the different required infrastructure elements and taking up the different roles. Such roles include, among others, (i) the deployment and management of the different teleoperated machines (trucks, vessels, cranes, etc.), (ii) the deployment and operation of a TO Centre; (iii) performing the remote operation service, (iv) setting up, maintaining and operating 5G networks, (v) road and port site management, (vi) making data available for the different enabling functions, (vii) offering the goods transport service, and (viii) retrofitting hardware and software into the vehicles and/or manufacturing new ones. On some occasions, the different actors will be required to cooperate: for instance network operators, authorities and site owners may have to cooperate before being able to deploy 5G networks.

For many required infrastructure deployments, it is unclear which party will invest in each different part. The investment decisions of different actors in the ecosystem mutually influence each other, and in many cases, they will find it more financially feasible to co-invest. Moreover, since the benefits of one investment largely depend on another, such uncertainty can disincentivize the different actors to take the risk to move first to deploy a partial but yet crucial element behind teleoperation, thus creating a sort of chicken-egg conundrum.

2.1.4 The role of supporting use cases and functionalities

Besides teleoperation of trucks and vessels, other use cases of 5G-Blueprint include the automated docking of trucks and the teleoperation of harbor cranes. In addition, the project will test a series of enabling functions (EFs) that aim to increase the safety and efficiency of teleoperated road transport[1].

The first of these use cases refers to the autonomous docking of articulated vehicles, such as trucks with trailers, in warehouses and distribution centers. The remote operator supervises the operation and takes control if necessary (e.g., if the vehicle deviates from the desired reference path). The drawbacks of manually docking articulated vehicles include the fact that it is a complicated maneuver, especially since the driver has limited visibility, and the fact that it is time consuming.

Automated docking can lead to efficiency and safety increases. First, it can be executed faster than manual docking. Second, the use of truck coordinates rather than a driver's view increases precision. Third, the fact that it allows such docking maneuver to be performed from both the truck's left and right angles can increase site capacity–note that, on the contrary, a driver's view of the back of the trailer is constrained when performing the maneuver from the right angle.

Another use case is the teleoperation of cranes in ports. Traditionally, cranes have a cabin on top with a driver physically present inside. Remote operation from a station setup in an office gives better vision to crane operators thanks to the perspective from different cameras and functionalities such as zooming. It can also increase operational efficiency, as a teleoperator can more easily change control from one crane to another. Teleoperation can also complement (semi) autonomous cranes for operations where safety (or regulation) requires a remote human operator, for example when loading/unloading a container on/from a truck. The crane operator can thus supervise the cranes and take control when necessary. The benefits of TO can also be extended to reach stackers or forklifts: for instance, reducing direct manual operation in warehouses can lead to efficiency and reduce risks for employees from the handling of dangerous equipment and cargo.

As mentioned before, one drawback of teleoperation compared to manual driving or operation arises from the fact that the remote operator is not physically present in the vehicle or equipment. This leads to a reduced situational awareness due to the loss of sensory perception of the environment and the reduced direct interaction with other road users. The EFs studied in 5G-Blueprint aim at addressing some of these disadvantages of teleoperation for road transport, increasing safety and optimizing logistics processes, for instance via the following:

- The **Human-Machine Interface (HMI) dashboard** placed in the TO station can increase road safety by enhancing the situational awareness of the teleoperator, thereby compensating some of the sensory perception loss related to remote driving. The HMI consolidates data streams from the vehicle or its environment (e.g. road-side cameras or other vehicles) to inform and advise the teleoperator, facilitating remote operation and making the route more predictive.
- **Intelligent traffic light controllers** allow the reservation of time slots at intersections for approaching platoons of trucks based on their speed and location. This can make driving smoother by guaranteeing that the entire platoon can cross an intersection uninterrupted, i.e. with the same green light.
- Lastly, **container ID recognition** using on-site camera feeds enables digitization and the easy recognition and tracing of containers and their cargo. Ultimately, it can also help with the automation of loading and unloading of containers in ports.

2.2 Related projects

The 5G-Blueprint project builds upon the lessons learned in previous related projects and initiatives. This section studies and summarizes the results of several of these projects; these results will then be used as a basis and as inspiration for novel business model designs and

[1] For a description of the different EFs, see https://www.5gblueprint.eu/about/enabling-functions/

recommendations. First, we provide a non-exhaustive but representative list of relevant work, representing the state-of-the-art of CCAM projects in Europe. Subsequently, we provide a more in-depth analysis of the most relevant projects.

Across Europe, several public and private initiatives pertaining to Cooperative, Connected and Automated Mobility (CCAM) have explored business model issues. A selection of these projects is presented in the following table.

Name	Year launched (and finished)	Technical scope (use cases)	Geographical scope (countries by ISO code)
Car2Car consortium	2002	C-ITS	Europe-wide
C-ITS Platform	2014	C-ITS	EU-wide
5GCAR	2017-2019	UCs such as cooperative maneuver, remote driving, and autonomous navigation	
CONCORDA	2017-2021	C-ITS, focusing on interoperability of communication protocols	Test sites in BE, NL, FR, DE, & ES
C-Roads Platform	2016	C-ITS Day 1 services	18 Member States and 7 non-EU associated members
C-MOBILE	2017	C-ITS	BE, DK, FR, DE, GR, IT, NL, ES, UK
CITRUS	2017	C-ITS for trucking	Flanders (BE)
Smart Highway	2018-2021	C-ITS and automated driving	Test site in Flanders
5G-MOBIX	2018-2021	Automation, truck platooning, remote operation	Cross-border corridors (GR-TR & PT-ES) and urban trial sites
5G-CARMEN	2018-2021	Cooperative manoeuvring, situation awareness, video streaming, etc.	Cross-border corridor trials (IT- AT-DE)
5GCroCo	2018-2021	Teleoperation, HD maps and Anticipated Cooperative Collision Avoidance.	Cross-border corridors (FR-DE & LU-DE) and smaller trial sites
5G Routes	2020-ongoing	CCAM, in road, rail and shipways	'Via Baltica-North' corridor (LV-EE-FI)
5GMED	2020-ongoing	CCAM, in road and railways	Mediterranean corridor (ES & FR)
5G-Blueprint	2020-ongoing	Teleoperation, in road and waterways	Belgian-Dutch port sites and border

Table 1. Examples of previous CCAM projects.

5G-Blueprint, together with 5G Routes and 5GMED, is part of a second wave of European projects dealing with CCAM (ICT-53-2020), all having an extra focus on (a) cross-border issues;

and (b) understanding the challenges on the business model side in order to pave the way for deployment of CCAM services based on 5G in Europe.

While preceding projects have proposed business models adapted to their particular technical scope focus, the main focus of these projects is the development, testing and deployment of CCAM systems. The novelty of the 5G-Blueprint project stems in its combined technical validation of remote operation use cases in cross-border settings, across multiple transport modes, making use of 5G connectivity, and with a strong focus on business and governance aspects.

The literature review of related projects aims to answer the following questions, among others: (i) what topics they commonly cover; (ii) what approaches they use; (iii) what network challenges and solutions they identify; and (iv) what business model solutions they propose.

2.2.1 Literature review

Previous CCAM projects and studies have helped pave the way for each other, also with regard to business-related aspects. Their learnings and findings are subsequently also adopted as a basis for the present work in 5G-Blueprint, and reviewed in this section.

Either from their direct observation of the shortcomings of current wireless networks or as a premise, all projects include the expectation that relying on 5G networks and associated new technologies (e.g., network slicing) will substantially improve network performance —in terms of latency, throughput, reliability, etc.— compared to previously available 4G/LTE networks; hence, 5G is identified as a potential enabler of large-scale deployments of future CCAM use cases. Consequently, the newest generation of projects have the objective to validate the performance of 5G technology for cooperative, connected, and automated mobility (CCAM) use cases. The names of several projects conspicuously indicate this to be the case: 5GCAR, 5G CARMEN, 5GCroCo, 5G Norma, 5G-Mobix, 5G Routes, 5GMED, or 5G-Blueprint itself. These projects focus on highway environments, but some (see, e.g. 5G-MOBIX and 5GCroCo) also have urban use cases and/or pilots.

All the following projects include cross-border settings: 5G CroCo, 5GCARMEN, 5G-MOBIX, 5G Routes and 5GMED. In addition, 5G-MOBIX, 5G CroCo and 5GMED include a teleoperation use case. For instance, in 5G CroCo [43] TO is seen both as a support for AVs when encountering complex traffic situations and as a way to overcome last-mile driving (i.e., the first and last parts of a long haul trip).

Regarding the methodologies used, previous projects conduct business model analysis, exploring and describing business models for CCAM. In general, however, they do not show the same depth as in the business model analyses planned in 5G-Blueprint. To delineate new business models, previous projects often rely on structured templates. For instance, the approach in both 5G CroCo [43] and 5G-MOBIX [44] projects, is to use the Business Model Canvas. Similarly, 5GCAR [45] used a template to identify the main business model elements per service: network requirements, parties involved in the value chain, potential customers, value provided to customers, etc. Recognizing the evolution from sector-specific value chains (e.g., automotive and telecom ones) to more complex and interrelated ecosystems, several projects also conduct a value network analysis, identifying categories of stakeholders and roles within the value network, showing some interactions, and/or defining possible configurations with regard to which actors may take certain roles [43–48]. Lastly, as in 5G-Blueprint, previous projects also studied the costs and benefits of their respective use cases; for instance, both 5G CARMEN [47,48] and CONCORDA [49] conducted an in-depth techno-economic analysis, quantifying the investment requirements of several network and/or C-ITS system elements.

Discussions on business-related solutions usually focus on a telecommunications perspective. Previous projects consider aspects such as network infrastructure sharing, network slicing or cloud computing as ways to deploy and operate 5G networks in a more cost-efficient manner and/or as ways to improve network performance and QoS. From a business perspective, these technologies may also induce changes in current business models and enable the entry of various stakeholders in the value chain for connectivity. Therefore, we cover them individually in the paragraphs below.

Several projects discuss network sharing as a cost-efficient way for MNOs to roll out network infrastructure without having to duplicate efforts. Network sharing between mobile network operators can lower their joint operational costs and capital expenses of deploying network components. Several projects review the different types of network sharing: i.e., passive, active (with or without spectrum), core and geographical network sharing [50]. 5G Mobix D6.1 [51] goes into more detail reviewing possible active sharing architectures, differing on (i) the extent of sharing among operators: radio frequency bands, base stations, core networks or Enhanced Packet Cores, and thus in terms of (ii) cost savings; and (iii) flexibility in terms of the ability to optimization or service differentiation. More specifically, they consider the following active RAN sharing architectures: Multi-Operator Core Network (MOCN), Gateway Core Network (GWCN) and Multi-Operator Radio Access Network (MORAN). Mostly relying on the same source as reference [42], they cite the following estimations of cost savings derived from network sharing:

- Passive sharing can save up to 16%-35% CAPEX and 16%-35% OPEX.
- Active sharing can save about 33%-35% of CAPEX (up to 45% when including spectrum sharing) and up to 33% of OPEX.
- Core network sharing, on the contrary, is estimated to offer minor cost savings.

In 5G PPP Automotive Working Group [52], three deployment alternatives are considered. The first involves no network infrastructure sharing, meaning that both CAPEX and OPEX for the network and fiber backhaul are borne by a single operator. In the second scenario, there is passive sharing, but active elements are deployed by a single actor. In the third case, where both passive elements as well as the active RAN elements are shared among MNOs, the estimated accumulated cost over time is the lowest.

Network virtualization technology, and more specifically network slicing, is expected to reduce the capital and operational expenditures of operating a 5G network, from the ability to virtualize certain functions and deploy different virtual networks on top of the same physical infrastructure. According to 5G PPP Automotive Working Group [52], it will also create new opportunities to apply different pricing levels and charge higher fees for higher QoS. Slicing will also allow to offer higher-QoS functions on top of a basic public access slice (e.g., one that offers common functionalities to all end users). While net neutrality rules may prevent slice operators to price- or quality-discriminate between customers of the public access slice, they may offer higher prices and functionalities to customers of a dedicated, purpose-built slice, as long as doing so does not reduce the promised QoS of the public access slice [53].

With network slicing, new roles appear in the value chain. Based on [50,53,54], we identify the following roles along with the stakeholders that may perform them:

- End users or subscribers. These may be teleoperation service providers but also individuals (e.g., drivers or passengers), depending on the use case.
- Slice tenants. This is a business user, and may be the same entity as the end user. It can be a MVNO, a site owner (e.g. an industrial company), a fleet operator, a TO service provider, a road operator, or a vehicle manufacturer. For instance, a different network slice could be provided to each OEM or TO service provider on behalf of its customers.
- Slice network operator. This can be either MNOs or other connectivity service providers, or network equipment and solutions providers (NESPs). But may also be vertical companies with the capability to operate a slice, such as big site owners or TO service providers.
- Network slicing provider. Here, it is likely that MNOs and/or NESPs perform this role, since it requires more technical telecommunications capabilities.
- 5G infrastructure providers. These offer the elements needed for the network slicing

provider to be able to implement the slices; for instance, core network functions and computing capabilities. Therefore, MNOs, NESPs and other ICT providers may play this role.

Most projects also tackle Cloud computing, often focusing on Multi-access (or Mobile) Edge Computing (MEC), although often deriving in quite technical discussions. MEC is generally seen as an enabler of ITS applications and CCAM. Since TO may require the vehicle to always be connected to the closest edge [52], the following business-related recommendations and findings of previous projects regarding this topic are also relevant to 5G-Blueprint. First, MEC platforms require interworking between MNOs in both within and across member state borders [43]. Second, common cloud usage by OEMs for CCAM applications is needed; on the contrary, using different cloud centers for the same applications would undermine the benefits of cloud computing [51]. However, the business models for Cloud computing and MEC in the context of CCAM remain uncertain, with many possible options in terms of cloud infrastructure ownership and cloud hosting service provision [see, e.g., 50,54]. In terms of costs, the cost model in 5G-CARMEN D6.2 [47] found that a MEC placement at the Data Centre was more cost-efficient than MEC based at the tower.

Different cross-border connectivity challenges are recognized, both at technical and commercial levels. For service continuity, seamless handover between networks and the availability of uninterrupted coverage are needed. However, this is a challenge around most EU country borders. Because many border areas are rural and have low population density, and thus there is limited demand by customers, the current interest (business-wise) of MNOs to undertake costly network deployments is low [47,51]. Currently, when a vehicle crosses a border and tries to switch to a roaming network, it often encounters service interruptions of several minutes until a connection with a new network is established or the closest edge is discovered [51]. While using a dual modem (i.e., multi-SIM) setup approach is a possible solution for the short term–since it retains connection to the old network until connection with the new one is established–making TO scalable will require a longer term solution. 5G stand-alone Core is seen as a potential long-term solution, as it would have better insights on the resource availabilities of multiple roaming networks and thus would be more efficient in steering vehicle modems to a suitable network [51].

5G CroCo [43] assumes that TO and AD will rely on accurate HD maps to identify the position of vehicles and traffic events. Such maps must be frequently maintained and updated using road and traffic data from service providers and nearby vehicles. Since these updates require substantial bandwidth and must be sent to many vehicles, HD Map components relevant to a local area can be hosted in MEC servers in order to reduce the demand to download large volumes of map data. This is in contrast to the more ambitious approach that (autonomous) vehicles rely on their own environmental perception or cooperative/collective perception, solely based on their sensors and/or communications with nearby vehicles.

In line with section 2.1 above, several projects identify collaboration and stakeholder involvement as a key challenge for the adoption of CCAM technologies. To accelerate private investments in 5G infrastructure along highways and cross-border areas, road operators and road authorities should collaborate with MNOs to facilitate infrastructure sharing (e.g., site sharing for towers) and the reuse of the existing infrastructure [44]. With the same goal to accelerate the deployment of 5G infrastructure, coordination among MNOs, site owners and authorities is seen as important in terms of reaching agreements on business models [51]. Regarding MEC, collaboration is necessary because scalable solutions will have to be cross-MNO and cross-OEM [43]. To guarantee service continuity, MNOs must cooperate for cross-border MNO handovers.

A specific example of stakeholder collaboration is found in the sharing of traffic data. It is argued that OEMs, MNOs, road operators, smart mobility providers and authorities should define data sharing agreements to monitor the entire data ecosystem [43]. However, it is unclear which authorities should take responsibility for orchestrating nationwide data infrastructures. In the context of passenger transport, collaborative data sharing between road users, road-side infrastructure and traffic centers requires data interoperability [51]; for that, it is recommended to create industry-standard data formats that facilitate multimodal transportation [44].

Another aspect representing a challenge to adoption is the uncertainty regarding which entities will take up certain roles within the value network. 5G CroCo's D5.1 [43] discusses the role of an ITS application operator who informs the autonomous or teleoperated vehicles on the road (e.g., about trajectories, speed, etc.) via V2X messages. This actor would handle the data generated by the vehicles or road-side infrastructure and maintain the software applications, possibly outsourcing their development and/or the processing of such data. The ITS applications would be located in the 5G architecture (e.g., in MEC servers). The responsible party for performing this role could be either (a) a national authority, (b) a consortium of road operators interconnecting their databases, (c) an MNO–although this could lead to a possible monopoly in the ITS domain–, or (d) other, third-party providers. Regarding V2X information services, potential providers include the following, as discussed in 5G NORMA's D2.2 and CONCORDA [46,54]:

- MNOs, who could bundle them with other types of V2X services in their portfolio.
- OEMs, who may seek to attract customers via this and other added-value services, such as enhanced maintenance or even the V2X connectivity service itself.
- Location-based connectivity service providers contracted by local or traffic management authorities that want to avoid the risk of waiting for nationwide MNOs to deliver the required performance.
- Other service providers that offer other services reliant on V2X connectivity, such as infotainment and navigation apps.

It is generally recognized that the issue of defining accountability and liability in case of accidents or damage to the cargo will be more difficult with 5G-enabled CCAM ecosystems, due to automation of certain driving tasks and the reliance on wireless telecommunications networks. Different projects identify the need to clarify responsibilities among stakeholders and define arrangements that are acceptable for all stakeholders involved and throughout Europe. This issue is further complicated if regulations differ among EU countries [44]. Furthermore, the transfer of part of the liability to other actors can be a business requirement for certain stakeholders to join the CCAM ecosystem; for instance, a liability shift to connectivity service providers by an OEM in case of network underperformance [46]. Indeed, it is generally understood that, with 5G, MNOs will be more involved in the sharing of liability compared to older generations of wireless networks that were based on best-effort reliability and availability, instead of performance guarantees [44]. However, how the responsibility will be shared between MNOs and automakers, and among MNOs themselves, remains unclear [43]. Network sharing will also raise questions regarding the end-to-end responsibility for network performance and availability among MNOs: for instance, who would be held responsible in case of infrastructure breakdown, an infrastructure tenant or the network owner? This issue could induce MNOs to change their business models, adopting some level of liability as well as revenue sharing, or integrating that risk into the pricing [43].

Furthermore, those projects covering teleoperation identify its challenging network requirements, recognizing that remote driving requires extremely low E2E network latencies, high reliability and high throughput. Both the 5GAA Automotive Association [53] and 5G-MOBIX [51] assume the need for a round-trip latency below 10ms. They also assume throughput requirements of 400kbps for the downlink and between 36 and 64Mbps for the uplink. This uplink need is mostly derived from streaming HQ video from cameras. While the actual speeds will depend on the number of cameras and sensors in the vehicle, they both consider 4 video streams.

Predictive Quality of Service (QoS) can be used to–before a vehicle enters a certain area–notify the teleoperator if the QoS required for TO cannot be provided. Together with prioritization of TO transmission–e.g., rescheduling transmissions for noncritical applications at times when the network has spare capacity– this can increase network availability and ensure service continuity [43].

Other commonly identified challenges include (i) the need to upgrade telecommunications infrastructure along roads [see, e.g., 46,50,51], and (ii) the need to clarify business models, revenue sources and business opportunities [44,50].

Addressing the challenge of costly deployments involves monetizing road-side network infrastructure as well as connectivity services for CCAM. These aspects are often included in the business model analyses of previous projects. For instance, 5G PPP Automotive Working Group [52] identifies the following revenue models for the provision of the connectivity service to vehicles: (i) a pay-per use connectivity fee paid by the CAM service provider for driving on (a section of) the road (similar to toll fees in highways); (ii) a one-time up-front fee paid via an intermediary; (iii) a recurring subscription; and last, (iv) a model where the fees are linked to their operational cost savings from maintenance, insurance, etc. However, which entity will do the billing in each case remains unclear.

A similar question revolves around who the direct customer of the connectivity service will be; in other words, who will pay for the 5G data: it could be end users directly, OEMs, road operators, etc. This issue is tackled in both the CONCORDA [46] and 5G NORMA projects [54], with the following main options being identified:

- The subscription to the service could be incorporated and priced in the vehicle. In that case, the automotive manufacturer would be the party paying the connectivity service provider (an MNO or MVNO).
- Similarly, the service could be sold to vehicle owners by OEMs (as network slice tenants) as a premium feature. In that case, it could be either charged by usage–if the volume of data usage is predictable–or per device.
- Alternatively, the end user could pay the communications service provider directly. A monthly subscription could be purchased independently by each individual user, and the billing could be linked to the account of the vehicle or the mobile device attached to the car. Another option is that there is a set of tiered prices to reflect different service levels, with extra charges for add-on functionalities. However, a scenario in which end users are responsible to contract the connectivity service would add the risk that the user is not willing to pay for it, in which case public authorities may prefer making the service mandatory.

To address challenges present at the border, 5G-CARMEN [47] proposed three business models using network slicing:

- First, a collaborative business model in which the involved network operators collaborate to design an end-to-end slice that covers the entire corridor.
- Second, a network Slice-as-a-Service (NSaaS) business model where operators that intend to cover the corridor have to lease a network slice from the operators that cover different parts of the corridor where they do not have a deployed network infrastructure.
- Third, a non-collaborative model: in this case, every network operator deploys its own network to cover the corridor independently from the others.

Finally, some projects also describe possible business models for teleoperation. Due to their closer link with the present deliverable, we review these aspects in more detail.

5G-MOBIX [44] discusses a business model for TO in case there is an issue on the road that an AV may not be able to handle. The remote operator in the control center is assumed to monitor one or various AVs at the same time. The authors describe a passenger transport service in which a bus drives between two cross-border municipalities, noting the potential for the service to be extended to urban or highway contexts. In this model, transport and tour operators provide the mobility service to passengers, contract 5G connectivity from MNOs to access C-ITS services, and contract the remote monitoring and operation service from ‘Control Centers’ stakeholders. These TO center owners and TO service providers also buy 5G services from MNOs, in order to perform the service. Further, these remote control centers are developed by universities and other R&D entities related to the automotive industry. Lastly, they identify the following alternatives to the business model:

- Transport operators managing a fleet of AVs may have their own control centers, and offer the TO option to other transport or tour operators, for instance charging an optional subscription on top of the rental fee for the autonomous vehicles.

- In a second variant, an AV fleet operator would offer the TO service to transport operators, taking up the costs of the TO center and the 5G service and deployment.

The 5GAA Automotive Association [53] describes two teleoperation business models for two different settings. First, they consider TO for passenger transport, more specifically the private cars use case, where the TO service provider charges end users, i.e. private car owners, for the service and receives financial compensation from insurance companies in exchange of data and analytics. However, it is the OEMs who pay insurers for liability coverage and communications service providers for the connectivity used by the vehicles. The TO provider owns and operates its own TO center, contracting network equipment providers like Ericsson, Nokia or Huawei, for the ICT infrastructure and services used by the TO center, such as cloud computing. The TO provider also pays for driver training and invests in the roadside network infrastructure that facilitates TO. In addition, the TO service provider collaborates with parking operators to ensure they can deploy the TO service in their premises.
Next, they consider TO as support to a fleet of AVs, where fleet operators provide a transport service to end users. Fleet operators, such as logistics service providers, enterprises with corporate cars, or urban ride-hailing platforms, may perform the remote operation of their own fleet of vehicles and manage their own TO center. The fleet operator role charges end users for the transport services, and takes care of the following cost sources: (i) the connectivity service, (ii) insurance, (iii) maintenance of the vehicles, (iv) the acquisition of (autonomous) vehicles; (v) road tolls; and (vi) and the TO solution, which is performed by a dedicated service provider. The TO provider pays for the devices, third-party software and network solutions required for remote operation, and receives financial compensation from insurance companies.

Lastly, the 5GAA Automotive Association [53] also identifies the value proposition of TO for different types of transport and two service types, and identifies possible ways to monetize the service as well.

Value added by TO	Type of transport	Type of service	Pricing model
Enabling drivers to work while on their journey	Either passenger or goods	Discretionary or luxury	Premium pricing, per event, per distance or per time
Driving a person without a driving licence or with disabilities (e.g., if same car is used by different family members)	Passenger transport, for a private car owner		
Performing risky/complex manoeuvers	Either passenger or goods		
Performing valet parking	Passenger transport, for a private car owner		
For drivers who suddenly become unfit to drive (ill, intoxicated, etc.)	Either passenger or goods	Urgent and unplanned, since it is safety related	Incorporated in the car price, as the capability will probably be a mandated standard for AVs
In emergency situations			

Table 2. Value proposition of teleoperation for transport use cases (based on [53]).

2.3 Deployment scenarios

In order to limit the scope of the teleoperated transport scenarios from a business and governance models perspective, a set of reference scenarios has been defined. Making assumptions in terms of deployment scenarios will allow us to simplify the business model analysis when considering an evolutionary approach, better differentiating between feasible business models at each stage, location and type of transport.

The three assumed scenarios are based on the specific geographical coverage of the teleoperated transport operation. These scenarios are classified as follows:

- **Scenario 1: geographically limited area with numerous (short distance) transports**: for example, a port area or industrial zone with interconnected supply/manufacturing chains. Examples would be major European ports and manufacturing or chemical plants, where TO would cover short transports within the site and to and fro distribution centers in the area. In this scenario, the TO center would be constructed to serve all interested users in the studied area. The 5G connectivity can be made available through private or public networks.
- **Scenario 2: major transport axis with significant transport flows**. TO operation can be offered by an independent Service Provider and/or may concur with 'in house' TO (i.e., if larger players have their own TO center). These scenarios include either roads or waterways where a significant volume of transport flows is present, for example a canal between two ports in the same country. Since public roads often cover a significant part of such transport axis, 5G connectivity providers must cover these segments as well.
- **Scenario 3: public road, across national borders**. In this scenario, which includes and extends the coverage of the previous ones, the TO operation across borders poses additional challenges. Crucially, in order to avoid any loss of control, TO and 5G connectivity providers need to ensure a seamless handover of connectivity sessions, teleoperated vehicles, and service monitoring. Therefore, this scenario entails the highest complexity for the challenge of guaranteeing continuity of service, but it also offers the largest geographical reach.

3 MARKET ANALYSIS

This section presents an assessment of the market for teleoperation offered as a stand-alone service (e.g., not used or offered as a back-up of automation). We provide a deep –albeit non-exhaustive– analysis of the market as of late 2021, focusing on the characteristics of the services as well as the business models used by the companies that are currently offering (or advertising their prospective offerings) of teleoperation. This will serve as inspiration when discussing the potential business models for teleoperation in later sections.

3.1 Introduction and approach

For any market assessment, it is important to start by identifying and delimiting the relevant market and market segments. Teleoperation services could be a market in itself, even if they could potentially be offered as a subprocess or part of a wider solution like a transportation service. Currently however, with autonomous and remote driving technology still novel, teleoperation services constitute a distinct market. Furthermore, TO services could be considered just a market segment, even if it covers different use cases. Alternatively, different use cases could be considered as distinct market segments. This will be determined, first, by how cost-efficiently the technology can be scaled to different use cases, which in turn depends on how flexible remote operation software is to handle the complexity of different vehicle types and environments. Second, it will depend on the role played by complementary features that enrich the value proposition and are offered as part of a single integrated solution. For instance, remote operation could be offered together with use-case specific vehicles, employee training or data analytics platforms. Hypothetically, technological barriers and use case singularities could allow to differentiate between the following market segments:

- **Road passenger vehicles**. Potential customers of the TO service include: mobility services providers (carsharing, intercity bus lines, urban public transport, taxis); automotive OEMs
- **Road freight vehicles** (trucks). Potential customers:, logistics companies or retailers with large fleets, automotive OEMs, distribution centers (for yard operations such as docking), mobility service (freight as a service) providers
- **Logistics**: cranes, reach stackers, forklifts and other equipment. Potential customers: ports, DC or, more generally, site owners; shippers
- **Waterway logistics** (vessels). Potential customers: ports, shippers
- **Urban micro mobility and delivery services** (delivery robots, electric scooters, etc.). Potential customers: mobility services providers, retailers.

To link this market assessment with our business model analysis, it is also important to compare the business models of state-of-the-art solutions. Many of the identified companies, due to the novelty of the technology and current economic and legal barriers, offer services that, beyond testing programs, are still prospective. Therefore, it is safe to assume that their business models remain at an exploratory phase. Nevertheless, it is relevant to review the choices behind their current value proposition. The main business model choices of teleoperation service providers for which information is publicly available include the following: (i) what use cases to cover, and (ii) how many features to integrate into the offering, besides setting up and operating the TO service.

3.2 Descriptions of existing solutions

Below we provide an individual description of the teleoperation solutions offered by the different companies identified in our market assessment. In general, companies offering teleoperation solutions aim at developing software that is vehicle brand-agnostic or even vehicle-type agnostic. Offering software that is interoperable with any brand and vehicle maximizes the pool of potential customers. In general, they also aim at offering more than just the TO service; for instance, some develop their own telecommunications technology, hardware, analytics platforms, or even their own vehicle. In addition, some companies offer training to become a certified remote operator.

Early use cases for remote operation appeared within military and mining operations, dealing with closed traffic areas where human operation was dangerous. In such applications, detonators, excavators, bulldozers, and other equipment are remotely operated. However, here we focus on companies that claim to develop solutions for goods and passenger transport use cases, which are more closely linked, and thus more relevant, to the present deliverable. In this context, most dedicated remote operation service providers that offer TO as a stand-alone service are start-ups and companies with a relatively small scale of operations–at least by the standards of the logistics and automotive sectors–, as can be seen from the ones described below.

Designated Driver claims to offer a system that can flexibly be integrated into any vehicle in order to be remotely driven and/or assisted. The company's value proposition is to offer different deployment and service options. First, the solution can be bought as a standalone, white-labelled remote vehicle control unit, including driver station and in-vehicle teleoperation software and off-the-shelf hardware components. Second, the software can be integrated into existing on-board sensing and computing hardware, and optionally it can also be integrated with fleet management software systems. Alternatively, the company also advertises teleoperation as a service with certified remote drivers. Lastly, Designated Driver also offers services to help integrate components. In 2019, Texas A&M University announced the intention to use Designated Driver's software to provide remote assistance and operation for its autonomous shuttles. The cited intention was to use teleoperation as a 'safety net' in scenarios where safety drivers needed to intervene, such as challenging road conditions and in case of sensor malfunction, with the longer-term intention to replace in-vehicle safety drivers.

DriveU.auto offers a software-based connectivity platform that enables teleoperation of vehicles by delivering ultra-low latency streams of high-definition video and audio to remote teleoperators. DriveU claims to offer the best latency performance available on the market by using proprietary dynamic video encoding and cellular bonding technologies. The platform is sold both with computing and sensing hardware included and as a software-only solution that is installed on the vehicle's existing hardware architecture. According to their corporate website, "the platform's SDK and APIs enable quick and straightforward integration." The company cites fleet operators, OEMs and Tier 1 suppliers as target customers.

Einride designs electric, autonomous, cabin-less trucks (pods), designed to autonomously carry cargo on public roads. They also envision long-distance remote monitoring and operation from a remote operation station through which the remote human operator can oversee and drive the pod. Einride also offers a freight platform that provides real-time data on, among others, vehicle emissions and cargo location and recommendations to reduce emissions and routing, via an app. Compared to most of their competitors mentioned here, next to selling the vehicles they seem to aim at providing transport capacity services, thus being a (potential) competitor to traditional transport companies.

Fernride end-to-end remote operation of driverless vehicles as-a-service for logistics customers. It offers an on-demand teleoperation service, charging also on-demand per usage, i.e. charging only for the service when requested. Fernride's solution is a vehicle-agnostic platform that includes hardware—sensors and cameras—, AI-based software—e.g., to create a 3D world from the sensor data—, communication technology—which they claim makes possible the transmission of HD data streams in less than 100 milliseconds—, and integration services. The company claims their solution allows human operators to remotely monitor and drive up to 20 vehicles simultaneously from hundreds of kilometers away. Fernride also offers a program where teleoperators, initially truck drivers, are trained using simulations. A main cited added value is increased availability and guaranteed uptime: TO aaS can be immediately and dynamically used to meet logistics customers' peaks of demand.

The company has focused on yard logistics operations, such as remote docking of trailers at loading gates. In 2020, together with DB Schenker and truck manufacturer KAMAG, Fernride tested automation of "shunting", i.e. the transfer of swap bodies, with yard trucks. Also in 2020, together with Tallinn's University of Technology and telco operator Telia, it tested cross-border remote operation of a self-driving shuttle using 5G.

Imperium Drive aims at offering teleoperation for on-demand ride-hailing services with driverless cars and last-mile deliveries with robots. Therefore, it targets (robot and AV) fleet operators as customers, as well as AV system developers and OEMs. It develops its own proprietary TO software and has in-house expertise in autonomous driving. Currently, Imperium Drive is performing trials and is operating only on private roads. While their goal is to eventually offer TO that supports services with fully autonomous vehicles; in the shorter term they will focus on last-mile driverless services; more specifically, deliveries and valet parking.

MWLC developed vision-based machine learning software for teleoperation and autonomous driving. The technology is used with own and third party vehicles. Its focus is on slow-moving routine goods transport. The company expects customers to take on their own TO services. This allows them to work safely with typically small, light vehicles. The TO technology has been designed with a focus on robustness to operate in different settings, including rural and remote settings. MWLC customers also use TO to train vehicles to become autonomous (i.e., reinforcement learning). Lastly, MWLC provides training in the use of its technology for the remote operators.

Ottopia claims to be the global leader in teleoperation. The company offers an end-to-end solution including remote monitoring, assistance and operation, and the teleoperation center. It states that currently, its remote driving solution is intended for low-speed use cases and fall back situations. Its portfolio includes proprietary AI-based software for telecommunications network optimization—predicting the cellular network or dealing with sudden connectivity loss—, dynamic compression of multiple video streams, streaming ultra-low latency 360-degrees vision HD video from a moving vehicle to a control center, collision avoidance, etc. This software is hardware agnostic, aimed at being integrated into any potential customer vehicle platform.

Ottopia's corporate website shows several existing partnerships. The company has partnered with Motional, which operates an L4 robotaxi service, to integrate Ottopia's teleoperation technology into the vehicles and offer remote vehicle assistance (RVA). Ottopia has also partnered with the BMW Group to test multi-SIM teleoperation technology on German public roads. In addition, it has partnered with T-Mobile to develop a joint offering to commercialize Ottopia's systems. It also uses NVIDIA DRIVE AGX platform to optimize its teleoperation software. Lastly, Ottopia also has a partnership with Easymile, a French company that provides autonomous vehicles such as shuttles and tow-trucks, with the purpose to integrate its teleoperation technology into EasyMile's vehicles to enable remote guidance and operation.

Phantom Auto offers remote technology solutions for many types of vehicles, including remote operation and assistance. It advertises remote operation "from up to thousands of miles away". To be able to transmit real-time, high-definition video with ultra-low latency, "Phantom's patented software seamlessly aggregates all available networks [and] dynamically reacts to network volatility". It claims to work on top of existing network infrastructure, including LTE, WiFi and 5G. Besides teleoperation and communications-enhancing software, the company also offers online teleoperator training. Additionally, it offers real-time data analytics software and end-to-end data encryption to securely optimize logistics operations and decision-making. Supported vehicles and use cases include the following: (a) forklifts and trucks for yard operations in distribution centers and intermodal terminals, (b) robots for material handling or last-mile logistics (i.e., delivery robots), and (c) passenger vehicles. Regarding TO with delivery robots, (potential) customers include Uber and Postmates. In 2021, at ITS ConGlobal, Phantom Auto tested its drive-by-wire teleoperation software with a Terberg terminal tractor.

Roboauto offers a development and integration of remote control technology into almost any possible vehicle. The technology consists of a vehicle sensoric set, a full or mobile remote station and Roboauto's software for connection via WiFi, LTE or 5G. The company cooperates with vehicle manufacturers and end customers (B2B, B2C). Its whole solution integration is fully modular according to the customer's needs.

Seafar is already providing TO services in the maritime industry. Seafar operates ships from their shore control center, and offer an E2E service, but they don't own the vessels themselves. They provide the remote captain/personnel, TO technology, the TO center and the TO service, but their customers are the owners of both the ships and the cargo. And they rely on Seafar for bringing the vessel safely from point A to point B. Therefore, Seafar acts as a kind of a ship manager, but only regarding the navigation part. Especially in deep sea shipping, it is quite common practice that ship owners rely on an outside company to provide them with the crew, even though the personnel on board then responds to the authority of the shipowners.

Vay aims to offer a mobility service in cities in which customers request a car via an app and the remote driver brings it to the pick-up point. The user drives to its destination, after which the remote operator relocates the vehicle to a parking spot or to the next trip's pick up location. It frees up the TO driver's time during the trip. Vay claims it will launch a commercial service in 2022 and is already doing tests in Berlin's public streets with a safety driver on board. The start-up works with vehicle manufacturers but retro-fits the cars themselves with their own TO technology. In their current concept they operate the TO Center as well. Lastly, it expresses the goal of covering other use cases (like deliveries) in the future, following a step-by-step approach.

Voysys develops "the visual system needed [to remotely operate] a fleet of machines" from a centralized location. Voysys also claims to offer the lowest latency solution on the market. It lowers latency by using multiple, redundant links and a super-fast congestion control algorithm to boost bandwidth and avoid latency peaks. Their system also optimizes bandwidth by only sending video streams that are crucial to the operator at any given time and using the latest codecs. It develops an architecture-agnostic software that can flexibly be integrated onto vehicles/machines. They also develop calibration algorithms that make sure the screen shows objects in the correct direction and allows for correct speed assessments. In addition, Voysys offers hardware and software to enhance the setup of the TO center and the experience of the remote driver; for instance, flexible screen solutions and a 3D engine that provides augmented reality features and can be used with a VR headset, a monitor wall or any screen setup. Lastly, it builds an open SDK and APIs that allow customers to build their own augmented reality features. The company's customers include Volvo Trucks and Einride.

Starsky Robotics is a now defunct startup that in 2018 tested a remotely assisted, driverless self-driving truck on a public road[2]. The company aimed at providing an "aftermarket retrofit kit" system consisting of software and sensing hardware to offer a realistic vision of the road to a remote driver located "up to 500 miles away". It aimed at offering shippers the possibility to have end-to-end driverless trips with remote operators that control the vehicle in the short haul and monitor multiple autonomous vehicles at once during less complex parts of the trip, such as on the highway.

Finally, it can be speculated that other players have not been identified as TO suppliers but are nonetheless competitors in this market. This is the case of **leading self-driving software developers**, who have the ambition to offer commercial AV services. These companies are, in general, building their own systems in-house, remaining more obscure in the reporting of their current TO capabilities. This would represent the opposite approach to offering interoperable (i.e. vehicle-agnostic) teleoperation as a service. In this case, the revenue-maximizing strategy would bet on developing a strong vehicle or logistics platform that holds a large share of the market.

Providing AV services will likely require having the functionality to remotely control a vehicle in cases of high complexity or software malfunctions, either because of technical or legal requirements. The legal requirement to have remote operation capabilities is especially likely in the case of deployments on public roads. Therefore, including teleoperation can increase safety

[2] https://www.ccjdigital.com/business/article/14936526/truck-completes-fully-autonomous-route-without-driver-in-cab

and/or help comply with regulations. As a matter of fact, according to CBInsights[3], already in 2017 several AV firms (Waymo, Toyota, General Motors and Zoox) were researching remote operation systems and had filed patents for remote operation technology, focusing on remote operation and assistance of passenger vehicles targeting challenging environments/situations where full autonomous systems may show limited capacity. To give an example, StreetDrone sells low-speed autonomous vehicles to be deployed at low-complexity urban and industrial environments, but they offer a teleoperation function as an extra, not a stand-alone service. In sum, to speed up the deployment of commercial deployments of autonomous vehicles, companies may invest in teleoperation as a backup. And once a market for stand-alone TO service provision emerges, they can easily enter it, since they will have similar technical and operational capabilities.

3.3 Summary of findings and comparison across suppliers

Company	UCs served/targeted	Value proposition	Country of origin/HQs
Designated Driver	Passenger and goods road transport	Multiple deployment options; SW-only, SW+HW, TO-aaS	United States
DriveU.auto	Road (passenger) vehicles, last-mile robot delivery, warehouse equipment	Connectivity platform both with hardware included and as interoperable software-only solution	Israel
Einride	Road freight	Own vehicle and TO service	Sweden
Fernride	Logistics (trucks, yard trucks, vans for the last-mile, forklifts in warehouses, etc.)	End-to-end (incl. TO centre) remote operation as-a-service. On-demand service and usage-based pricing.	Germany
Imperium Drive	Passenger transport and delivery	Proprietary TO and AV software, offers TO service as B2B.	UK
MWLC	Low-speed freight and delivery use cases	TO and AV software for routine low-speed transport tasks. Customers operate vehicles and run TO services.	The Netherlands
Ottopia	Any (personal mobility, road freight, forklifts, agriculture and mining vehicles, reach stackers in ports, delivery robots)	E2E: SW, HW, TO centre, etc. Vehicle and customer platform agnostic	Israel
Phantom Auto	Forklifts, trucks, delivery robots, passenger vehicles (a.o.)	TO and communications software + training and analytics services	United States
Roboauto	“Almost any possible vehicle” (mowing equipment, demolition, mining, logistics)	E2E: development and integration of TO technology (remote station, SW, retrofitting the sensing HW).	Czech Republic

[3] https://www.cbinsights.com/research/autonomous-vehicle-teleoperation-patents/

Seafar	Vessels/water navigation	E2E services: system incl sensors, SW and HW. Support (Seafar Shore Control Center), analytics platform. Can take care of the connectivity as well.	Belgium
Vay	Passenger transport (car sharing service) in urban areas.	Own TO technology offered within their own urban car sharing service with remote operation to pick up points and for parking/relocation.	Germany
Voysys	AVs, machines for mining, construction, etc.	Multiple complementary solutions: SW to optimize connectivity and the visual system, HW for the screen setup and open SW to build extra AR features	Sweden

Table 3. Summarized comparison across teleoperation service providers.

So far, the incipient teleoperation service provision market is dominated by dedicated new entrants, rather than traditional vehicle or equipment manufacturers or leading driverless software providers (who nevertheless are also exploring the technology).

Teleoperation is often part of an evolutionary approach, covering the goals of (i) having a positive use case before full autonomy is available, especially for those use cases involving open road or water environments; and (ii) contributing to the capability to offer full autonomy-based services sooner, e.g. by training software or gaining fleet management capabilities. In general, for vehicles, the cited long-term goal is to have TO as an enhancement service to a driverless service. Many companies expect remote human intervention to be required by law or be necessary in challenging circumstances that the AV cannot control as safely. Therefore, AV service providers are a common target customer in B2B2B or B2C models, while other firms target logistics providers in more direct, B2B models. For passenger transport, some firms also target B2C models, the customer being the end user of the service (i.e., the passenger).

While we can expect the market to scale up, it cannot be assumed that the offered solutions scale easily in terms of deployment areas and situations. For instance, some companies offer teleoperation at low speeds, which does not necessarily scale to higher speeds in an economically feasible way.

Regarding value propositions, we observe that several companies offer an end-to-end solution, for instance including in the package a SIM card, training (e.g., Phantom Auto), the retrofitting of hardware (e.g., Roboauto) or even the manufacturing of their own vehicle (e.g., Einride). In contrast, others offer multiple deployment options, including, often besides the E2E option, the provision of software only or TO on-demand (as-a-service). In addition, while some offer to just install the TO station at a customer's premises, others both manage and operate their own TO center (e.g., Seafar). Lastly, many parties offer remote assistance and indirect remote control, for instance to support path decision-making in case of road obstacles.

Finally, while some companies focus on specific use cases, either related to freight (e.g., Einride, and Seafar) or passenger transport (e.g., Imperium), other companies target many types of use cases, with the ambition to teleoperate any type of vehicle as well as equipment (e.g., Ottopia and Phantom Auto).

4 VALUE NETWORK ANALYSIS

To be able to assess the economic impact of teleoperation in cross-border logistics settings, as well as to draft sensible business and governance models, we need to consider the entire value network. In this exercise, we plot the main business roles whose involvement is crucial to enable the use cases of the project.

We define a value network as a theoretical construct that depicts the set of business roles and interactions required to develop a certain product or innovation and deliver it to market, each step or role adding value in the process. In practice, a value network is graphically illustrated by a series of interdependent and connected nodes that represent these business roles.

Since a value network describes a more complex economic environment than the 'value chain' concept [55], we choose to use the value network approach to analyze the specific economic environment of cross-border, teleoperated transport. With the adoption of digital technologies and services within the automotive and logistics industries, supply chains have become more complex, requiring a broader perspective.

Even though their scope is broader than in the concepts of 'supply chain' or 'value chain', value networks are still limited to a certain environment. More specifically, 5G-Blueprint covers different deployment environments (roads and waterways) and aims to explore different technologies (automation, CACC-based platooning, 5G connectivity) in different novel operational and geographical settings (remote control, cross-border areas). Therefore, the entire value network will consist of different layers and includes traditional stakeholders as well as those more specific to the novel use cases.

Value networks also help study connections of economic nature between different roles. This usually involves illustrating the flows of revenue, value and other streams (e.g., data or knowledge). The objective is to show how value is co-created by a combination of independent stakeholders that perform the different, mutually-influenced roles [55].

In addition, it is important to have a clear view on the entire value network to identify where bottlenecks may lie, and make sure we do not overlook them. Key roles and/or interactions remaining unfulfilled threatens the adoption of the co-created innovation.

In practice, several value network analyses performed in similar projects provide a description of the relevant stakeholders involved in the development or marketing of an innovation. To avoid confusion, we make the distinction between the concepts of stakeholder and role. While we can define a stakeholder as 'a person or entity that participates or has an interest in the development of the innovation', a role refers to the action or function played by such a person or entity. It follows that a role may be played by different stakeholders, and that each stakeholder can play different roles. For certain roles, the actual allocation to a specific stakeholder will be contingent on a particular business model.

4.1 Methodology

First, we plotted a draft of the value network based on desk research. We identified a list of layers, which in turn include the specific roles and responsibilities. We started by identifying all the key roles involved in creating and delivering value in the studied teleoperated setting; then, for clarity, we grouped these more granular elements into a common function (the layers). This draft was circulated within the project consortium, and later updated with the feedback we received.

An initial version of the value network was presented in D3.1 [8]. Building on this and the assumed deployment scenarios, this analysis has been updated and extended in the present deliverable: first, new roles and actors responsible for the different roles have been identified; second, the initial analysis has been enhanced and complemented by a discussion of the key interactions and bottlenecks within the value network. Therefore, the present study looks at the value network in more depth, in order to assess the impact of future remote operation use cases on the current situation.

The importance of collective design and validation is paramount, as no single project partner has an in-depth understanding of the entire ecosystem, due to its scope and complexity. Expert input from within the 5G-Blueprint consortium has been the main source for the analysis on value network interactions and potential bottlenecks; consequently, this represents an exploratory research of the potential impact of TO on current practices. The process of input gathering relied on several steps: (i) individual feedback to the draft version, (ii) a general workshop in a consortium-wide call using an online, structured white board for live response collection, and (iii) a series of dedicated workshops, each focusing on the single layers of 'Connectivity', 'Vehicles and equipment', 'Transport' and 'Teleoperation'. These workshops took place between June and October 2021.

Overall, we identify six different layers and a total of over 40 roles. This results in a comprehensive -albeit not exhaustive- picture of the value network. For simplicity, some elements are individually omitted and considered to fall under a bigger group; some roles could be broken down into more granular ones, for instance the provision of other network equipment or vehicle components, including the orchestration of edge cloud applications or chipsets for computation in vehicles. For instance, in the value chain of edge computing, sub-roles involved include edge orchestrator, edge node owner, back-end cloud services providers and data center providers.

The role identification is meant to suggest an allocation of roles to actors who are potentially willing and capable to fulfil them. In the initial iteration, these potential actors were still unknown for most roles, but using feedback from our industrial project partners in a later stage helped us identify the different specific relevant stakeholders for each role. Lastly, section 4.3 maps the main required interactions amongst roles, looking at end-to-end cooperation in terms of liability and data, as well as identifying potential bottlenecks. We discuss what would be required from different actors in order to (i) encourage the adoption of the several roles, hence the participation of key actors in the value network, and (ii) enable teleoperation use cases and the provision of teleoperation services.

4.2 Value network identification: description of roles

The architecture in the figure below identifies six different layers of roles involved in the overall teleoperation use cases value network, together with an initial allocation of each role to the actors potentially willing and able to fulfil it. This role allocation shows the potential able and willing actors that could fulfil each role. If key roles are not taken up by any entity, the chances of the innovations being adopted will be threatened, since the different stakeholders will need certainty that other actors will take up the complementary actions and responsibilities. Therefore, our business model analysis will discuss options and provide recommendations regarding key roles.

Figure 2. Initial value network for teleoperation services. Role identification and allocation[4]

It must be noted that not all roles will be equally relevant across the three deployment scenarios assumed in section 2.3. For instance, the following roles may not be relevant in Scenario 1: 'ETA sharing & travel info services', as well as governance roles like 'traffic management', 'road permits', 'cross-border 5G continuity', 'cross-border continuity of TO'. Since these roles assume an open road and/or cross-border deployment, their relevance will be contingent on the characteristics around each specific deployment site (e.g., certain ports or industrial zones).

Below, we start the descriptions of individual roles from the bottom layer, as this 'Teleoperation' layer has the most direct relationship with the provision of the ultimate teleoperation service and represents the most novel part of this analysis.

4.2.1 Teleoperation layer

The teleoperation layer refers to the specific technology and tasks relating directly to the remote operation of vehicles and machinery.

Provision of technology (software and HMI). Technology providers provide the technology for the vehicle and for the remote station from which a teleoperation driver can control a vehicle, vessel, crane, etc. On the one hand, this consists of the technologies aimed at creating and increasing the situational awareness of the remote driver, in other words providing enhanced perception of the environment, which includes TO software, equipment such as HD screens, wheels and pedals, possibly augmented reality applications, etc.; on the other hand, it includes messages that aid the safe operation of a vehicle from a TO center, shown in the human machine interface (HMI) to optimize the remote driving function. The HMI includes a dashboard where messages on speed advice, warnings, navigation and routing features are shown to the remote operator employee. These messages represent important functions to enable teleoperation.

Teleoperation (TO) service provision. The introduction of teleoperation also makes new roles

[4] Legend. RA = road authority (incl. traffic agency); NESP = network solutions and equipment provider; M(V)NO = mobile (virtual) network operator; PRO = private road operator; SSP = security services provider. * = OEM, logistics/mobility company, TO service provider, or fleet owner.

possible, for example providers of teleoperation services, i.e. those services where a customer (e.g., a transport company) requests a remote driver to drive a vehicle from a certain point to another. This service can be expected to be provided from a teleoperation (TO) center by a service provider.

Teleoperation (TO) Center. This role refers to the ownership and management of the physical center from which teleoperation is performed. This center may be owned by the owner of a site or area where the TO service is offered (e.g., a port or road authority). Alternatively, these entities can outsource this role to companies that specialise in this role or that offer it together with the TO service.

Teleoperated fleet management is a new role responsible for activities that require interaction with local operations, road users and fueling/charging stations. It is assumed that these interactions will be provided via a mix of manual and audio-visual signals. These activities include, among others, the following:

- For the current driver responsibility of docking, communicating to the TO driver when a vehicle is ready for docking, after receiving said request for docking. And when being notified by the TO driver that docking has been executed, communicating that all is clear for loading.
- Communicating, digitally, with an employee of a gas/charging station that the truck is requesting fuel via an audio or visual sign (e.g, via a screen in the truck), or providing payment in a similar way. When the task is done, the fleet manager can notify the TO driver that the vehicle is ready for departure.
- Taking care of maintenance. Vehicles with new hardware (e.g., drive-by-wire and sensing equipment) will require different or additional maintenance.
- Handling assistance calls, for example when road assistance for a vehicle has arrived at its location.
- In addition, the responsibility to check that a vehicle is always fully operational could also fall under this role. This can mean simple safety checks like making sure no one is under the vehicle, all lights are functioning, etc. This is another task that is currently the responsibility of the manual driver, and for which responsibility would change hands with TO.

Current truck drivers could perform this role after receiving the relevant training. But the responsibility for this role would likely fall under the TO center manager.

In the case of waterway transport, a TO fleet manager could take the responsibility of managing the journey, managing the fleet, or ensuring that the cargo is properly loaded in the vessel.

Training of employees. As mentioned before, teleoperation entails a radical change in the nature of work for drivers, skippers or port equipment operators. At an initial stage, before remote operation is deployed in a certain location or area, new or current employees must be (re-)trained to acquire the necessary skills and know-how. This training may either be offered by the same company that provides the remote operation service, by the TO center, or by another, specialized entity. There may be a learning curve for remote operators to be able to handle a higher ratio of supervised vehicles per person.

Remote operation action. This refers to the actual task of performing the teleoperated driving, operation and monitoring of vehicles or equipment. These tasks will be taken over by workers at a TO center. The introduction of teleoperated driving and barging will change the work of drivers and skippers and reduce the need for the traditional role of driver. In addition, the new position of a teleoperation driver, skipper or crane operator is created with different job requirements and employment conditions. Even though we group them into one single role for simplicity, operators who are responsible for different types of vehicles or equipment may require different skills, training, workplace settings, locations, dashboard information, etc.

4.2.2 Transport layer

Before allocating the roles to the different stakeholders, it is important to note that this allocation will be influenced by the kind of transport considered. First, containerized transport entails the use of big standardized containers that can be used by different modes of transport (i.e., by rail, ships or trucks). Second, bulk refers to cargo that is loaded and transported unpackaged, and thus loosely poured into the tank truck or the ship. Examples include liquids (e.g., petroleum and oils) and solid commodities like grains or cements. Third, break bulk refers to packaged, individual cargo items that are loaded individually. Examples include cars or machinery parts. Lastly, conventional includes, for example, palletized cargo.

Every kind of transport comes with different characteristics and responsibilities with regards to (un)loading the cargo, lashing and securing it, the software used at ports and warehouses, the handling and port equipment used, etc. Due to the difficulty of focusing on the whole spectrum of transport, we will focus on containerized transport. Container logistics is best suited to introduce teleoperation, at least at an initial stage. This is due to the following reasons, among others:

- The use of standardized dimensions
- The fact that containers can be loaded and unloaded to different modes of transport without being opened
- The fact that handling is completely done via cranes or other container handling equipment, without a truck driver being needed
- The fact that containers are numbered and tracked using computerized systems
- The wide use of digitized document flows (e.g., for customs)
- The fact that container terminals are using Terminal Operating Systems, which makes a software connection with teleoperated or autonomous vehicles less difficult to realize
- The fact that containers are the most used transport type in maritime shipping, with more and more bulk products being containerized

Containerized transport also offers downsides. For instance, the opening and closing of twist locks is a manual action. However, the downsides of conventional, bulk and breakbulk transport represent a bigger challenge. Reasons include the lack of standardized dimensions and the fact that the lashing and securing of the cargo is done by the driver. In addition, for conventional transport, drivers mostly load their truck themselves; and for conditioned goods, cooling needs to be set at the correct temperature by the driver.

From the point where cargo arrives at a port by ship until it reaches the motorway with a truck, multiple logistics-related roles are involved at the different stages of the trip. Some straightforward roles entail **loading and unloading** the cargo, **identifying and assigning containers** in real-time, and **providing navigation, localization and estimated time of arrival (ETA)**. Both transport companies as well as terminals can perform the loading/unloading role, while the Container ID role could be performed by specialized service providers or also by logistics terminals themselves.

To further optimize travel times in distribution centers, port areas and roads, the **logistics chain optimization** role takes into account different enabling functions. First, in the case of non-cooperative driving, reserving and reassigning slots to trucks when there are conflicting requests for a green light can improve traffic flow. Based on the (re)assigned slots, trucks can adapt their speed in order to reach an intersection at a more optimal ETA. Second, assessing and communicating parking availability to trucks can also make a truck's journey more time-efficient. Furthermore, other enabling functions involve detecting anomalies or unforeseen events such as road hazards and accidents ahead, and this information will ultimately be shown to remote operators via the HMI/dashboard.

(Non-remote) on-board driving and navigation. This refers to manual driving and steering by drivers and captains who are either self-employed and hired on a trip-by-trip basis or contracted as permanent staff. Skippers and truck drivers will be aided by teleoperation, but (during the short- and mid-term) teleoperation technology will not make them redundant. Therefore, they will still hold, to some extent, responsibility for the well-being of the vehicle and the cargo. They are an important stakeholder since they are subject to be affected as their job changes as a consequence of remotely operating certain tasks or parts of the trip. In certain deployment scenarios, an entire route or 'milk run' may be remotely operated, removing the need for a human driver or supervisor physically on board. These employees performing the manual driving task may be under contract by logistics operators or other fleet owners.

The **freight service provision** role will likely be played by traditional transport companies. Transport companies take responsibility for the transport of physical goods with employed drivers and a fleet of owned or leased vehicles. They take care of the transport activities directly on behalf of a shipper or indirectly for a logistics service provider with outsourced transport.

For waterway transport, another important role is **crew management**. This role may be performed by the TO service provider or the manager of the TO center, subcontracted by large fleet owners, who often do not manage their own ships, similar to the case of cargo owners. The responsibilities of the crew management role include hiring crew members, replacing the on-board crew with people willing to work onshore from a TO center.

Lastly, the **operation of logistics centers**. Logistics centers are locations (warehouses and terminals) where teleoperated vehicles and barges load and unload goods. These locations must be adapted to receive and handle teleoperated vehicles. This requires adjustments in communication with the teleoperation driver and solutions for the tasks that are currently still being performed by drivers. Many terminals also offer a buffer function, meaning they keep a container at the required temperature until the company needs it (maybe for a few days), and may offer priority shipping of containers for companies that want the container shipped the same day.

4.2.3 Vehicles & equipment layer

The vehicles and equipment layer covers the provision of those physical elements that will make it possible for vehicles, machines and port infrastructure to be remotely operated.

Manufacturing of trucks and barges. We expect trucks and barges to be sold by vehicle manufacturers (OEMs), much as is the case today. The level of automation and teleoperation capabilities of the supplied vehicles will evolve as the technology matures.

Provision of port and DC equipment. This includes other vehicles or elements that are subject to be teleoperated, namely cranes, terminal tractors and reach stackers in ports, and forklifts in warehouses/distribution centers. These elements need to be built with the ability to be remotely operated.

Provision of enabling (sensing) hardware. There are different types of sensing components, for instance cameras, ultrasonic sensors, radars, and lidars. These elements can be provided by different vendors. Combined, they help the vehicle's software system map its driving environment in detail and identify surrounding objects. Importantly for remote operation, cameras give a HD vision of the road to the human (operator) eye. Several cameras will be needed to have forward, backward and lateral views of the vehicle's surroundings, as well as to cover potential blind spots. In addition, these cameras will have to offer HD night vision.

Provision of precise positioning systems. This role implies the provision of high-accuracy vehicle positioning and is likely to be played by an equipment manufacturer or integrated into other roles of this layer. Precise positioning may be enabled by GNSS receivers in vehicles and roadside infrastructure. It was noted that the relevance of this role will depend on future technology developments.

Development and provision of vehicle software. Enabling teleoperation will require vehicles to have an updated set of artificial intelligence and computing capabilities compared to the status quo. Connected and automated driving (CAD) software will be necessary in case teleoperation is not performed during an unmanned vehicle's entire trip. For instance, a possible scenario consists of TO centers focusing their responsibility on supervising vehicles and only taking action whenever it proves safer or more efficient to do so.

Vehicle SW/OBU integration. In order to be remotely operated, current trucks and barges must be adapted. In the first phase, OEMs do not yet deliver these solutions and retrofit solutions will be built into existing equipment by technology developers or equipment providers. More specifically, hardware built on top of current vehicles may include on-board units, which contain telecommunications and computing elements (e.g., antennas and processors). As the technology matures, the OEMs will build the equipment that makes teleoperation possible in their vehicles, in the manufacturing stage. The required technological components may be developed in-house or assembled from different Tier I suppliers.

4.2.4 Connectivity layer

The communications or connectivity layer must in turn take several elements and types of actors into account.

The **provision of 5G connectivity** services, for instance via a connectivity subscription, will be done by Mobile (Virtual) Network Operators (i.e., MNOs or MVNOs). We distinguish between long-range and short-range communication. Long-range connectivity provision refers to 5G connectivity. Regarding short-range connectivity provision, it refers to C-V2X (more specifically, in the long run, 5G NR-based C-V2X), because the 5G-Blueprint project uses 5G networks.

The **mobile network operation** role refers to the deployment, operation and maintenance of the mobile networks that support the provision of long-range (5G) connectivity. As the name suggests, this role can be expected to be played by current MNOs. One aspect that makes MNOs the natural stakeholder to perform this role is that they own the spectrum licenses that gives them the right to use a certain frequency band in a certain country. MNOs may also be the owners of telecommunications networks, but ownership is not tied to this role. Ownership models in which a neutral host owns the network and leases it to multiple tenant operators are becoming more popular. Similarly, the deployment of RAN can also be done by MNOs (that buy RAN equipment from equipment vendors) or by third parties (as in the neutral host model). 5G business models can also rely on private network deployments, which may be offered (and owned) by traditional MNOs or other players, such as micro operators (μO). Private networks are those deployed in a specific site, such as a port, according to the site's own needs. They differ in terms of how many elements are actually standalone and which ones are part of a public network.

Provision of **managed services**. Network equipment and solutions vendors (NESPs) will offer AI-based managed services to optimize the operation and management of 5G networks.

Provision of **core network and radio access network (RAN) equipment**. Network equipment and solutions vendors (NESPs) will also supply (non)standalone 5G core technology to network operators or owners, as well as RAN equipment (e.g., base stations) and small cells. This also includes virtualization infrastructure (NFVI). The role and responsibility to deploy these elements may be taken up by different actors.

Provision of **network function virtualization (NFV)**. This can include network slice orchestration and management. The role of NFV includes the development and the provision of NFVs that can be used by the connectivity provision role to create dedicated slices taking into account different services KPIs (or requirements). More digitalized networks enable more division of functions by further decoupling hardware from software elements; however, some of these roles and functions may also be merged and thus fulfilled by the same actor. NFV providers could be the equipment vendors (especially in the transition step), the MNOs themselves or new companies (SW developers). However, NFV providers other than MNOs will likely not (for the first few years of the adoption of NFVs) provide themselves the network slices as it requires also a pipe on the transport part of the network and also a part of the spectrum allocated to those slices. This role also does not include the provision of NFV infrastructure, which is likely to be played by vendors (NESPs).

Cloud/MEC provision. (Edge) cloud providers will offer data storage and processing, whether in centralised locations or at the edge of the network, depending on the connectivity requirements in terms of latency and other aspects. Cloud computing capabilities can be offered as a service or built in proprietary data centres at a customer's premises.

Policy and regulation. This role covers the definition and enforcement of regulations and policies relating to network aspects, such as allowing (active) network sharing or assigning spectrum licenses. It may be played by national and/or supranational bodies. National authorities may include National Regulatory Agencies (e.g., BIPT in Belgium), while an example of supranational authority is the EU-wide BEREC.

Deployment of roadside infrastructure. Lastly, deploying small cells and fiber networks by the side of the road will enable vehicle-to-infrastructure communications. It is unclear who will be responsible for deploying these elements, as they can be used for traffic management purposes, C-ITS services and road user-oriented entertainment services. It may be done by a road operator–either public or private–or a third party. In similar European projects it has been argued that road authorities, as owners and/or managers of road infrastructure, must play a critical role in aligning with the automotive and telecom industries to deploy the technology [43].

4.2.5 Governance layer

Central to 5G-Blueprint, there are several governance-related aspects worth considering. These roles will be key to enable the teleoperation use cases to be deployed in real-life settings such as ports, logistics centers and open roads. Moreover, they will also be key to foster the involvement of different actors in the ecosystem and the defined roles.

Port and road authorities can expect to keep playing their traditional **management and oversight** roles. In addition, besides managing traffic, road authorities may be responsible to hand out **permits** for teleoperation in public roads. To that end, authorities would need to define the system requirements and operational limits for vehicles and TO services (e.g., in terms of vehicle speed, road characteristics, telco network KPIs and amount of supervised vehicles per remote operator). Having a framework for regulatory permits may also require prior changes in national traffic codes. Road management and operation can be done by either private or public entities, depending on the contract; the former case usually involves public utility-type long-term contracts for the monopolistic operation of the road as well as obligations regarding the maintenance of the infrastructure.

Liability coverage. Liability for damages may shift hands with new actors being directly involved in the driving and operating tasks of vehicles and machinery, specifically in the case of open road use cases. As remote operators take control of vehicles and make driving decisions, TO is subject to human error, and these operators be considered responsible in case of accidents. A tricky case may be when a remote operator is 'only' responsible for overseeing a given vehicle. Moreover, damages may be attributed to the connectivity provision, or may be considered the consequence of the underperformance of sensors or remote operation software systems. Alternatively, the complexity of assigning liability may result in collective responsibility. As many parties may be subject to liability claims, it needs to be defined which partners are legally required to cover liability claims or contract a policy from an insurance company to cover such potential claims. Uncertain liability may also lead to stronger SLAs and higher costs (e.g., from redundant network elements).

Cross-border continuity of service: teleoperation. This role and the next have the responsibility to guarantee the seamless continuity of the teleoperations service as a vehicle crosses the border. This specific role refers to the responsibility of guaranteeing cooperation between actors, rather than dealing with technical telecommunications aspects. For instance, coordination may involve the 'handing' of the control and supervision of a remotely operated vehicle by a TO center to another. Moreover, it needs to ensure everything is in place from a policy perspective, for example, if licenses to perform TO are valid across countries.

Cross-border continuity of service: connectivity. The coverage of a given telecommunications network will not reach the entire teleoperated trip for some of the scenarios discussed, or at least the network will not be able to cover the entire area while meeting the defined performance KPIs. Therefore, continuity of service will require a handover between 5G networks of different national MNOs or between public and private networks. It is unclear who will perform this role or the exact responsibilities that it carries; for instance, it may entail guaranteeing that the necessary service-level agreements are in place or defining and enforcing roaming obligations. This role may rely on market agreements between MNOs (e.g., SLAs) and/or supervision and action by public entities (e.g., supranational regulatory bodies). To enable end-to-end seamless connectivity in cross-border situations, and thus seamless roaming, MNOs may also need to adapt their networks.

Data governance. This role has the responsibility to ensure that data crucial to the project use cases are exchanged and shared in fair terms between data owners. It may entail defining data ownership and sharing rules and terms, including the definition of standardized formats. Furthermore, it may also entail building and/or operating a centralized and common platform that aggregates data sets and makes them accessible, which would mean effectively merging this role with the supporting 'data exchange & aggregation' role. A later section of the value network analysis (4.3.2) maps the data needs of different stakeholders in more detail.

4.2.6 Support layer

The support layer determines those roles that, while more indirect, are still necessary or useful to enable the project's use cases in practice. For instance, **setting standards** may be necessary for teleoperation technology (both hardware and software) and vendor solutions to be built according to similar and interoperable specifications. Otherwise, there is a risk of market fragmentation, which can cause a duplication of costs and limit scale. Relatedly, **homologation** refers to certifying vehicles and equipment to ensure minimum quality requirements are met, and hence that they are safe to be operated remotely in potentially dangerous environments. Both these roles can be played by public entities or third parties such as an industry association of automobile manufacturers and/or Tier 1 suppliers (e.g., global standards setting bodies).

The **provision of security and credentials**. This role is based on the concept of a Public Key Infrastructure (PKI), in which an accredited certification authority (here referred to as cybersecurity services provider or SSP) issues digital certificates that are used to secure communications messages. Such an entity encrypts communications and stores public keys, granting access to them to trusted actors only. This role can be played by a provider of automotive cybersecurity solutions. Certificate authorities can also be public authorities, such as a road authority or a traffic agency.

Data aggregation and exchange. This role entails operating a platform that aggregates data sets and makes them accessible. This may be done by several actors in a decentralized manner, or vice versa. Moreover, in the case of a more centralized platform, this might behave like a marketplace. Furthermore, this role may be played by data owners or by third parties, including public entities. Lastly, this role may also be severed into two, as in the case where a service provider enables the sharing of data between owners via APIs, but without aggregating different data sets itself.

HD Map provision. If, as assumed in 5G CroCo, TO requires the use of HD maps, such maps must be frequently maintained and updated. Smart mobility service providers can stream map updates to the TO control center or the OEM, selling them through a subscription or bundled together with other services.

The role of **infrastructure finance** involves private parties that contribute to finance the deployment of road and/or communications infrastructure, which will require substantial amounts of money. This role could be played by institutional investors or infrastructure operators. In a port setting, an alternative option could be a port authority or a joint venture of port stakeholders. Different investment vehicles could help provide an attractive risk-return balance, such as infrastructure equity funds, public-private partnerships or project finance.

Finally, further **research** will be needed after this project in order to help technology advance further and deliver more mature and cost-efficient solutions. This research could be done by universities, industry players or follow-up public-private European projects.

4.3 Value network interactions and configurations

In this section, we discuss the main interactions amongst stakeholders that will collectively enable teleoperation use cases. We consider two crucial types of transactions, namely liability and data flows. In addition, we discuss where other possible bottlenecks to the adoption of the different roles and responsibilities in the value network may lie.

As the driving or operating task shifts from an on-board driver, operator or captain to an equivalent professional working from a remote TO center, the derived liability in case of accidents or damage to the cargo may shift from the currently responsible parties to new stakeholders. Adding complexity to this, certain responsibilities may shift towards autonomous systems or towards other employees that would have to be hired to substitute the manual tasks that drivers currently perform.

Teleoperation use cases are also very data intensive: each vehicle is constantly transmitting multiple camera and sensor feeds to the TO center in real time, and additional traffic information is sent, in real time, to the remote operator to enhance the safety of driving from a distance. The sharing of data among many parties will be necessary to enable 5G Blueprint's use cases without interruption and across borders. Therefore, we try to bring understanding on how the different actors must exchange data in the market.

Lastly, it is important to identify potential supply chain bottlenecks that can stand in the way of the explored use cases being adopted in practice. When teleoperation solutions are finally technically able to be commercialized, their adoption will depend on a functioning value network. We find recent examples of bottlenecks in the supply shortages of containers and semiconductor chips, which affect the logistics and automotive sectors. In a complex value network, the scarcity of a single element can impact production capacity, and indirectly have negative consequences on operating margins, jobs, and consumer prices. Another bottleneck can be that some of the key roles and responsibilities identified are not taken up by any stakeholder: CCAM brings an increased convergence of sectors (automotive, telecommunications, teleoperation, etc.), causing value networks to become more complex. This can pose a challenge for the uptake of value network roles if their associated risks and potential return remain unclear or unattractive.

4.3.1 Liability

4.3.1.1 Teleoperation layer

Before a TO Center or TO service provider is willing to engage in remote operation, insurance terms need to be agreed and contractual responsibility across the value network clarified. The distribution of liability will also affect the prices of the TO service, which will incorporate the extra costs derived from insuring oneself against this liability, and in turn will affect the business case. Of course, the liability question also depends on the scenarios, as they differ in terms of operational design domain. In the case of TO of trucks on open roads, after permission is granted by authorities to perform remote driving, it needs to be clear what entity will be responsible for the permit.

Liability is one of the biggest issues in both trucking and shipping. And legislation is a crucial influential factor to consider when talking about liability shifts derived from teleoperation or other degrees of higher autonomy on public roads. Nevertheless, teleoperation providers are still facing regulatory uncertainty regarding liability.

Current legislation does not allow ships to navigate fully unmanned. Similarly, trucks cannot drive on the open road without a person on board. In addition, current legislation considers the manual truck driver responsible for such driving. There is also legislation around when cargo is to be considered delivered, what the moment of handover is, etc. In a potential future without a human on board, it is likely that the teleoperator will be considered the person responsible for a vehicle while it is being remotely operated. However, this remains uncertain.

In waterway freight, today the captain on board is responsible for everything happening on the ship, not only for steering it safely. For instance, the captain puts his signature down to confirm that the loading and unloading has been done correctly. And as of today, no regulation at neither the national or international levels has yet defined who will assume the legal responsibility for whatever happens to the ship when the captain is no longer on board. If the tasks and decisions currently made by captains are broken up and transferred separately to different actors, e.g. to the TO center or the on-board automation systems, then the captain's liability may also be shifted to different actors, and regulation or market agreements would become more complex, needing to define who becomes liable for each discrete decision.

However, future liability arrangements in case of TO will not only depend on legislative mandates but also on multilateral agreements by market players. Reaching agreements can avoid having many redundant systems in the vehicle, which increases complexity as well as costs. But performing remote operation entails a complex value chain, and market actors should collaborate in order to ensure that the service is liable in every sense, which may imply making sure that the liability is distributed. While OEMs will remain responsible if something goes wrong in the vehicle itself, as is the case today, they will be reluctant to assume liability unless they provide the full systems, i.e. all the hardware and software, even if they would take the TO service provider role. Therefore, other stakeholders would be liable in case elements provided by third parties fail. For instance, the TO technology retrofitter/integrator or TO service provider could become responsible if something fails within their system, and the MNO may become responsible if the network does not maintain a required latency level.

Other aspects could be more straightforward or remain the same. In general, even if a third-party company provides the crew and the captain on board of a ship, the captain acts under the command and responsibility of the ship owner, meaning that the company providing the captain does not take any operational responsibility. The insurance policies of the shipowner would cover the damages. In the case of Seafar, this remains the same for captains that do the remote operation task from their shore Control Center.

A challenging point in distributing the liability, however, is drawing the lines (in other words, the limits) between actors, because there are many possible overlapping or interacting elements. To allocate responsibilities it should be feasible, after an incident, to prove where the source of the problem was. Workshop participants had the impression that this would be doable, although time consuming and expensive. Currently, when a road accident happens, usually OEMs perform a thorough investigation to uncover the origin of it. Moreover, new vehicle system designs might ease this process, becoming similar to black boxes in planes, and the nature of CCAM technologies makes it possible to collect a lot more information about the vehicles and their environment, thus helping trace back what went wrong.

Similar to the black box concept used in aviation, systems for recording and storing vehicle data could help analyse and potentially identify the cause of an accident or other liable damage. Besides helping clarify where liability may lie in case of accident, these data would be interesting to insurers, who would be interested in analysing the performance of teleoperated driving. Automakers or fleet owners, as owners of such data, could be interested in sharing the data with them if it potentially leads to lower insurance premiums. These systems could take the forms described in Böhm et al. [56], namely 'Event Data Recorder' or 'Data Storage System for Automated Driving', which represent approaches that are either already included in upcoming EU legislation or in standards being developed.

Liability issues can also influence which parties are willing to take on the role of TO service provider. The following questions also arise: Would logistics companies feel comfortable remaining liable, being responsible for their employed teleoperators instead of their manual drivers? Would a specialized TO service provider be willing to assume this liability if the enabling equipment is installed by a third party? Would vehicle manufacturers be willing to teleoperate their own autonomous vehicle fleets, if they provide their own mobility or delivery service?

4.3.1.2 Transport layer

Once more, liability in the context of teleoperation proved to be a complex issue. Along the transport layer of the value network, questions about the distribution of responsibilities involve the following:

- Who will be responsible for the safety of the vehicle? This is of course tightly related to the aspect of liability for injuries or casualties in case of accident, since guaranteeing the safety of crew and passengers starts from the safe maneuvering of vehicles or equipment.
- Who will be in charge of the safety of the cargo? This includes securing it, checking for damage before it is loaded, or even to make sure the cargo does not contain illegal material.

Both for ships and trucks, driving safely requires that the loading is done correctly. The way a truck or a vessel is loaded affects its safety, and in turn the safety of the cargo and the driver or crew. For example, the load of a trailer truck needs to be spread over the container it carries; on the contrary, overloading the front could place too much weight on the front axis of the truck. This is more challenging and requires more oversight when heavy goods are loaded or unloaded at different stops during the route. Besides the safety issues, overloading a truck can cause an economic loss to the transport company as well. While on the road, authorities may check if the total weight of the truck is in order. If it is not, it can result in a fine. But even if the total maximum weight is not exceeded, these checks carry costs from the need to unload the truck and to stop driving momentarily.

Likewise, putting too much weight on a vessel or loading it in an unbalanced way could lead to the ship sinking, depending on the depth and characteristics of the body of water the ship is driving through. The sinking of a ship may also have environmental or economic consequences, for instance when dangerous material is spilled or when the vessel blocks a canal.

For waterway transport, a large part of responsibilities –whether it is navigating, maneuvering, entering the port, loading cargo, etc.– currently falls on the captain on board of the ship. With TO, the responsibility is basically shifting from the captain on board to either to the captain onshore or to the systems. But it remains unclear who does what exactly when there is no captain on board. While some personnel may remain on board of a teleoperated vessel, the captain will still be the one person from the crew responsible for the ship.

According to Seafar, a present blocking point for TO is at the regulatory side: there is no regulatory body that allows them to shift the navigation responsibility from the captain to the system. In addition, regulation of maritime shipping does not allow coastal and seagoing vessels to sail without any crew. In contrast, for inland navigation it is more flexible, and it is easier to negotiate with a single country in order to get permission.

The (un)loading without a captain on board is also a challenge. The need to have a liable person or entity that places its signature to assume the responsibility of delivering the load correctly will remain. If part of this liability is shifted to a new service provider, that role will need to receive some compensation for it.

For maritime shipping, there exist different types of marine insurance, including the following:

- Property insurance, both for hull and machinery and cargo. In the case of damage to the vessel, policies usually include maximum amounts to insure for the perils of sea navigation or fire.
- Liability insurance, which among others covers damages caused to third parties–such as

the crew or other people, the environment, or third-party property– and to the goods, in case the cargo is lost, damaged, or delivered late.

Damages due to network breakdowns or connectivity losses are currently often insured in the same way as if a ship would be damaged by an unavoidable natural catastrophe such as sudden strong winds (i.e., treated as force majeure).

In the case of trucks, TO would entail a liability shift from the driver or the transport company to other parties. Today many responsibilities fall on the driver or, by extension, to the transport company employing her.

- First, the responsibility for the safety of the vehicle and the transported goods for the driven part of the route. For instance, if a company ships breakable items and they are broken by the time the truck arrives at its destination, it is the transport company (or the insurance of the transport company) that is currently liable.
- Second, the responsibility for the lashing and securing of the load when (un)loading. For containers, it entails locking the twist locks and securing the container onto the truck's chassis. To secure bulk goods, lashing is done with straps. Nowadays, this action is also the responsibility of the driver or the transport company that loads the truck.

With the introduction of teleoperation, several questions arise:

- For (un)loading, will the transport company's employees remain responsible for the securing of a container, e.g. to (un)lash it from a truck? Or will the fact that the terminal or another party secures the cargo increase the terminal's liability? Especially if the (remote) driver does not have the possibility to check it physically, but needs to assume it is OK, the transport company may not be willing to remain liable anymore. However, this may shift a lot of new responsibility to the terminal side, which the terminal might not be willing to take.
    - It could be that this requires a process change. For example, the terminal could use aerial pictures to confirm there is no damage at the top of the container, and based on them hand over the responsibility to the transport company.
- Would transport companies consider paying a third party to shift their current responsibility? Is there value in adding this extra expense to avoid the need to pay insurance for this responsibility?
    - Again, it depends on the type of transport, since the capability to do the lashing and securing of the load is very different between containers, bulk, etc. For the locking and unlocking of the twist locks of a container, a service provider situated at the terminal, such as Kloosterboer, may be willing to do so as long as they are financially compensated for the extra employees that would be required. In short, the liability shift induced by TO will be more difficult to solve for transport types beyond containers, because they are less automated and less standardized.
    - With containers, which are usually owned by big shipping companies, responsibility usually lays on the party shipping the goods, as they are already on the terminal when they are being booked to be picked up to be brought somewhere. Containers are already loaded and weighed before being released at the sending (terminal) side, and most of the containers are already locked and sealed. Still, you may have a problem with the loading when there is a mix of goods, for instance when a heavy good is put on front. Therefore, a transport company may still use an employee to check that.
    - For repetitive operations, when there are sufficient daily truck runs, the transport company may prefer to have its own employee deployed at the customer's site to load the trucks. This is how Transport Roosens currently handles this issue at Toyota's plant. In such cases, it may also pay off for a transport company to have a trustworthy third party to do that for them.

Lastly, for 'full load' trucks, the shift of responsibility for securing the cargo when loading would be easier to determine when the vehicle starts and ends its journey on the premises of the same party, since then it could be attributed to this shipper. However, most of the time, the truck is not sent to the shipper's own premises but to their customer's premises.

It is clear, then, that the adoption of remote driving will impact current driver responsibilities. In road logistics, a manual truck driver is not only responsible for the driving action but for other actions as well; for instance, before starting a journey a driver is expected to check if the tires are properly maintained, lights are working, the cargo is secured, undamaged and in line with documentation, etc. In 5G-Blueprint's D3.1 [8], the driving responsibilities in Figure 3 were identified.

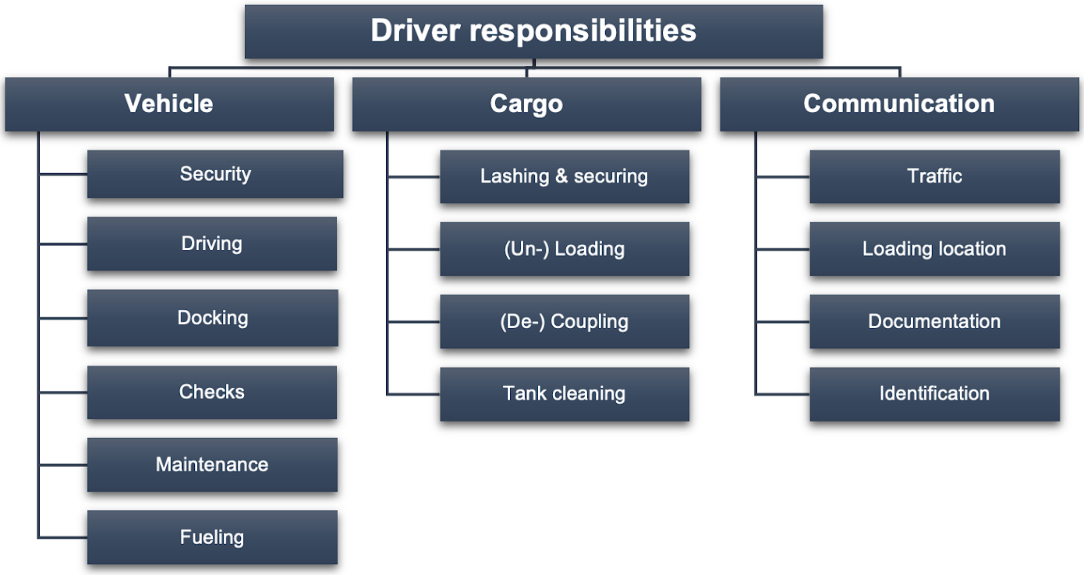

Figure 3. Truck driver responsibilities for current, manual driving [8].

While the driving task can be performed by a remote operator, other responsibilities will need to be taken up by other parties or systems. In addition, while some activities can be automated (such as docking or securing the trailers), others will require the physical presence of a human, at least in the foreseeable future. Therefore, D3.1 [8] also discussed different possibilities for the reallocation of these driver responsibilities, often concluding that a new value network role– namely, a TO fleet management– would likely take over some of these responsibilities. In addition, impossibility to fully exclude manual tasks will also require deploying additional employees at certain local sites, leading to additional transportation costs. According to current industrial standards (i.e., CMR, Incoterms), the logistics service provider is the responsible party for transporting the goods undamaged, even if the cargo was not inspected or secured by the transport company itself. With the reallocation of tasks, the liability for induced damages may also shift. All these responsibility shifts and costs must be taken into account, as they would be derived from the introduction of teleoperation.

Some examples of responsibility shifts and additional costs discussed in D3.1 [8] include the following:

- Traffic-related communication when the truck malfunctions and must stop at the side of the road (e.g., deploying traffic signs) may become the responsibility of the TO fleet owner
- The inspection of the cargo, as well as its lashing and securing, may be done by an employee hired by the (un)loading site owner, the receiver/dispatcher of the cargo, or by the transportation company.
- Similarly, the loading and unloading of goods could shift to a warehouse operator in those cases where the type of cargo and current customer agreements require a truck driver to

do the (un)loading.

- Lastly, fueling stations could hire extra people to do the fueling task manually. The TO fleet manager would take care of the communication between the vehicle and this local employee.

As described in the value network identification, a TO fleet manager role may be responsible for some current driver responsibilities like maintenance. In addition, it could take care of presenting, collecting and checking the required documentation for each transport, e.g. at a warehouse or customs. The responsibilities of the TO center will go beyond the driving of the truck from origin to destination; rather, it will likely take over some current responsibilities of the driver, including the responsibility for the role of TO fleet manager.

4.3.1.3 Connectivity layer

Since teleoperation services are highly reliant on continuous, ultralow latency connectivity services, the main question refers to which party would become responsible for damages caused (indirectly) by a connectivity failure. With current networks and business models, MNOs indicate that they would not see a business case in doing so.

MNOs argue that they can promise a probability of reliability, but not a performance guarantee. In other words, they cannot promise that connectivity will 'never' fail. They cannot guarantee ultralow latency (e.g., below 10ms) with 100% reliability, especially for nationwide coverage and a single use case. Even with 5G and network slicing, having assurance on always having such latency in combination with high uplink and other TO requirements was deemed as unrealistic. In addition, by controlling just the connectivity part, MNOs can only influence end to end latency of TO to a certain extent. Even when offering coverage on-demand, they do not have full control of all possible circumstances. From an MNO perspective, their promise in terms of latency with a certain reliability (say, 99.999% of the time) will be limited to the latency present in the connectivity path (i.e., from the fiber and radio paths to the core or to a local or central breakout).

Another instance where a liability shift may arise is in the case of a potential power outage. Since it is not feasible that telecommunications networks include backup systems (e.g., batteries or generators) next to every mast to supply the necessary power in any possible instance and for as long as an outage lasts, power outages are an issue to consider. Because connectivity providers share the power grid, all providers in an area are similarly affected if the grid goes down. In some cases, this could be covered by a force majeure clause, for example in the case that lightning damages the infrastructure.

However, a power outage on a single cell site would not be a disastrous event, as cell sites can be each other's backup: the modems inside mobile phones and other devices are always seeing several MNO sites at any given moment, and the one with the strongest reception is the one that provides the service; as the device moves, a new site takes over. In their core, MNOs can see when a device needs such a handover and (automatically) supervise them. However, if a power outage affects an entire region, the issue becomes more challenging to solve. Since towers and other infrastructure where MNOs co-locate their equipment are usually shared among different operators, MNOs usually use the same power line. So, to promise 99.999% reliability and availability, they would need to make sure the different masts have different power suppliers or are located at two different portions of the grid. Notwithstanding, it was noted that how to provide backup power for the equipment in a specific area is also a novel aspect for MNOs to explore.

While SLAs cannot guarantee these latency requirements with absolute reliability, MNOs will have the ability to provide assurance on what service levels are available within a certain geographical region, i.e. publishing the parameters that the network (or network slice) is able to provide in a certain area. In addition, other, more straightforward incidents could be included in the SLA with a defined party as the responsible one, for example if there is a mechanical defect on the operator's equipment.

With current 4G/LTE services, which are considered best-effort networks, network providers usually do not care for which particular use case their enterprise customers use their connectivity, or in what particular device they put that SIM card. Two reasons are net neutrality regulation and that they are not liable for the end service quality. However, with the introduction of 5G and all of the technical capabilities it brings, enabling use cases like TO, the MNO is being pulled into the value chain, becoming more closely involved into whatever their customer will be doing with the connectivity. This is specially the case for a service that requires high reliability and ultralow latency like TO, which has the potential to bring a liability shift to the MNO. The fact that 5G and network slicing reduces the risk of network performance failures compared to current networks might also encourage MNOs to take part in the liability discussion.

Therefore, future SLAs between TO service providers and network/connectivity providers could include promises of acceptable service levels for the connectivity provision, with attached capped penalties in case of underperformance. These mutual agreements could include promises of certain performance parameters, linked to the assumption of certain amounts of liability in case they are not met, with the disclaimer that occasionally connectivity may fail (i.e., offering a reliability ceiling as well).

4.3.1.4 Vehicles & equipment layer

Regarding road vehicles, a possible liability shift would be from vehicle manufacturers to mobility service providers (SPs) or telco operators. Teleoperation SPs may be considered responsible for the performance of the service they offer, besides sitting at the end of the value chain in close contact with the customer. However, telco operators may absorb (part of the) responsibility for network failures, as discussed above.

Another relevant aspect to consider is the performance of the hardware embedded or retrofitted in the vehicle to enable TO, including the sensors. In general, defining a clear homologation and testing process by certification agencies was seen as another prerequisite to defining agreements involving liability shift towards vehicle and equipment manufacturers and system integrators.

As discussed before, even with high levels of reliability, the telecommunications network may always go wrong. Similarly, the TO technology provider can offer a best-effort guarantee that TO can function 24/7 but with a disclaimer that everything may eventually and occasionally fail. Consequently, vehicles need to be designed in such a way that TO remains safe even when the network has distortions.

Some safety mitigations will be built by default via automations, while others will rely on adding redundancy. A current example of redundancy is using two SIM cards for cross-border transports. An additional one involves having a safety driver in the truck, but more difficult scenarios will be more challenging if TO is to be kept cost-efficient. In the case of TO with barges, just a smaller part of the crew may remain on board, already offering higher operational efficiency.

Within a single port or industrial site, an aspect to consider is the interaction between the teleoperated vehicle and other vehicles. For instance, at BASF Ludwigshafen, the teleoperated vehicles always have priority. But it is the transition to wider scenarios that involve long-stretches of public roads, and the subsequent increases in environment complexity and speed, that are seen as a huge step in terms of the level of redundancy needed and the liability, certification and legal changes required.

4.3.1.5 Conclusions

To recap and conclude the liability discussion, we show, graphically, the main potential liability shifts derived from the introduction of teleoperation in goods transport, plotting them in Figure 4. These represent the main potential shifts across the four studied layers of the value network, which are the most relevant for the liability topic. It is important to note that these shifts from the current responsible actors to new ones represent partial transfers of responsibility, linked to the specific tasks or causes studied above.

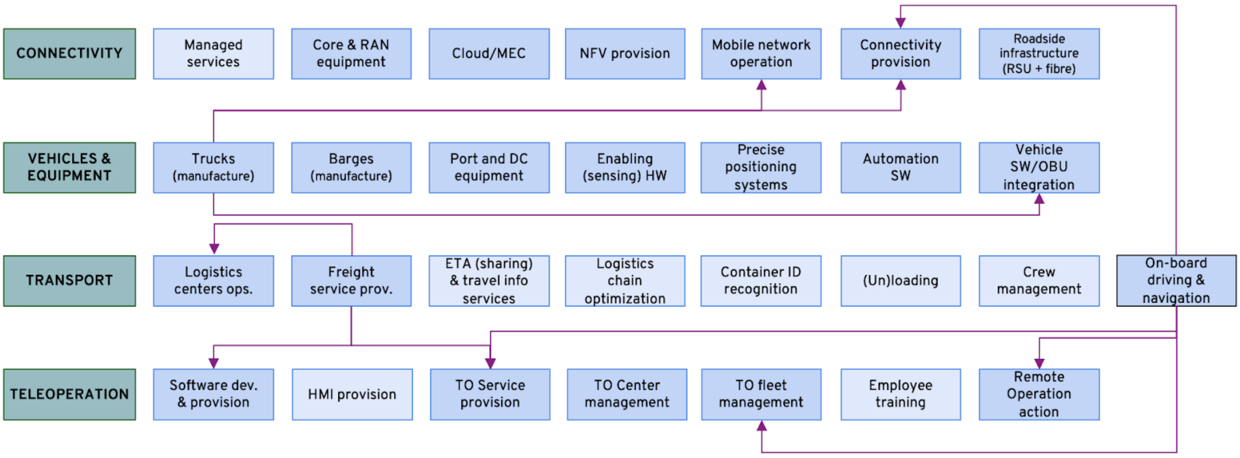

Figure 4. Potential liability shifts derived from the introduction of teleoperation in goods transport.

Figure 4 shows how, compared to the status quo, on-board drivers and captains may transfer liability to remote operators for the driving action, and to TO service providers for damage to the cargo in certain circumstances. TO fleet managers will take up some of the current responsibilities of truck drivers for several tasks along a transport journey. In addition, logistics service providers may transfer the legal responsibility that arises from issues with the securing and (un)loading of the cargo; for instance, to TO service providers or to terminal sites where the tasks are performed. Vehicle manufacturers may transfer the liability in case of a vehicular system failure to the companies integrating software and/or hardware into their branded vehicles. Lastly, we can also observe how connectivity service providers may be subject to a higher liability risk in the future, as they may be held responsible in certain situations, e.g. when an accident happens due to a network failure.

This would lead to new contractual arrangements identifying each party's liability in advance, and would have a cost impact as well, derived from the responsibility to contract insurance policies. Achieving an attractive business case may require MNOs, vehicle manufacturers and TO service providers alike to assume part of the liability, but an appropriate division among them is still unclear.

In practice, if a partner refuses to assume liability for the issues related to its own service or product, this could disincentivize a TO service provider to offer or invest in remote operation, as it is unclear if prospective TO providers would be willing or able assume the liability for any failures along the supply chain. Not offering a guarantee on the service would also make it more difficult to convince a transport company or forwarder to contract TO as a customer. It was argued that a liability distribution needs to be regulated, in order to have security on which roles will assume responsibilities in case something goes wrong. Therefore, the actual distribution of liability will be subject to future legal mandates as well.

A failure of remote operation may stem at different levels: the vehicle HW, the telecommunications network, the remote driving, etc. In certain cases, it may be straightforward, for example if the TO driver makes a mistake, but identifying a clear cause of technical failures may be more challenging. In conclusion, liability is a main concern, but the issue of liability shifts is a very complex one.

4.3.2 Data sharing

Supporting or enhancing teleoperation, several data flows are relevant to consider, stemming from vehicles or their environment, such as roadside infrastructure, cameras in ports, data from other vehicles, etc. Both TO use cases and EFs require gathering and putting together information from multiple sources. Information sharing is thus crucial, but not without its challenges.

Remote driving entails the constant, real-time sharing of several data streams that need to come from different sources along the value chain. Traffic data needs to flow to the HMI (the dashboard) that sits in the teleoperation station to inform the remote driver. Vehicles or TO drivers need to communicate the status and location of a vehicle to other parties, for instance so a docking station in a port can anticipate the arrival of this approaching vehicle, or for other parties to supervise the location of vehicles for safety reasons. In addition, the sharing of in-vehicle data may also help solve liability claims in case of accidents.

This was considered more relevant for the safety-related enabling functions than for the logistics optimization ones. This includes warnings about traffic incidents or about approaching VRUs. However, 5G-Blueprint is still being exploring whether these messages will be an enhancement to the remote operation action or a necessity for it, and also which ones will be really valuable for TO. But for those that prove to be valuable, then a question is related to the willingness to pay for this information, for instance by the TO service providers. It is known from the C-ITS domain that the willingness to pay for such information is low. Needless to say, the providers of the enabling functions will expect a return for the service. Since this discussion is still emerging, it is still unknown if the current state of sharing is a bottleneck for TO.

Another challenge relates to how such data sharing and aggregation would be done. Potential data exchange infrastructure would have strong similarities to the fleet management centers that are currently in place for public transport or logistics. Public transport operators have huge operation management centers, collecting information about the status of the road and the bus stop locations from different sources. An option is that, in the future, these management operation centers will also take care of additional information or activities related to teleoperation. However, building this type of facilities, at such a scale, was seen as unfeasible for specific sites like ports. It must also be considered that these data centers for public transport are arranged differently from region to region.

Next, we engaged in a discussion on whether the site owner (e.g., a port), in its orchestrator role to facilitate the use case of TO in their area, would also set up the infrastructure needed for the sharing of enabling functions and TO data, such as a data exchange platform. A central party in an industrial (private) zone, such as a port authority or a large company like ArcelorMittal, is a possible candidate to organize it with, or for, their partners, including logistics companies and freight forwarders. Next to the work of keeping ports operational and related tasks like customs, port site owners could adopt the additional task of taking care of data sharing; however, that would increase the complexity of their operations, and would require extra personnel.

Vehicle manufacturers currently collect data from vehicles to improve the performance of their vehicles and make better products. The majority of the data that is currently gathered is performance data: speed, consumption, components-related information (e.g., tires), etc. This data is mainly shared with suppliers. Driving styles and driver history data are shared with insurance companies. But OEMs do not collect that much information regarding the external environment of the vehicle (e.g., the road). There are opportunities also to share data with road authorities to improve roads based on what the vehicle records, for example, regarding holes on the road. But it is still being studied how to structure the data for this data sharing. In certain situations, such as a specific traffic environment, a remote operator would need or benefit from these recorded data about the external environment of the vehicle; since operators may have a simultaneous view of many vehicles when monitoring a fleet, such data would enhance their awareness of the road environment.

Furthermore, to provide intelligent transport services, service providers like Be-Mobile rely on real-time mobility information. Currently, the data they need is mostly GPS/position data from lots of vehicles. This is used, for instance, to calculate travel times and predict traffic jams. Several parties need this position data, for instance for intelligent traffic light control or vulnerable road user notification services. With TO, more information would be sent to the remote driver compared to what is currently shared with manual drivers. These types of information would be more important for a TO service provider, for example to know the locations and status of traffic lights in advance, or to generate speed advice when approaching an intersection. Nevertheless, positioning data is already being shared today, so its potential lack of sharing is not identified as a bottleneck in terms of enabling TO in the future.

Besides TO driving, real-time traffic data sharing is important to address priority choices for emergency services, TO truck platoons or public transport (PT), among other use cases. Traffic management authorities would rely on this data to manage traffic in intersections. Currently, some priority choices are predefined based on agreements between the parties, for instance between PT Operators (PTOs) and local authorities about when to give priority to PT vehicles. PTOs are licensed to get this priority and need it to manage their schedules and to optimize their route times.

It is not entirely clear what kind of feedback needs to be provided to the TO driver. If you need all 3 axles motion in terms of rotations, then you need to also send that sensor data to the TO operator, but if you can assume that the TO driver is experienced enough that he does not need the 100% feedback, you may send less. Then, by not sending these data, you are not clogging the uplink as much. But this is just one of the questions at the human level that still need to be solved.

The challenges of data sharing are in principle the same whoever takes the TO role. However, if a certain organization takes multiple roles, there is no need to find a financial return for a data transaction among those roles, possibly also avoiding the need for an intermediary. An example would be when an OEM is the entity performing TO to drive vehicles from its own manufacturing plant to a shipping point.

Data sharing is especially relevant for 5G Blueprint's enabling functions, for instance distributed perception (EF4). To extend the range of a vehicle's view of its own environment, distributed perception relies on other road users sharing the view with a vehicle. Traffic data are gathered from multiple sensors, cameras, GPS devices, etc. and sent in real time to the HMI and to other vehicles. This enables the detection of road anomalies ahead (e.g. detecting VRUs at intersections or other unforeseen events). For the recognition of containers (EF6) and their subsequent allocation to a teleoperated truck, container IDs will be detected when being picked up by spreaders, the information is then processed on Room40's Scene Analytics platform, and afterwards shared with other parties. Similarly, logistics chain optimization services (EF8) also rely on real-time analytics and combining different data streams, for instance for buffer parking optimization. Building on 5G-Blueprint's D7.1 [57] and the discussion above, the table below also considers the required data flows for these EFs, although without the intention to be exhaustive.

For simplicity, Table 4 and Figure 5 below only plot the most relevant possible data flows, focusing on the use case of teleoperation of road vehicles. Dotted lines indicate that an interaction is uncertain.

#	Receiving actor	Data received	Offering actor	Input/source
1	Traffic managers / Road operators	Speed and position data from vehicles	Vehicle manufacturer or TO service provider	Vehicle positioning devices (a.o.)
2	Data aggregators (and related SPs)	Aggregated traffic data to generate analytics-based services	Vehicle manufacturer, traffic manager	Vehicle positioning devices, roadside infrastructure (e.g., cameras, sensors)
3	Transport company or Logistics center	Container recognition and monitoring	Service provider (e.g., Sentors)	On-site cameras
4	Mobility SPs (e.g., Locatienet, Be-	Real-time dynamic maps of the road/site	Data aggregators (and related SPs)	TO and other vehicles' GNSS

	Mobile) to calculate ETA, VRU warnings, etc.	with detected VRUs and obstacles		data, VRU devices, roadside infrastructure, etc.
5	Mobility SPs to calculate ETAs at relevant waypoints	Time slot reservation at intersection	Intelligent traffic light controller	Precise positioning of the TO Vehicle
6	TO Service provider to calculate speed advice for a platoon	Time slot reservation at intersection	Intelligent traffic light controller	Precise positioning of the TO Vehicle
7	TO Service provider & TO fleet manager	Assessment of parking availability	Logistics site (maybe via SP)	CCTV in parking + vehicle streams
8	Insurance companies (maybe via TO or mobility service providers)	Aggregated data on TO driving patterns and performance	Vehicle manufacturer	In-vehicle data recorders
9	TO Service provider	Notification that vehicle is ready for docking, loading, etc.	TO fleet manager (and vice versa)	Remote driver and on-site personnel input
10	TO Service provider	Combined situational awareness EFs: maps, info messages, VRU warnings, etc.	Mobility SPs	Warning collector + ETA info services (#4 & #5)
11	Logistics site (to prepare for docking), traffic light controller	ETA of the TO vehicle towards its destination and route waypoints	TO Service provider or TO fleet manager	Data services received (e.g., #6, #10)
12	TO Service provider	Requesting TO for a certain action	TO vehicle	In-vehicle SW systems
13	TO vehicle	Notification prior to TO take over	TO Service provider	Remote driver input
14	TO Service provider	Dynamic map of QoS & coverage	MNOs or Connectivity SPs	MNO network mgmt
15	TO Service provider (maybe via smart mobility SPs)	Dynamic speed limits or other traffic signage	Road operators or traffic managers	Traffic mgmt centers
16	TO Service provider	HD video streams and other driving data	TO vehicle (via its OBU)	In-vehicle cameras and sensors
17	TO vehicle	Control data, teleoperator's commands	TO Service provider	TO system + remote driver

Table 4. Description of the main data flows supporting teleoperation of road vehicles.

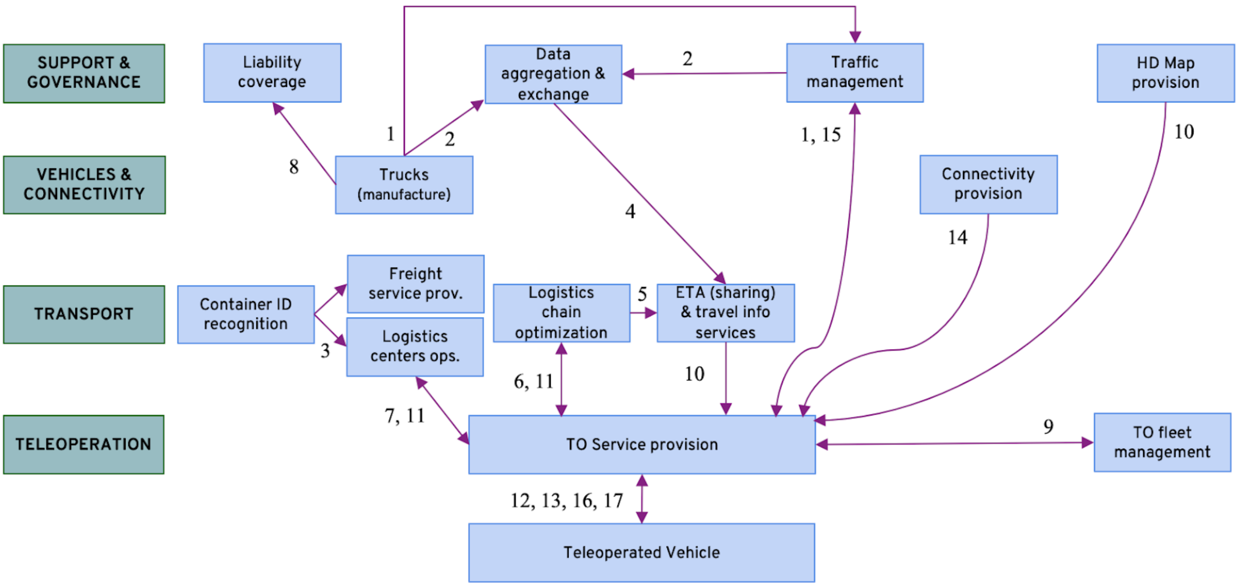

Figure 5. Simplified value network plotting the main data interactions in Table 4.

Also for simplicity, other data flows are not plotted because they happen within a single value network role, although between different entities. For instance, traffic managers of different countries need to exchange data for monitoring, at a macro level, the movements of teleoperated vehicles embarked on a cross-border journey. Likewise, TO service providers must share data to identify vehicles and give instructions in the face of handovers; before taking over the remote control of a vehicle, a remote operator must receive information regarding the vehicle's status and position.

Several data streams are gathered and processed within a single TO Centre and its elements, which contain the following:

- The TO station or cockpit displays the different audio-visual streams to the remote operator. It includes a primary display showing the main video feeds from the truck, vessel or crane, and a secondary display (i.e., the dashboard) showing additional information from the EFs, such as a real-time map of the route and warnings.
- The control unit, which integrates data from EFs and other sources, and selects which information is shown to the teleoperator at each moment in time, after processing it. Furthermore, it processes the input from the teleoperator (e.g., steering, accelerating, or braking) and sends it to the vehicle.

In addition, other flows involved secondary roles that are not included in the identified value network above. As described in the value network identification, a teleoperated fleet manager role may be responsible for interacting with local operators that, as explained before, may take care of some current driver responsibilities, such as fueling a truck.

In terms of incentives to engage in these data transactions, different reasons can be identified:

- Complying with regulation, in case the sharing of certain data is made mandatory.
- Receiving other in-vehicle or traffic data in return, as it may be relevant to use for traffic management or for building added value services.
- Lastly, the receiving entity may offer financial compensation, either directly or indirectly. For example, the financial return may be priced in a connectivity subscription (e.g., #14) or lead to a reduction in insurance premiums (e.g., #8).

Building on previous project studies [57] that provided an understanding of the data sources and types that need to be considered for teleoperation use cases, this section has intended to provide more clarity on which specific actors will be responsible for providing the main data required, as well as how the different roles can be expected to cooperate to share such data among them. In addition, it tries to highlight the main data requirements to perform each role.

4.3.3 Bottlenecks & opportunities

In this section, we discuss some aspects that can represent a potential bottleneck to the adoption of 5G Blueprint's use cases. In addition, we also discuss how TO could be a solution to bottlenecks that are currently present in the transport value network layer.

The aspects discussed before also represent potential bottlenecks derived from TO: for both unclear liability and data exchange agreements, this can be the case if no responsible party is identified, or if the identified one is unwilling to take such responsibility. A general challenge for adoption is thus the complexity of the value network in itself, which will require reaching agreements among the different stakeholders regarding data exchanges and liability coverage before remote driving operations can become a reality.

Complementing these discussions, this section goes beyond these aspects and starts discussing a different potential value network bottleneck, namely the seamless delivery of high-QoS connectivity.

4.3.3.1 Cross-border continuity of 5G connectivity

In a situation where a device (e.g., a vehicle) exits the coverage area, the connectivity provider needs to rely on the network of another operator to provide the connectivity service, thus needing an agreement to ensure that the connectivity is provided seamlessly and with the promised quality. This handover may happen between a private and a public network or between public networks of different states. For instance, the vehicle of a Belgian customer will have a SIM card from a Belgian MNO and a commercial contract with that MNO. When crossing the border, the customer is not only expecting the same kind of service level in the Netherlands, but also that the handover at the border is managed by its connectivity provider as part of the service agreement.

It must be noted that the high-performance service level being considered to support TO is not the same as the one of the average current connectivity subscriber roaming across networks. This makes the cross-border handover for TO an important and challenging aspect that, if not provided seamlessly, would represent a bottleneck both operationally and business-wise. MNOs are still researching how to orchestrate the handover from their network to another one when a vehicle travels across the border while (i) having the other MNO understand what sort of service has been sold and (ii) avoiding having two SIM cards (of the respective MNOs) simultaneously in the vehicle.

At the moment, there is no clear way to manage a cross-border handover where the MNO is directly negotiating for its customer for a specific service level that in turn has its own specific pricing level. Current roaming agreements are much simpler and thus not really applicable for the TO use case yet. Therefore, it is possible that in the beginning there will be a period where customers will have to use two SIM cards and two parallel commercial contracts with respective MNOs at both sides of the border. To overcome this challenge, operators have to first research how to set up the handover and the slicing orchestration. Second, they will also have to explore the billing side.

In contrast, seamless handover/roaming between a private and a public network should be easier at the commercial level, because it is clearer what each party wants. For example, if a port site has its own cell towers and its own core network, and it would request an MNO to let its port users roam on the MNO's public network when they exit the port area, then that port can send an exhaustive description of its requirements to the MNO. Alternatively, it may be the case that the private and public networks belong to the same party, for instance if the public MNO also offers private networks for certain customer segments. In that case, the complexity of the commercial aspect would be removed. In both cases, the required knowledge is more accessible.

This does not imply that handover between private and public networks entails no challenges. Usually, such handover addresses only a relatively small group of users, i.e. those users covered by the private network. And it is always the case that the request is to roam the private network users to the public one, rather than the other way around. Since roaming agreements normally work on the basis of reciprocity, there is the risk that the customers of the public network would come into the range of the private network and overload it. Therefore, an agreement where a public network provider supports the customers from a private network would have to take this potential issue into account. In contrast, for roaming between public networks, the goal is that both networks' customers roam on each respective MNO's network, thus naturally involving bidirectional orchestration and agreements without worrying as much about potential imbalances in the collaboration between the two networks.

While even cross-border bilateral contracts between operators would be manageable, because two MNOs can easily coordinate to solve the specific local challenge, the difficulty lies in scaling the agreement, i.e. making it usable for the industry. This is because enabling that any SIM card is supported by any other possible MNO, and vice versa, requires a much larger scope of coordination. As an illustration, a given teleoperated vehicle crossing the Belgian border and wanting to roam on Telenet's network may be using a SIM card from any other possible country.

Another difficulty is that roaming agreements can change in the future. For example, while today a Belgian MNO's SIM cards may be roaming on KPN after crossing the Dutch border, in the future they may be roaming on Vodafone. Similarly, if an MNO has an arrangement in place to provide connectivity to a factory's own private network, it could well be that in a few years' time the site owner would switch and transfer its contract to another provider. To both mitigate this uncertainty and reduce the practical complexity of roaming, there needs to be some kind of scalable international template, or blueprint, that standardises future handovers. Writing such a blueprint goes beyond establishing a technical capability between a given pair of MNOs in the cross-border area between Belgium and the Netherlands. Having contract templates that are applicable to any other MNO also requires an understanding of what needs to change in the current relationship between any two MNOs that have entered into roaming agreements.

Once the vehicle travels to a different country, an MNO should be able to supply its home subscriber an equivalent service to the one offered domestically, just like it is currently done when mobile phone users roam across Europe. As explained by KPN, the way their current roaming is set up is that if a KPN subscriber travels to another country, her device will constantly look for the strongest connection independent of the provider. Therefore, the roaming subscriber driving along a German highway would be constantly handed over between different networks. Since KPN has roaming agreements with all German MNOs, and national (intra-country) roaming agreements are not in place, a Dutch subscriber roaming in Germany may have better coverage than a German subscriber of a single German network.

Still, the MNO (often) does not know, once its SIM card is in another country, that it is going to roam onto a certain network with certain specific characteristics. But in the case of TO, the MNO will need an assurance that the host network will have the necessary latency, throughput, and other requirements. Therefore, the commercial agreement will need to be more specific about the service level provided when roaming. Otherwise, MNOs would have to define constraints requiring their customers to have a SIM card from a list of supported foreign networks. In addition, the roaming agreement will not be designed for home subscribers that visit another country sporadically, but rather for routinary trips across possibly multiple borders.

4.3.3.2 Transport layer

Within the transport value chain, some existing issues relate to time that is inefficiently used. One example is the substantial queueing and waiting times at port sites, due to capacity shortages. Ships ready to unload their containers may await their turn until space and equipment is ready to handle their cargo, sometimes for a few days. With the impact of the COVID-19 pandemic, the timely availability of containers and container ships has diminished. At the moment, these are exceptional issues affecting different ports around the globe. For a transport company like Transport Roosens, a current solution to this issue is buffering almost 90% of the containers they handle on their own facilities, where they must store them at the required temperature. This buffering may be done at the port site as well. Many terminals also offer a buffer service, keeping containers for some days after their arrival and then transporting them to a transport company's site.

Likewise, trucks may await for their chance to (un)load their containers. Such waiting does not entail being stopped, but it is rather more like a traffic jam, where trucks have to move on slowly and the driver needs to be aware and drive a few meters every now and then while she is in the queue. This means that the driver cannot do an alternative task simultaneously.

For both road and waterway transport, time estimation at the port is not up to the TO center to handle but has mainly to do with the port's organization and traffic control. But TO can help mitigate the exposed issues, adding productivity to the transport value chain. First, by allowing the (remote) driver to do another task in the meantime. Second, by increasing the cost-efficiency of driving at night: since waiting times arise from the fact that most businesses want to pick up their containers at similar times, the morning and afternoon rush hours are very predictable, at least at the inland terminals; remote driving overnight, outside of rush hours and when there is less availability of drivers, could be another source of value added by teleoperation.

We must make a distinction between types of cargo. Transport of containers represents a more readily available opportunity for teleoperation to be deployed as a starting case, compared to other types of cargo like bulk or tank. Container-based logistics is more automated (due to it being highly standardized), and may be rely on further automation in the future. For instance, checking whether the container is properly secured or loaded could be measured with sensors placed in the (already sealed) container. It may still require, however, that a human operator is still present for (un)loading, unless twist locking becomes automated. Another reason is that the (un)loading process for other types of cargo like tank requires special equipment at the destination.

TO applied to short haul transport may be a more ready example as well. 'Milk runs', involving short but constant trips, represent a lot of the transport that is being done today, and could already benefit from the mentioned waiting time gains. In some cases, this entails cargo going consistently back and forth from a factory to a big automated warehouse in short trips, maybe using several dozen trucks every day. This can happen both on closed premises or over a few kilometres of open roads. Similarly, after containers are transported by barge to an inland terminal, these milk runs are mostly served by the inland terminal and distributed locally, typically within about 15 kilometers of that terminal, and often in industry terrain such as business parks, rather than on the highway. Teleoperated milk runs could thus be done first on closed environments and then, only after the safety of TO is proven, be scaled to short stretches of public roads as in Scenario 2.

We must also differentiate between different ways in which a truck is loaded. TO would be much less challenging for transports where cargo is entirely unloaded at a single, final location, compared to those where several deliveries need to be made throughout the route. In the latter case, you may need someone in the truck to make these deliveries or to check if the load is correctly distributed inside the trailer. On the positive side, the impression of the consortium's experts is that, for both bulk and container transport, most of it consists of these 'full load' transports.

In waterway shipping, we must differentiate across the several ways companies operate, especially with regard to inland navigation. Inland shipping is a traditional market where ship owners are often either (i) families who also operate, and may even live in, the boats, and (ii) companies who own very small fleets of ships. For them, reducing their crew with teleoperation would not be very valuable from a financial standpoint. Nevertheless, similar to trucking, the reason why inland navigation is interested in TO is because of the challenge to find the crew to hire; there is a shortage in labor supply as well. In contrast, for large ships and companies with big fleets, the prospect of reducing their crew is an important incentive to adopt TO. A difference between waterway and road transport is that for the former, reducing part of the crew on board of the ship already brings an attractive cost saving, while on a truck you cannot cut personnel per vehicle unless you remove the driver altogether.

Besides remote operation, automation and the enabling functions defined in the project can also contribute to solving some of the aforementioned bottlenecks. For instance, container ID recognition in harbor sites helps monitor the location of the cargo as it is transported around and (un)loaded. On the site itself, container recognition helps lower the waiting times of processing idle containers. While container ID recognition is a technology that is currently available, the innovation in 5G is that it can be operated as a service with the data processing taking place centrally.

Automation may also help solve the queueing issue inside port premises in an efficient manner. For instance, it might be possible to have a system that automates the (un)locking of the twist locks in the future. In fact, such systems are already available on the market for containers, although not for pellets or bulk. This manual locking and unlocking is very time consuming for terminal operators, even if it only takes one or two extra minutes per container. Similarly, when loading trucks, taking care of the twist locks requires just a few minutes before the cargo can set off, but it adds to several other actions that need to be performed when loading. Another potential solution to gain time and reduce the number of in-site, physical actions requiring personnel would be to automate the opening and closing of containers, after the instruction is given by a remote operator. A combination of teleoperated and automated processes, mutually enhancing each other, may be the most effective or efficient way to deploy TO. This, however, needs to be explored further.

Finally, before adopting autonomous or TO technology in transport value chains, a prerequisite is the use of digital documentation to replace certain paper-based processes, such as CMRs, that are often used in port environments. Controlling the adoption of these processes is outside of the control of transport companies. The business requirement of digitizing transport documentation was already explored in D3.1 [8], where it was noted that the e-CMR protocol is expected to be made mandatory in the EU by 2026. As mentioned in section 4.2, container transport is best suited to adopt teleoperation at an initial stage because of its wide use of digital documents.

5 BUSINESS MODEL ANALYSIS FOR TELEOPERATION WITH 5G

While there is potential for cost savings in the logistics sector and thus potential demand from TO applications, the business case still depends on the adopted business models, which remain uncertain. Exploring feasible business models is necessary to clarify ways in which services can be provided in a way that benefits different stakeholders and incentivizes them to take up the identified key roles in the value network. In addition, business models have to address the challenge of monetizing the investments required to enable TO in practice.

The present analysis proposes a wide set of options regarding different crucial roles in the value network, and assesses their feasibility in the context of Belgium and the Netherlands, proposing also specific business models for deploying TO solutions. The identification of the underlying granular choices behind these business models offers more flexibility to the analysis and facilitates its reuse, hence providing a blueprint for implementation in other contexts.

With the aim to bring clarity on the potential business models for TO with 5G, this section relied on a methodology that consisted of four steps:

- First, desk research was used to process the relevant literature on a topic (CCAM) and domain (business models) basis.
- Second, structured written templates were distributed within the consortium's relevant experts in each topic. This is explained in more detail in the next paragraph.
- In parallel, based on the initial findings, workshops were organized to discuss business model aspects in more detail.
- Lastly, further analysis was performed to delineate more elaborate business models based on the discussed options.

Regarding the second step, two different versions were distributed for transport and connectivity topics, respectively. For guidance, a brief background text was provided, based on a review of the identified challenges and remaining open questions from a business model perspective from academic literature and previous EU projects' findings. This structured approach is reflected in the tables included throughout this section. As it can be observed, it tries to distinguish the possible differences per deployment scenario (if any). The main guiding business model questions included the following aspects:

- What are the main assets required (e.g., a fleet or infrastructure element) and which stakeholders would invest in and own them?
- Which stakeholders can be expected to be (i) the direct, paying customer and (ii) the service provider in each business model option?
- What crucial coordination or input would be required from other stakeholders?
- What is the specific intended added value provided to the customer in each model?
- What are the most feasible monetization strategies? This refers to pricing models, revenue sharing schemes, etc. As inspiration, the template provided a list of pricing strategies based on business model literature.

5.1 Business model options for key governance and connectivity roles

The remote operation of vehicles involves real-time streaming of HD audio-visual and sensor feeds from a vehicle to an operator in a remote station, using the uplink in the network. This would pose a substantial challenge to the telecommunications network, especially on the uplink capacity. In addition, ultra-low latency is required to perform teleoperation in a sufficiently safe way. 5G has the potential to enable teleoperation use cases by delivering the requirements identified before: lower latency, higher bandwidth, wider coverage, and seamless availability. However, in order to do so it requires investing in the deployment of new network equipment and infrastructure, and may also need to rely on parallel technological improvements such as network slicing (among others).

But practical feasibility of teleoperation from a network perspective will depend on aspects beyond technical ones. As a result of the mentioned characteristics of TO, this use case may need dedicated network capacity, which in turn would entail investments to densify the network and scale the deployment area of TO. Therefore, business models need to consider cost-efficient options for 5G infrastructure deployment as well as options to monetize these deployment costs. Furthermore, seamless roaming is crucial to ensure 5G service continuity across EU member state borders and between public and private networks, and roaming agreements need to sort out commercial aspects.

The delineation of possible business models needs to take into account all these aspects, as well as the provision of the connectivity services. The discussion below aims at bringing clarity on these relevant topics.

5.1.1 Cross-border 5G continuity

To guarantee uninterrupted remote operation, coordination between MNOs in the form of roaming is required. (Cross-border) handovers may happen between private and public networks. To ensure seamless service availability and reliability, MNO handovers must not introduce excessive latency. Currently, service continuity is a challenging aspect, with handovers often resulting in long service interruptions. To deal with this issue when a vehicle crosses a Member State's border, TO service providers can add redundancy, having simultaneous contracts with two telecom operators providers. However, the dual SIM/modem is a suboptimal and undesired solution in the long-term.

While there are existing templates for roaming contracts (e.g., from GSMA), seamless roaming requires extending these commercial agreements. Commercial challenges for seamless roaming include measuring usage to bill visitor subscribers and cross-border coordination amongst MNOs, among others. 5G-Blueprint will explore further how to extend these contracts in more detail, from a technical and/or governance standpoint, but the lines below already look at the value added of roaming services from a business perspective.

Handover could be understood as a service provided from one network operator to another. Cross-border service concepts are not new. For an operator with a single (home-) country focus this can be quite a complex endeavor as this requires technical and administrative procedures with many other operators. This effort, by definition, takes the form of a specific service thus warranting a price premium to recover the costs of effort. Operators with a presence in more than one country have it easier as they can retain this effort more or less internally. This does impact the scope though, as an operator with a single national market will set this up with all foreign operators (e.g., KPN would arrange this with all Belgian MNOs), thus extending its service to the sum of the geographical coverage of those Belgian operators combined, whereas a multi-country operator would be limited to its own geographical footprint only (e.g., KPN customers enjoy better coverage in Germany compared with competitors active in both Germany and The Netherlands).

Scenario 1: geographically limited area with numerous (short distance) transports.

In this scenario we assume the "cross-border" handover to happen between the service area of a private network offered by a Private Network Operator (PNO) using its own spectrum under a local license and the (relatively) ubiquitous public network provided by an MNO. The private network service is assumed to be offered in a restricted industrial area such as a harbor, and the local connectivity service offered to a select group of users. The coverage area of the public network overlaps with the local coverage of the private network, but the PNO can offer a better grade of service for its users, which justifies the investments made in the private network. For session continuity a bilateral agreement between the PNO and one (or more) MNOs is necessary. Here the PNO will be the customer and the MNO the provider of this cross border continuity service. The service consists in that SIMs from the PNO (here, the 'home' network) can use the network of the MNO (as 'visitors'). The SIMs of the PNO have a preference for their home network wherever its field strength exceeds some minimum requirements. For a seamless session continuity between the two networks, network data needs to be exchanged, the network configurations need to be harmonized and user data needs to be routed to an agreed (IP-) address. It is likely the MNO wants to be compensated for the effort to establish and maintain such service to the PNO, whom it considers as its customer. Thus an entry fee, a subsequent fixed periodical fee and a usage fee would seem to be a justifiable model.

Scenario 2: major transport axis (via road or water) with significant transport flows.

In this scenario the MNO does not have one distinct customer. To set this scenario apart from scenario 3 it is assumed that all usage takes place within the coverage area of one MNO. Compared to "ordinary" traffic, the traffic required for TO in this scenario demands a relatively high uplink capacity, high reliability and low latency by a large number of users in a limited geographical area. It is noteworthy to mention that the balance between uplink capacity and downlink capacity is prescribed in international agreements among the MNOs. To fulfill this need, an MNO would need to build additional capacity: since the use of radio spectrum in the areas where this capacity is provided is not optimal, providing the required uplink capacity will mean that the downlink is over dimensioned (given the fixed uplink/downlink balance). To justify this investment, a special service needs to be developed by the MNO to which the TO providers can subscribe. This service will only be available in well-defined geographical areas, such as a highway corridor. The coverage area of this service always overlaps with the service area of the MNO (i.e., it is additional capacity to already existing coverage). The service consists in that the subscriber will have priority/precedence over 'ordinary' customers in the designated area. Since this advantage shrinks with the number of priority users competing for the limited local capacity, the MNO could add an admission control mechanism to prevent that this priority service is given to a new user when the number of active priority users that have accessed the network already consumes the available capacity. However, capacity management to provide additional capacity in the areas where priority is in high demand is at this moment impossible, because rules on privacy (GDPR) do not allow to follow the whereabouts of individual users. Thus the automated capacity management process is not adapted to priority services. This prevents the "organic growth" of corridors where capacity is added to support this priority service.

Scenario 3: public road, across national borders.

From a technical perspective, this scenario is similar to scenario 1 in many aspects: first, there is an entity (in this case a MNO) that provides radio coverage using its own spectrum license; second, this entity has its own customer base, the SIMs of which have a preference for their 'home network'; third, MNOs have a service agreement which allows their users to roam into and use the 'visited' network. What sets this scenario apart from scenario 1 is that, in principle, the coverage areas of both networks only slightly overlap at the borders. Furthermore, the roaming agreement between the two MNOs is (almost) always reciprocal, hence both MNOs act as providers as well as customers to each other. But since the home and visited networks can offer dissimilar grades of service to their own users, an operator can agree to offer their roaming customers the same grade of service in its network to which the visitors are subscribed in their home network (when technically feasible). To this end, both operators need to exchange service attributes for their roaming customers and harmonize the interpretation of these attributes in the visited network.

Another service to the customers of the MNO is the seamless session continuity whilst crossing the border of the coverage areas of the two MNOs. This can be accomplished in at least the following two ways:

- On an application level. Since both networks need to slightly overlap at their borders, user equipment equipped with two modems (and two SIMs) can use an application to simultaneously connect one modem to the visited network while the other remains connected to the home network. In non-overlapping areas, both modems would be connected to the available network, either the home or the visited one. To the MNO this method is (almost) invisible, and it does not impact existing roaming arrangements.

- As a network feature. With a single modem, the networks of the home and visited operators must allow a handover similar to an intra-network handover. To this end, both networks need to act as if they are equivalent, and need to do (an additional) effort so that configuration items on both sides of the border are synchronized. While it seems impractical for MNOs to charge each other for this effort, this will add to the costs to maintain a roaming relationship. The most plausible method of settlement is probably a usage-based fee by which the visited operator charges the home one (with reference to the actual user consuming this seamless roaming service).

Scenario	Customer(s)	Provider(s)	Pricing strategy	Party investing in the required assets	Distinctive added value	Input required from other parties
Scenario 1	PNO	MNO	Entry fee, a subsequent fixed periodical fee and a usage fee		Higher continuity of QoS connectivity service for PNO's visitor SIMs	Network data to be exchanged via third-party platform; user data to be routed to an agreed (IP-) address.
Scenario 2	TO service providers	MNO	Fixed fee to access the service; premium usage fee	MNO (building additional capacity)	Priority on high-QoS connectivity compared to ordinary users	Privacy regulation to enable automated capacity management
Scenario 3	MNO (home)	MNO (visited)	Fixed fee to access the service; possible premium fee to meet enhanced QoS of home network		Continuity of QoS connectivity service when crossing borders; if possible, contracted grade of service in visited network	
Scenario 3	MNO (home)	MNO (visited)	Usage-based fee based on actual user consumption	Both MNOs (effort to synchronize configur ation items on both sides of the border)	Session continuity when crossing the border of two MNO coverage areas; settling synchronization costs of roaming	

Table 5. Business model options, per scenario, for the cross-border 5G continuity role.

5.1.2 5G connectivity service provision

About who will be the customer. The first aspect discussed here revolved around the party that would be the customer of the connectivity service for teleoperation, i.e. the one who would pay the MNO (or other connectivity SP) for a subscription or the SIM card. Potentially, it could be an OEM, a TO service provider, a fleet owner, etc.

Currently, TO service providers usually include the SIM card in their TO package, as they focus on offering end-to-end solutions. In a future where TO technology is incorporated in vehicles, the TO SP role could become more disintegrated from the enabler/retrofitter role. Then the question of which party is the customer of the connectivity can become even less straightforward.

The traditional business models of MNOs will likely evolve from selling a SIM card in a B2C or a B2B manner to B2B2B or B2B2C models where the buyer of the SIM card is not the end user of the connectivity. Currently, for automotive use cases, MNOs are already supplying connectivity for the OEMs' vehicles in a wholesale, B2B2C way: while vehicle manufacturers are the customers of the connectivity service provider, the individuals purchasing a car are offered the option of having premium connectivity on board of the vehicle, for instance to access music and video-on-demand streaming platforms. The OEM sells premium connectivity as one of its option packages for the vehicle, thereby passing the cost to end users via a lifetime connectivity package paid upfront with the purchase of the vehicle.

These 'intermediated' (B2B2X) models will likely become more relevant in future remote driving scenarios where new network infrastructure needs to be deployed across a site or along roads, where the risk for those investments will need to be distributed among different parties. An example of a business model would be one in which this enterprise party (i.e., the 'B') in between is a port site owner; alternatively, it can be a TO service provider, with a logistics company as the end customer, thus implying a B2B2B model. The connectivity service could then be incorporated and priced in the TO service. From an MNO's perspective, not having direct contact with end users could affect its bargaining power and see its margins reduced. Still, models in which a connectivity subscription is purchased and paid directly by the final customer are also possible.

Challenge to price discriminate based on latency. Establishing service levels based on latency is something MNOs have never done before. And charging differently based on these distinct service levels is a complicated challenge to solve. At the least, managing the latency to offer it as a service would require network slicing. But even with network slicing, another potential limitation is that the infrastructure must be up to the task, because not all cell towers are capable of providing this. For instance, it should be checked whether the deployment area has good fiber optics and good transport networks.

Another issue is about capacity. With current 4G networks, MNOs usually do not care whether the users of the SIM cards move within the network; if they suddenly have capacity issues at a certain location, they can do load balancing, steering customers from one cell tower to another in order to keep the load below a certain threshold. However, TO use cases require so much dedicated network capacity, especially in the uplink, that dealing with almost every capacity issue would require offering additional coverage or capacity on-demand. This is based on 4G and non-standalone 5G. Whether SA 5G would allow MNOs to price based on the cost of what they specifically supply to the market in terms of latency is something that they do not know yet.

Current pricing models. Currently, connectivity pricing is mostly volume-based. And the pricing per GB of data usage is usually done on a best effort basis, rather than offering SIM cards tied to a dedicated user profile. When extra capabilities are offered, for instance to increase reliability or availability, then a premium is charged above the price per GB that is transported through the MNO's network. Beyond best effort services, MNOs can also give a certain application priority on the network resources, allowing users of the mobile network to have a sort of pseudo slice. While challenging due to net neutrality constraints, this service allows the customer to not have to compete for bandwidth with every other consumer located in the same area.

TO would require adding layers on top of generic wireless connectivity services in order to increase their reliability. The project's MNOs identified three value-adding commercial service levels that are currently in place:

- First, giving a certain application **priority to network resources**, discriminating in favor of this application wherever the device is located;
- Second, **guaranteed bandwidth**, which means not only not having to compete at equal terms with other applications, but reserving a portion of the network resources for a specific customer or application. For instance, allocating 1Mb per second of dedicated up-link bandwidth, which is similar. to having a virtual slice. This guaranteed bandwidth is being priced on a 'per case' basis;
- Third, on top of that, they can offer **coverage on-demand**, meaning that the MNO tailors the coverage on a specific site to whatever the customer needs. For dedicated coverage, either the customer also invests in coverage, or if there is enough traffic the MNO may cover it entirely.

However, as opposed to bandwidth, they are not yet able to make any promises with regards to latency or availability. And the challenge arises precisely when introducing these additional requirements. This challenge is not only due to higher costs but also to the difficulty to price discriminate, as mentioned above. Since the first two levels rely on an MNO's generic infrastructure, the remaining customers will suffer from what is given as a priority. Pricing different levels of service based on this concept would therefore entail not only adequately pricing the premium service but also taking into account a possible compensation for the remaining users. In addition, reserving specific bandwidth, and thus a little piece of spectrum, a very costly resource, also drives up costs. Lastly, dedicated coverage also carries extra costs from deploying the necessary additional equipment.

About who will be the connectivity service provider for (cross-border) TO. There are different possibilities:

- MNOs. A motivation for MNOs to provide connectivity services for CCAM is to enlarge their subscriber base. However, compared to B2C services that target a mass market, B2B use cases require tailored solutions with higher performance, which may require high incremental investments to densify their networks, and in turn may require co-investing with site owners or customers. MNOs will aim to generate economies of scale by using their 5G infrastructure for different use cases, which may require finding alternative revenue streams–besides TO services–in the same locations where coverage is enhanced.
- MVNOs. B2B applications represent an opportunity for specialized virtual operators. Depending on the use case, the ability to deliver services tailored to the specific needs can give them a competitive advantage compared to nation-wide public network operators. For automotive use cases, MVNOs like Transatel or Cubic Telecom are connectivity providers to OEMs.
  - Industry customers. Automotive companies, for example, already offer connected car services using MNOs' networks: as an illustration, in South Korea, Hyundai was reportedly registered as an MVNO since 2015, while Kia was recently considering applying for an MVNO license [58]. OEMs may seek to attract customers via added-value 5G-based services like TO or the V2X connectivity service itself. Already with 4G networks, MNOs sell internet access as an underlying foundation for industry players to provide connectivity services on top. To increase convenience for their customers, the value proposition of OEMs could consist in offering a subscription with a bundle of 5G connectivity, teleoperation and other services (e.g., remote updates).
- Micro operators. In the case of private networks, another type of connectivity service provider could be a micro operator. This is a connectivity service provider that only operates within a specific site or local coverage area [59], having a local monopoly within

the space it serves from exclusive access to site-specific network infrastructure (e.g., small cells) or other resources (e.g., customer data). It may be dependent on the MNO for spectrum. To be successful, micro operators need to serve specific requirements [59], for example via deploying and operating tailored network slices. An example can be found in the Belgian port of Zeebrugge, in which the port owner acted as a micro operator for its customers, using Citymesh to manage and monitor its private network [60]. Lastly, a country's policy regarding the allocation of spectrum licenses directly to the industry will influence whether big industrial players decide to have their own private networks, in turn influencing their choice of connectivity service provider.

As 5G networks will be used for many vertical industry services, 5G offers the opportunity to unlock new revenue streams with possibly higher revenue per user than B2C applications. However, the average margin per user (average revenue minus average cost) may not be higher if offering new services for B2B applications requires densifying public networks or deploying private ones. It may also require investments in backhaul (fiber) and cloud elements. In more isolated sites, as well as in less densely-populated cross border areas, finding new revenue streams will be especially challenging. Potential revenue sources need to be explored further, to understand if networks will be able to simultaneously cover the distinct needs of all the different service types, besides leaving enough free uplink capacity and other resources for TO. But theoretically, possibilities for scenarios 2 and 3 (where TO is performed in the open road) include in-vehicle infotainment services (such as video streaming or augmented reality), remote diagnostics for electric cars (e.g., checking battery status), remote maintenance or software updates for autonomous vehicles, and C-ITS services.

Finally, MNOs also have business model choices regarding the provision of connectivity services for specific verticals. An example is the 'Use case enabler' business model [61]. This entails MNOs developing comprehensive and tailored solutions for specific use cases, in order to speed up their adoption and valorize an early position before their competition. In order to do so, operators have to complement tailored connectivity (e.g., a slice that covers the specific requirements), with additional solutions and services such as support, maintenance, after-sales or technical advisory. In addition, operators will have to build close relationships with customers to better understand vertical-specific customer needs. These agreements may be accompanied by different kinds of financial arrangements, such as cost or revenue sharing models that reduce the asymmetry in upfront capital expenditures of initial network investments or future profits. However, due to specialization efforts, it may only be feasible for each operator to target a few use cases.

Table 6 below provides a simplified and non-exhaustive set of possible options for the different deployment scenarios, based on the aspects that have just been discussed. While still requiring more in-depth validation, the options below were initially identified as the most natural or feasible in the context of 5G-Blueprint.

Scenario	Customer(s)	Provider(s)	Pricing strategy	Party investing in the required assets	Distinctive added value	Input required from other parties
Scenario 1 (road transport - trucks)	B2B: Freight service provider; or TO service provider B2B2B: same above via site owner	M(V)NO in case of public networks; MNO or micro operator in case of private networks	Two-tiered subscription: volume-based + premium for guaranteed bandwidth or priority; Usage-based, coverage on-demand	To densify a public network: MNO or MNO co-investing with customer or site owner; Private network: site owner (possibly co-investing with customer)	Easy to understand by customer; predictable OPEX	National or local 5G spectrum license from public authority
Scenario 2 (waterway transport - barges)	B2B: Freight service provider; or TO service provider	M(V)NO (public networks)	Same as above	MNO or MNO co-investing with customer (but since different areas, MNO may need to pre-finance the CAPEX investment)	Easy to understand by customer; predictable OPEX	National 5G spectrum from public authority
Scenario 3 (water or road transport)	B2B: Freight or TO service provider B2B2B: same above via road operator or OEM	M(V)NO (public networks)	Same as above; plus possible revenue sharing between MNO and road operator	MNO or MNO co-investing with port or road operator (but since different areas, MNO may need to pre-finance the CAPEX investment)	Easy to understand by customer; predictable OPEX	National 5G spectrum from public authority

Table 6. Business model options, per scenario, for the 5G connectivity service provision role.

5.1.3 Network Function Virtualization (network slicing)

TO and EFs will require the use of network resources, often to service multiple vehicles simultaneously. Network slicing will allow MNOs to optimize network resources and bring them the opportunity to provide tailored performance by allocating into each slice the network functions and resources required to meet the specific requirements of a given use case.

Network slicing technology enables the creation of multiple, end-to-end virtual networks (i.e., the slices) on top of a common physical infrastructure, with each individual slice providing specific QoS in terms of throughput latency, reliability, etc. [62]. By using the same physical infrastructure to create distinct virtual networks, slicing can lead to cost savings [42]. From an MNO's perspective, providing network slicing is similar to offering priority, since dimensioning for the different slices is (in principle) similar to dimensioning for different priority classes. Nevertheless, slicing would offer a significantly finer granularity compared to contemporary priority services.

Network slicing technology will also help enable new revenue models that use price discrimination to charge differently for different QoS levels [52,53][5]. This way, connectivity service providers can establish higher prices for premium performance, for instance in terms of lower latency. In addition, by helping dynamically manage network QoS parameters, slicing will also allow connectivity service providers to charge customers dynamically for the functionality offered at any given time [63]. Nevertheless, as it was reported in the previous section, adapting pricing to distinct latency levels remains a challenging task that will also require having the proper infrastructure in place.

Different parties may offer connectivity-based services and content on top of a network slice. However, the services that will be supported will depend on the slice type. 5G-Blueprint's D7.1 [57] discussed the attributes of different relevant slice types.

	mMTC	eMBB	V2X	hMTC	URLLC
Name of the slice type	massive Machine Type Communicat ion	enhanced Mobile Broad Band	Vehicle to Everything (communicatio n)	high performance Machine Type Communicati on	Ultra Reliable Low Latency Communicati on
Best suited for	Infrequent and small messages, potentially with a high number of devices	Voice and Video services	Machine to machine communication whilst at least one of the parties is mobile	Precursor to URLLC which is not yet achievable with current RAN technology	Mission critical services with low latency tolerance and high long-term reliability
E2E Latency	Not very Sensitive	Not very Sensitive	Highly Sensitive	Highly Sensitive	Extremely sensitive
Availability	Regular	Regular	High	High	Extremely High
Throughput	Low	High/Mediu m	Low/ Medium	Low/ Medium/ High	Low/ Medium/ High
Radio	Full	Full	Full	Localized/	Localized

[5] Even though as explained in section 5.1.2, distinct pricing based on latency levels is challenging even with network slicing, since capable cell towers, fiber optics and transport networks must be available.

Coverage				Full	
Examples of 5G-Blueprint applications	EF3, e.g. for the uplink from intelligent Traffic Light Controller messages to the cloud	HD Camera stream (uplink) [between TOC and TOV]	Sensor data (position, speed, etc.) from cranes, vehicles, to the TO center Short-range LiDAR data between TOV and following vehicles in a platoon	Ship control interface (UC1) Vehicle control interface (UC2a, 3, 4) Crane control interface (UC2b)	

Table 7. Characteristics of network slice types (modified table based on [57]).

In the context of 5G-Blueprint, an example in which network slicing can help use network resources more efficiently is the following. For a given remotely operated vessel, data streams can potentially be split into different slices, thus helping balance the uplink load from HD camera feeds by using, in parallel, other slices for data that rely more on downlink, such as vessel control inputs.

Network slicing also allows for higher flexibility and autonomy. A network slice can be provided dynamically as a service (NSaaS), instead of as part of an E2E connectivity offer. In addition, MNOs can delegate the management and operation of network slices to a slice tenant, and tenants may provide their own communication services on top of the slice [64].

For simplicity, the related roles to orchestrating network slicing were grouped under 'NFV provision' in the value network we defined in section 4.2, besides physical infrastructure providers. In the literature review section, we described some of the new, more detailed roles that network slicing brings to the connectivity value chain; most notably slicing providers, slice operators, slice tenants and end users. Relying on a similar classification, Kukliński et al. [65] and Oladejo et al. [66] discuss two complex business models for network slicing. They argue that a business model that assumes slice creation and provision based on single infrastructure and providers would not properly allow to exploit the flexibility and dynamism that characterizes network slicing technology. Therefore, they present business models based on dynamic slicing and decentralized resource allocation for settings where multiple infrastructure and slice providers are present, as well as multiple slice tenants. Such a multi-domain, decentralized approach enables the pooling and brokering of network resources owned by multiple (physical and virtual) infrastructure providers. These resources are traded, sliced and dynamically allocated to meet the needs of slice users.

More specifically, Kukliński et al. [65] propose the model shown in Figure 6. In their model, network resource allocation and deployment of slices relies on a brokering mechanism. They identify three types of brokers, as summarized below:

- The infrastructure broker selects and allocates (physical and virtual) infrastructure resources based on the demands of slice providers, which depend on price, QoS, and coverage area criteria.
- The slice broker pools infrastructure resources from different providers and provides discovery of such resources. It also negotiates the deployment or termination of a slice with slice providers.
- The service broker allocates new services to slice users (or customers) based on their request. It provides discovery of available third-party services and their prices.

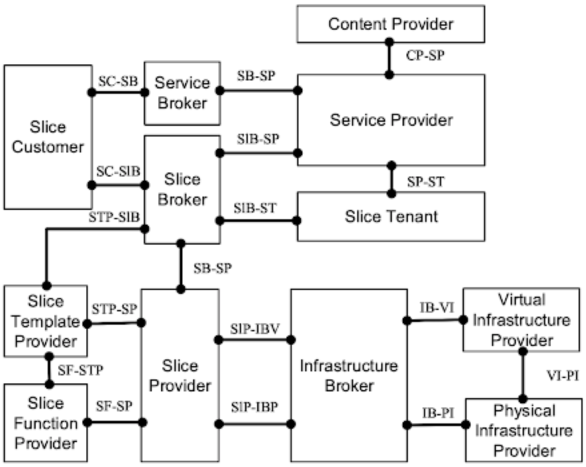

Figure 6. Multi-domain, brokering-based business model for network slicing [65].

In this model, the network slice provider creates slices based on the functionalities requested by either a slice tenant, a slice user or a service provider, based on templates and SLAs. The slice provider also monitors resource consumption to bill the slice tenant. Slice users may use several slices simultaneously, possibly operated by different tenants. But this slice user may also not be a separate actor than the slice tenant.

Relatedly, Oladejo et al. [66] propose a three-stage auction game where network resources are traded at different levels. For instance, multiple providers of slices bid to acquire virtual resources from multiple MVNOs or tenants, in order to match the desired connectivity demands of slice users. In turn, the MVNOs bid to acquire resources from multiple infrastructure providers, in order to meet the demands of the slice providers.

The table below presents several business model options for the offering of network slicing services in the different deployment scenarios. These stem from an initial exploration of feasible options for teleoperation. However, this needs to be explored further and validated for the specific targeted deployment areas of the project. For instance, a question in the context of 5G-Blueprint is whether slice brokers are needed: for one, they add an additional layer of complexity which is potentially not optimal when deploying a critical URLLC connectivity service. Second, MNOs may prefer to be in direct control of the E2E provision.

Scenario	Customer(s)	Provider(s)	Pricing strategy	Party investing in the required assets	Distinctive added value	Input required from other parties
Scenario 1	1) End customer, directly 2) B2B2B: via MNOs as slice tenants that combine slices and sell connectivity 3) Site owner or group of customers in the same area (e.g., freight or TO SPs for trucks)	1) MNO, creating a slice within its own network 2) Neutral host infrastructure providers (maybe allocated via a slice broker) 3) MNO could create a slice to act as the private network of a local customer	1&3) Usage-based + premium for QoS level; 2) MNO bids for resources via auction; end customer pays per use	1) MNO or MNO jointly with customer 2) Infrastructure provider (neutral host)	1) MNO remains in control, less complexity, which seems favorable for URLLC 2) For MNOs, lower CAPEX to switch to 5G (but likely also a lower profit margin due to higher OPEX)	National or local 5G spectrum license from public authority
Scenario 2	Same as above, except for the private network and local spectrum options.					
Scenario 3	Same as above, except only relevant for MNOs that cover both sides of the border with their own services.					

Table 8. Business model options, per scenario, for the offering of network slicing

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5.1.4 Network infrastructure deployment

5G networks may, to some extent, be built on top of the existing 4G (passive) infrastructure. But as discussed before, providing higher QoS, including ultra-low latency, will likely require new infrastructure deployments along roads or within logistics sites.

About private vs public networks. In Europe, most of the expected incremental benefits from 5G will come from 'vertical' applications. A common feature across industrial use cases is the aspect of private networks for local deployments. Private networks are thus expected to become more relevant with 5G due to the expected emergence of use cases with stringent requirements that previous generations' networks cannot address. While meeting QoS requirements in terms of latency, throughput, coverage, etc. will largely rely on virtual solutions like slicing, it may also require the deployment of dedicated infrastructure at a customer's site.

Some MNOs, as well as network equipment and solutions providers, offer entirely private 5G networks. However, other MNOs, such as the ones in 5G-Blueprint, may prefer to upgrade their nationwide public networks to provide the additional QoS via so-called coverage on-demand in dedicated locations.

However, this coverage on-demand can resemble a private network in practice, as it can mean working with dedicated network slices and adapting the radio access network to the customer's needs, but with the core network remaining the MNO's public one. In practice, it can mean deploying base stations in the premises of a factory or in a port area, in order to guarantee latency and reliability according to the site owner's needs. Such coverage on-demand can yield the same user experience as a private network, or even higher, since a customized network can be inferior to one that relies on a public core, depending on its characteristics, and hence, cost. In addition, issuing slices on top of a generic MNO's network can also offer some of the benefits of a private network, albeit a virtual one.

For the mentioned reasons, a future where private networks are deployed on each specific local area is not considered very realistic, especially in Belgium and the Netherlands. As implied by this, this will vary per region, depending on influencing factors such as the level of coverage by public networks; in both Belgium as well as the Netherlands, this level is very high compared to other European countries, with 4G nationwide networks covering over 95% of the territory with their existing infrastructure. Therefore, site owners in other countries may follow a different approach when choosing what type of network to deploy.

Nevertheless, current examples of companies that have reported using a 5G private network in the project's region include Arcelor Mittal, the Brussels Airport and the Port of Antwerp-Bruges. These represent large sites with huge volumes of operations in their respective sectors.

A private network deployment can rely on the spectrum (licenses) owned by an MNO or, alternatively, on radio spectrum owned by the site owner itself. These private networks can be operated by network operators, network equipment providers, or by industrial players themselves. In the latter case, private networks make sense for large sites such as large manufacturing plants or ports.

About co-investment for network deployments. There are also different possible options regarding the parties who will be responsible for the upfront investments in upgrading and densifying public networks as well as deploying private networks. One specific case relates to the offering of coverage on-demand, which is considered separately in the next paragraph. In general, we identified the following options as being the most realistic ones for teleoperation use cases. In every option, the identified actors either invest using internal funds or by arranging the raising of external capital themselves.

- An MNO entirely finances the deployment of the infrastructure.
- An MNO and local stakeholders co-invest in it.

- Multiple MNOs deploy the infrastructure, with multilateral network sharing agreements.
- A non-operator 'neutral host' invests, providing infrastructure access as a service to M(V)NOs, who act as tenants. This is more likely for infrastructure alongside roads or canals than within a private site.
- Local stakeholders invest in their own private 5G network, possibly relying on a third-party to integrate equipment from multiple vendors (see the Open RAN topic below).

About deploying coverage on-demand. There are different, non-mutually exclusive options regarding who would pay for deploying coverage on-demand, which may entail a substantial investment. It could be financed ex-ante, either by the client, the MNO, or by a co-investment between the two. It could also be paid ex-post with more expensive SIM cards, charging more for a connectivity subscription.

This will depend on the available business opportunities of each deployment area. In an area where the MNO does not envision having any other customers that would use the connectivity in parallel, the investment costs would likely be translated into the ex-ante project price. In contrast, if there are additional users (or use cases) that could benefit from an enhanced service and coverage, the pricing strategy would adapt to share the costs across the potential customers. And instead of charging an upfront fee, the MNO may even take care of the initial investment in the cell sites, equipment, and fiber optics. It was mentioned that these potential parallel market segments are more available in industrial areas than in highways. Highways are more limited in terms of alternative commercial opportunities, except covering user devices of people riding in cars.

It will likely be the site owner of a port or other industrial zone that contacts the MNO to request an upgrade to their connectivity to enable TO in their area. Subsequently, the MNO would consider what sort of network infrastructure is already available in the site, and assess what dedicated elements (e.g., what radio equipment) need to be deployed on top of it to guarantee the desired capacity. The MNO would start hunting for additional use cases that could be served by the same connectivity, and investigate if there is enough potential for additional sales in the area, since an isolated use case like TO will be unlikely to provide enough return from the connectivity service alone. Then the MNO would reach agreements with the site owner on rent prices for real estate on which to build base stations, and discuss the preferred locations for the cell sites.

When deploying coverage on-demand for a specific area, an MNO may also include international roaming in the offered package, even though sorting out roaming agreements is a considerable challenge, as discussed above.

About network sharing. As mentioned in the literature review of previous projects, network sharing is a commonly considered approach for MNOs to roll out network infrastructure without having to duplicate efforts. MNOs may share passive or active infrastructure elements, as well as spectrum and core networks. Passive elements include, among others, backhaul, masts, and air conditioning, while active elements include antennas and other RAN elements. An MNO may enter into a long-term agreement to lease its own infrastructure to a competitor, but operators may also agree to invest together in the deployment of such network elements, especially in the case of active sharing.

The benefits of sharing infrastructure include reduced energy consumption and cost savings for both CAPEX and OPEX. By lowering the combined deployment costs between MNOs, sharing can incentivize investment and in turn can lead to a quicker deployment, especially in less populated areas where providing coverage is more costly [42].

However, network sharing may also hamper competition, especially in the case of active sharing and the sharing of core networks. Therefore, sharing agreements are subject to approval by national and EU authorities, with tolerance levels varying across NRAs [42]. Concerns derived from higher market power include the following: (i) that sharing deals are unfair to MNOs outside the deal, (ii) that innovation incentives are reduced, and that (iii) incentives to invest further improve coverage are also reduced. Besides competition concerns, infrastructure sharing may not be possible due to insufficient space on masts (to deploy RAN elements from different operators) and stringent electromagnetic radiation limits.

From a business perspective, an additional challenge of network sharing is related to the distribution of liability: an MNO that is leasing infrastructure from another could be held responsible in case of infrastructure breakdown [43]. Therefore, this risk will likely be included in the price of the leasing.

Since the network QoS needed for teleoperation are expected to require the deployment of 5G infrastructure to densify current access networks with base stations and/or small cells, as well as installing fiber backhaul capacity in certain locations, entering into arrangements to spread the costs among operators will be an important aspect for the business case of teleoperation.

In the context of 5G-Blueprint, the MNOs involved noted that passive (tower) sharing is always considered when thinking about prospective deployments for 5G. Whenever possible, tower sharing can be expected to be used as a way to save costs. While more active RAN sharing also promises cost savings, and thus will also be evaluated with new deployments, it carries a potential drawback regarding implementing slicing at the RAN level: resource allocation among different slices that would compete for the same radio resources would become more challenging. Lastly, more specific active RAN sharing architectures for cross-border network sharing (MOCN, GWCN and MORAN) have so far not been considered.

About neutral hosts. Relatedly, a way of sharing networks is via the business model of a neutral host. Neutral hosts are entities that deploy and/or operate infrastructure. Neutral hosts own network infrastructure and act as asset and capacity as a service providers, leasing wholesale access to multiple M(V)NOs tenants, who provide the connectivity service on top of it. Examples of neutral hosts are independently-managed companies that are spinoffs from MNOs (e.g., Vodafone's TowerCo or CK Hutchison Networks) and specialized real estate companies that aim at building large portfolios of cell towers (e.g., Cellnex or American Tower). The past few years have shown a clear trend in the European tower industry towards wireless operators carving out their infrastructure asset portfolios and transferring numerous sites to neutral hosts like Cellnex.

About Open RAN. Open RAN refers to the concept of opening interfaces for certain elements (SW and equipment) within the RAN, more specifically focusing on the functional split between radio units and distributed units. If standardized, this would allow the building of 5G (private) networks by purchasing interoperable radio equipment components from different vendors. Today, traditional vendors sell network equipment together with maintenance contracts as proprietary, integrated 'closed' systems. With open interfaces, the integration of the discrete components (for example, the baseband, software, radio, etc.) could be done by either a PNO or MNO, a traditional or new vendor, or a third party (e.g., an IT company) [67].

Dinges et al. [67] discuss the potential benefits and downsides of Open RAN. Open RAN is expected to increase competition and drive prices of radio equipment down, while higher competition from the entrance of new vendors can in turn increase product innovation in the longer term. Open RAN is thus an opportunity to reduce CAPEX when deploying 5G networks. However, it also entails uncertainty regarding supply chain resilience and total costs of deployment. The costs of integrating multi-vendor RAN components could increase TCO in certain scenarios. In addition, the current level of maturity of the underlying technology and standards would make it challenging for Open RAN deployments to meet stringent performance requirements–in terms of latency, throughput, reliability, power consumption, etc.–in the short term.

5.2 Business model options for key transport roles

The transport layer of the identified value network included the following roles:

- The operation of logistics centers
- The provision of logistics/freight services

- The provision of several information services, including ETA sharing, container ID recognition, and other travel, safety and optimization services
- Crew management for ships and barges
- Loading and unloading processes
- Manual driving and navigation

This section goes into more detail into some of these roles within the transport layer of the overall value network. Besides (un)loading, the transport journey at the loading and unloading locations involves different activities, namely (i) registering the vehicle, (ii) accompanying and docking the vehicle, (iii) inspecting the cargo, and (iv) supervising the (un)loading process. In the case of TO of driverless vehicles, these activities are no longer performed by the driver and must be taken over by another party. If these activities are taken over by the shipper (as a client of the transport operator), they can be contractually arranged directly in the transport order. Another option is that the logistics site where loading or unloading takes place performs these tasks. Alternatively, the supervision and inspection tasks may be performed by a neutral third party, similar to a cargo surveyor in maritime bulk shipments of grain. In that case, an additional party becomes involved in the supply chain.

The main identified stakeholders in the transportation sector include shippers, logistics service providers, transport operators and other information service providers.

- Shippers are the owners of the goods that need to be transported. They will contract one or more logistics service providers to organize the logistics activities required for the entire fulfilment process, including transportation. A shipper hiring the transport of its goods will a priori not be concerned about whether this is realized with or without teleoperation. However, shippers are concerned with the opportunities for cost reductions that the use of TO can bring to the logistics service providers that are contracted by the shipper. Additionally, if TO brings a shift in tasks and responsibilities that requires the involvement of the logistics facilities of the shipper's customers, the shipper may be needed to initiate and negotiate these conditions in the Incoterms or with other arrangements.
- Forwarders/logistics service providers. These actors are responsible for designing and organizing logistics solutions for shippers. They may operate a logistics facility, storing and managing inventories on behalf of the shipper, and receiving and dispatching goods from the shipper's suppliers and customers, respectively. Logistics service providers that are also responsible for organizing inbound or outbound transport may drive the introduction of TO because they are pressured by shippers to reduce the costs of operation, although transport is outsourced to the role of a transport operator. On the other hand, logistics service providers that only operate facilities may experience no benefits from teleoperated transport services and would only be confronted with a request to perform those additional activities that are currently part of a driver's job.
- Transport operators take responsibility for the transport of physical goods with employed drivers and a fleet of owned or leased vehicles. They take care of the transport activities directly on behalf of a shipper or indirectly for a logistics service provider with outsourced transport. In many cases, a transport operator will not be able to apply TO without the cooperation of the shipper and other logistics stakeholders because a number of traditional driver tasks must be completed or supported at loading and unloading locations of shippers or logistics service providers.
- In addition, other service providers are present: these provide management systems for planning and monitoring of logistics activities (which may include container ID recognition), or route guidance and optimization services (e.g., booking slots for traffic lights or parking space at terminals based on ETA). These information services rely on the exchange of information between different actors in the value network, as explained in section in 4.3.2.

Sections 5.2.1-5.2.4 start considering the automated docking of articulated vehicles, such as trucks with trailers, in warehouses and distribution centers. This is one of the use cases in 5G-Blueprint. In automated docking, which can be considered an extension or complement to the (un)loading process, the remote operator supervises the operation and takes control if necessary. As mentioned in section 2.1.4, automated docking can lead to efficiency and safety increases.

Next, we consider some of the enabling functions (EFs) that are tested in the 5G-Blueprint project. EFs aim to increase the safety and efficiency of teleoperated road transport. They either increase safety from enhanced situational awareness or offer more predictable and optimized trips. All EFs are ultimately merged to offer concise advice through the HMI in the TO Center. They can thus be understood as information services that are provided to the TO service provider, but that can be used and sold for other purposes as well. The data for these EFs may come from different sources such as vehicle telemetry and sensor data or roadside infrastructure (see section 4.3.2). While 5G-Blueprint covers eight EFs[6], we will focus on the following two:

- Vulnerable road user (VRU) interaction. This EF provides warnings about the presence of VRUs in the anticipated path of the teleoperated vehicle. Therefore, it helps overcome one of the drawbacks of TO compared to manual operation or driving, namely the loss of sensory perception and a reduced interaction with other road users (e.g., eye contact with other drivers).
- Container ID recognition, which provides a message with the ID of the relevant container. It may be used, for instance, to detect the entry of containers in ports or to detect containers with dangerous goods.

Finally, this section also covers the role of the provision of the logistics service, focusing on road freight. More specifically, it discusses the potential impact of TO on the current pricing strategies for logistics services.

5.2.1 Automated docking

The value of an automated docking system for a logistics service provider or warehouse operator is increased productivity (docking faster), less damage to vehicles and fewer potential injuries. The value of automated docking as a service is that low to no investment is required from the logistics service provider. An automated docking system consists of local infrastructure (cameras, connectivity), an in-car system (connectivity, control system and actuators in the vehicle), 5G communication services, and software for monitoring and controlling the operation from a TO center. An automated docking system is used by logistics service providers operating fleets of vehicles. The logistics service provider is dependent on the availability of the local infrastructure to operate the automated docking system.

We can distinguish two business model options in terms of which parties provide the service and invest in the main required assets:

- **Automated docking as a system**: a logistics service provider and/or a shipper buys the technical components from systems suppliers and contracts the 5G connectivity service from an MNO, and also installs the system components on the facilities and in the trucks they operate. They will invest in the in-car systems and purchase the communication services as the use and benefits of the automated docking system are primarily linked to the vehicle. The shipper and logistics provider will make mutual arrangements in their contract about the investment in the local infrastructure. If a logistics SP has to invest in the local facilities, he will aim to recover its investment within the duration of the contract period. The preference for buying and maintaining the system itself or using it as a service depends on the preferences of the company (with regard to the capital and technical knowledge available in the company itself).

[6] For a summary of the different EFs, see https://www.5gblueprint.eu/about/enabling-functions/

- **Automated docking as a service**: a third-party service provider invests in the local infrastructure and contracts the 5G communication services from an MNO or other connectivity service provider. This service provider will thus be liable for the damage caused by the incorrect functioning of connectivity. Logistics service providers take a subscription with this third-party SP in which a fee is paid for each docking operation that is made using the system. The use of a service is attractive to logistics service providers who load and unload at a large number of different locations but do not have a contractual relationship with these locations, since they would not need to invest in the local infrastructure. Automated docking as a service is also attractive for logistics centers with many visiting trucks. They also do not have to invest in local infrastructure, but they do have to cooperate in setting up such a system. A main advantage for a logistics center is that productivity of docking will increase without the need to invest in the system. But they must offer the facilities for placing the equipment and supplying energy. This will require a contract between the docking service provider and the logistics center. In this setting, transport companies would invest in the in-vehicle systems themselves.
    - Example: similar to Unit Load Device tracking services, where airports do not have to invest in the system, but give a third party an incentive to roll out the service at multiple airports, logistics service providers can use automated docking at the multiple locations they visit.

We can also identify two options regarding the pricing strategy used:

- Pricing of automated docking services to transport companies. The pricing would be based on the number of automated docking movements, assuming that a successful docking is the performance that a transport company wants to purchase.
- Pricing of automated docking services to warehouse operators. A service provider benefits from quickly rolling out locations where the service is available, so the pricing strategy would involve sharing the derived revenue with the owner of a warehouse.

Lastly, we review in a bit more detail which parties would invest in each of the main required assets:

- Investment in local infrastructure: the investment in local infrastructure is dependent on the logistics operation. A first option is that it is realized by the logistics service provider or by the shipper that is operating the warehouse. In that case, it would be part of their internal business case. Another option is that the investment is made by an automated docking service provider as part of its business model.
- Investment in in-vehicle systems: the in-car equipment will be purchased by the logistics service provider owning the trucks.
- Investment in software for the TO center: the investment in software in a remote control station will be made by the provider/user of the control station.
- Investment in 5G network infrastructure: A MNO network operator that invests in the 5G network infrastructure will want to hedge the risk on this investment with a long-term contract with a docking service provider or the warehouse operator.
- In any case, collaboration from warehouse operators will be required to install the local infrastructure and get access to energy and systems for maintenance.

5.2.2 Container ID recognition

While container ID recognition is a technology that is currently available, the innovation in 5G is that it can be operated as a service with the data processing taking place centrally. 5G can thus be used to make it more operationally efficient. For connectivity service providers, container ID recognition could be an additional revenue source in the port area.

The distinctive value of a container ID recognition service based on 5G compared to a local system is the expected higher availability of service of the systems. Local systems with less components are less susceptible to failures. Any software malfunctions can be solved faster in a central system than in a decentralized system. Central or decentralized does not make much difference for software updates.

A container ID recognition system based on 5G can be used by terminal operators that need to identify the containers that are entering or leaving their yards at the landside as well as the sea or inland shipping side. The ID recognition system can be installed at the gate and on gantry cranes for loading and discharge of seagoing and inland vessels. The systems are installed at semi-fixed locations.

About who would be the provider of container ID recognition as a service. A container ID recognition system consists of (i) locally installed cameras and sensors that capture an image of the area in which an identification number is printed on a container, (ii) a 5G connectivity service to transmit the images, and (iii) a central processing unit that receives the image and aims to detect the container number. The centralized processing of the images indicates that container ID recognition is offered as a service by a service provider. The service provider may adopt two propositions:

- **Full service option** in which the service provider invests in the installed cameras and sensors, contracts the 5G connectivity, and processes each image for a service fee.
- **Limited service option** in which the systems and connectivity are purchased and installed by the user (i.e., a terminal operator) based on the specifications of the service provider. The service provider analyzes images for a service fee.

Pricing strategy. The main cost drivers are (i) the installed equipment, energy and maintenance, (ii) 5G-communication costs, (iii) software development, and (iv) the processing of images (computational services). If the 5G communication costs per image are relatively stable, the pricing model consists of a fixed monthly fee to cover the costs of equipment and software together with a variable fee for each container successfully identified. Since each user requires its own equipment and service, there are no network effects. There may be economies of scale in software development and central processing; in that case, the service provider's strategy would be to increase volume and gain market share. In that case, offering the service at marginal costs or at variable costs could be an effective pricing strategy.

Lastly, we review which parties would invest in each of the main required assets for offering container ID recognition as a service:

- **Investment in local infrastructure:** The investment in local infrastructure (cameras, control unit and 5G communication unit) can be performed by the terminal (the service user) or the service provider. Which option is selected is dependent on the outsourcing strategy and IT capabilities of the terminal, as well as on the service capabilities of the SP. For distant customers and areas, the service provider might request the terminal to be responsible for the infrastructure and connectivity.
- **Investment in central processing:** The service provider invests in the central processing unit that is used to analyze the images and identify the containers.
- **Investment in 5G network infrastructure**: Another party will need to invest in the 5G infrastructure within the terminal area. This will likely be an MNO, possibly co-investing with other MNOs or with a site owner (see section 5.1.4 for a list of co-investment strategies).

5.2.3 Warnings of approaching vulnerable road users

A 5G based warning system of approaching VRUs relies on a 5G network, cloud processing, and software in vehicles and control rooms. It is important that the software is integrated and not offered as a stand-alone app. The service can create value for the following two main types of stakeholders:

- **Transport operators**, since it would result in (i) fewer accidents, (ii) fewer premiums for damage and accidents, and (iii) lower driver loss due to accidents. Vehicles could have a good overview of vulnerable road users that may cross their path. The warning system would process all the movement data of road users sending signals about their position, speed and heading.
- **Vulnerable road users**, because it would result in (i) higher safety perception on the road, and (ii) lower insurance premiums since insurance companies have less costs for claims handling and processing. VRUs that want to be sure they are detected by vehicles may send a signal making available their position, speed and heading.

These two types of stakeholders can also be the customers, and would represent two distinct market segments that the information service provider could target.

The warning system for approaching VRUs consists of (i) an app that VRUs can download on their mobile phones, (ii) 5G connectivity for communication of data from the VRU to (iii) a central processing collecting and analyzing all the data, (iv) 5G connectivity to the vehicle or TO center, and (v) software in the vehicle or TO center to inform the (remote) operator. It is assumed that processing of all the data will take place centrally.

An important condition for effectiveness in providing security is that all data of VRUs is available to all service providers that offer these services. This would avoid that a user of the service is not safeguarded from being hit by a vehicle just because it is affiliated with another service provider. An option would be obliging market parties to share this data, while ensuring that the privacy of the users is safeguarded (e.g., by mandating that the data is anonymized first). However, if operators are obliged to make the collected data available to competitors, this will lower the incentive for the operators to become active in connecting vulnerable road users themselves. It may therefore be desirable to regulate that market, whereby the parties that have fewer connections with road users must compensate the others.

About pricing strategies. It is essential for providers that they have a large reach among vulnerable road users. A large customer base (and the derived network effects) would allow them to offer the app for free to pedestrians and cyclists. If the 5G data consumption in the user's phone is limited, the user will want to pay for the communication costs via a service bundle. In that case, if the costs of the warning service increase, the provider will have to bear all or part of the costs. The SP can offer transport companies a subscription service based on the number of vehicles. If the communication costs for the VRU data are on the account of the service provider, the rate can also be based on the number VRUs on the routes driven by vehicles. By analyzing on-board computer data, a service provider can estimate the busiest points and the expected data consumption in advance, but can also monitor this during the use of the service.

5.2.4 Logistics services

To understand with which business models TO can be introduced in the logistics sector, it is important to first determine how the technology can be integrated into the business model of logistics services. This section discusses the potential impact of TO on the current pricing strategies for logistics services.

Currently, the price of logistics services is normally determined based on the distance and expected time of the trip (e.g., to calculate vehicle, driver and fuel costs). An estimate is also made for loading and unloading times and any waiting and unproductive time in between transport orders. The hourly rate is dependent on the time of day, with possible additional charges for evening and overnight transports. In general, the fixed fees cover the hours spent on loading, unloading, waiting and unproductive time and the variable ones depend on the hours spent in the route, being primarily determined by distance and route type. Waiting times are generally included in the price; for example, waiting times in container transport are only paid after 2 hours of waiting and only if the client is informed at that time that extra waiting time will arise. Therefore, the financial benefits of TO in terms of uptime and reduced idle and waiting times will accrue to the transport operator, all else equal.

However, if the transport operator needs collaboration to be able to implement these benefits, it will probably have to share some of these benefits with the shipper or other facilities owner. One process that can support logistics service providers that move to remote (driverless) operation is the digitization of transport documents and the ID recognition of trucks. To facilitate the registration and administrative processing of a visit to a logistics center, the digitization of the entire process of interaction between the truck or the back office of the teleoperator is essential. The automatic pre-notification of a visit and the load, the registration at the gate, the assignment of a dock/loading, the registration of the unloaded or loaded goods and the drawing up and exchange of the consignment note can prevent delays in the entire process and reduce the need for standby back office support. Hereby the transport operator needs the cooperation of the shipper and the consignee.

Usually, shippers and consignees also outsource the loading and unloading to logistics service providers. With TO, the transport company may need support to physically load or unload a truck or trailer, or at least to inspect the cargo, when the teleoperated vehicle arrives at a logistics center or at the warehouse of the consignee. Even in relatively simple cases like in container terminals, a person might still be needed to overview the loading process and to fix the twist locks. And since it is the shipper that can negotiate the conditions for delivery at these locations, the logistics service provider will want to be reimbursed by the shipper if it has to execute additional activities.

Would TO affect the current pricing models for logistics services? With TO, the investments on vehicle equipment would increase, and therefore so would the annual depreciation costs. And 5G communication costs would be a new cost component. However, the cost structure for remote operation will probably not change significantly compared to the current prices of logistics services based on manual driving, even though the expected (un)loading and unproductive times may decrease. While there is a shift in costs for the (un)loading and inspection processes, a TO service provider can in principle use the same basis: a fee for the length of time a teleoperator is engaged with the vehicles of that specific customer, including wage costs (depending on the time of day) and vehicle depreciation costs for the journey. This could be priced on a journey basis as a complete package, together with communication costs[7].

5.3 Business model options for key teleoperation roles

As described in section 4.2, there are several roles and responsibilities in the ‘Teleoperation’ value chain. The teleoperation service will not be offered in isolation. First, it will rely on the input of multiple mobility data service providers, received via the dashboard, as shown in section 4.3.2. Second, the role of TO fleet management becomes especially important to interact with other stakeholders along the goods transport journey. For instance, when a truck arrives at its destination, professionals at a local site may help with opening the truck’s doors, checking the cargo for damages, unloading, etc. As an example for water transport, TO service providers need to know from port managers where the vessel has to be docked, and captains on shore will rely on traffic controllers to check for potential conflicts with nearby vessels.

Other roles are related to other types of elements required to enable TO in practice. This includes the following:

- Hardware: for instance, the devices installed in vehicles to collect and transmit data to the control center via 5G, or to sense the vehicle’s environment (e.g., cameras, lidars or sound detection systems).
- AI-based software and its updates. This includes software installed in vehicle’s systems

[7] The potential pricing strategies for the TO service provision are discussed in section 5.3.1.

to support autonomous tasks or CACC-based platooning, or at the remote operator station to support the HMI or manage and assign trip requests and book traffic-light time slots at intersections.

These required hardware and software elements can be integrated in vessels or trucks, either built during the manufacturing process or retrofitted by system integrators based on third-party systems.

Central to the TO service is the person that will perform the action from a remote control center. And consequently, the responsibility of providing training for these remote captains or drivers. The company that employs or contracts the remote driver or captain will be the business role that is technically capable and responsible to provide the TO service. Therefore, it is the most relevant one to focus on in the business model discussion. We also focus on a second key role, the deployment and management of the TO control center, from which trucks or vessels are monitored and/or operated from distance. Besides its key importance, the TO central is a relevant one to consider because of the potentially challenging infrastructure investments to deploy it, as well as the fact that the business models behind it remain unclear.

Consequently, this section provides a discussion of the main challenges and relevant business model aspects for the roles of teleoperation service provision and control center management. We can identify the following unknowns:

- Regarding the TO service provision role:
    - Who will play the role of service provider?
    - Who will be the direct customer of the service in each scenario?
    - What are the possible value propositions of TO service offerings?
    - What will be the role of OEMs in allowing TO in their vehicles?
- Regarding the TO Center role:
    - Which party would own it and/or invest to deploy it?
    - Which party would manage it?
    - Which party would employ the remote operators?
    - Where would it have to be located?

This discussion is relevant for all 5G-Blueprint’s use cases, from supervision and operation of barges, cranes and trucks to the remote supervision of automated docking of articulated vehicles in warehouses and distribution centers.

5.3.1 Teleoperation service provision

A teleoperation service can take shape in different ways. It can involve the simultaneous monitoring and assistance of several trucks or vessels, and more ambitiously, direct control of a vehicle (i.e., full remote driving), on which we focus in this section. The remote operator may take over the control of a vehicle in case of emergency (e.g., if the autonomous system fails), in complex driving situations (e.g., when the vehicle joins or leaves a platoon), when a remote operator hands over control to another one in the same TO center (e.g., during a shift change) or in another center (e.g., when the vehicle crosses a border or coverage area).

5.3.1.1 Value propositions of TO offerings

From the findings of the market assessment, we can identify the following advertised value propositions of current TO offerings:

- Some service providers aim at targeting all use cases, including goods and passenger transport (e.g., Ottopia and Phantom Auto), while others focus on logistics (e.g., Einride and Fernride).

- Some offer an E2E solution including a SIM card (with a 5G connectivity subscription), employee training, (e.g., Phantom Auto), the retrofitting of hardware (Roboauto), or even manufacture their own vehicle (Einride). Others offer multiple deployment options, including software only (MWLC, DriveU.auto), TO as a service (Designated Driver) or TO on-demand with usage-based pricing (Fernride). While offering the TO service alone would require the customer to take care of other aspects, the TO SP would avoid incurring the financial risks on the investments in, for instance, developing software or owning vehicles.
- Some offer to install the TO station in a TO center, while others like Seafar manage and operate a full TO center.
- It is also interesting to note that some AV software system developers claim to offer TO as support to their fleet of AVs, but do not offer TO as a service.

This shows that different value propositions are possible, depending on how many ancillary services are included in the TO service 'package'. For road freight, the case that would most resemble the status quo would be offering the TO service to transport companies that operate their own fleets of trucks and employ their own teleoperators. In such a case, the transport company would contract TO to optimize their operations by increasing the uptime of their fleet and reducing the idle times of their drivers. TO would likely be used only for those trips in which TO is expected to enhance efficiency. The transport operator would have the choice to also deploy its own control room and retrain its own teleoperators. However, this would only be feasible for transport operators that can operate at sufficient scale to allow teleoperators to change from vehicle to vehicle efficiently, i.e. without introducing substantial idle time. Alternatively, the TO center may be leased, in order to avoid assuming the economic risks on the value of the assets.

Specifically for barge transport, Seafar currently offers three types of services relying on remote operation and monitoring by a captain from their 'Shore Control Center'. All three can extend navigation time and optimize crew time efficiency on board, but to a different extent. Operational efficiency arises from increased uptime, and in turn from the flexibility to operate vessels beyond the times when the onboard crew is available, and from avoiding idle times are reduced. In addition, automation increases scalability by allowing a single operator to simultaneously monitor multiple vessels. From least to most ambitious, and from lower to higher automation, these three service levels are the following:

- Crew supported navigation. Here, a captain remains on board but a remote one can take over certain functions during rest hours.
- Crew reduced navigation, for highly autonomous vessels. Here, part of the crew activities are done remotely, which allows to reduce the amount of crew needed on board of the vessel.
- Unmanned navigation. Offered for automated barges on fixed routes, this offers the highest increase in cost-efficiency. These vessels are entirely monitored from the TO center, with remote operation always ready to offer support.

About the inclusion of the SIM card in the TO service offer as well, the project partners involved in offering remote driving explained how they currently do it:

- MWLC sells vehicles and software both with and without SIM cards. In specific cases, the clients themselves purchase the SIM cards, which makes sense for clients located in other countries. When providing the technology, MWLC explains to their customers what kind of connectivity requirements are needed.
- Seafar. Similarly, it depends on the customer type. For customers who own one or two ships, Seafar can include the SIM card. But owners of large fleets would likely want to take care of contracting the connectivity service themselves; it may be cheaper for them, since they would probably also put it to other uses. In that case, Seafar's role would be to

provide the TO service on top of the connectivity.

- Roboauto, in contrast, offers a full package. They pay for the connectivity, and then pass this cost to their customers.

A last aspect affecting the value of the TO service refers to waiting times. The ratio between the amount trucks per TO is the consequence of the service level agreement between the TO service provider and a transport company. The transport company may be able to negotiate the preferred waiting time. Being able to wait a bit longer may result in a cheaper TO service since fewer remote drivers are needed per vehicle. On the other hand, the transport company may have to pay for the buffering service in the meantime. This choice will also depend on how time sensitive the cargo is.

About who will be the customer of the TO service. First, in the case of inter-terminal/warehouse transport by road or water (i.e., in the context of scenario 1), the customer of TO transport services may be a shipper or a terminal that delivers cargo to another terminal or to a warehouse. Second, in the case of the teleoperation of other elements, the direct customer may be a port manager or site owner (e.g., for cranes or reach stackers) or a warehouse site owner (e.g., for TO of forklifts). Third, in the case of terminal-to-hub transports, the customer may be a logistics service provider or transport operator who has to collect and deliver containers at terminals and uses a decoupling point to optimize transports between hinterland and terminals. Currently, the transport operator usually carries out these transports itself. Lastly, in deployment scenarios covering long stretches of open roads, customers may be automakers or other AV fleet owners.

5.3.1.2 Who will play the role of TO service provider?

An important question is which party would become the TO operator. The following discussion enhanced the initial allocation, which hypothesized that this TO operator could be either an OEM, a transport company, or a new kind of specialized TO service provider. The emergence of specialized SPs can be expected and considered a realistic option in any of the deployment scenarios; as reviewed in the market assessment (see section 3), many young companies are currently offering or advertising TO services, although still with limited scopes or functionalities.

Vehicle manufacturers may enter the teleoperation service provision market, as in the use case of mining, where manufacturers like Volvo offer their own solutions. Still, mining is a much less complex environment, not requiring so much automation. As in the case of self-driving, some OEMs may aim at offering an E2E solution to teleoperation customers. But they would have to develop the capabilities or outsource the technology development task. As the value of software-based services increases relative to the vehicle hardware, competition in the automotive industry also increases, which could motivate OEMs to offer TO services themselves. Such competition brings the threat of losing bargaining power in the automotive value chain, but brings opportunities for the OEM to expand revenues with new services as well as. OEMs could thus provide TO and other after-sales services for their branded vehicles.

Another possible TO provider is a transport and logistics company, who would otherwise likely be the customer of the service. These companies have truck drivers on their payroll, and could offer them training to employ them, in the future, in a control station of their own. Similarly, shipping companies with many vessels would like to have full control of handling their vessels, so they may prefer to perform the teleoperation task themselves. They could also provide it as a service to smaller fleet owners that do not have the available capital to build their own control center or cannot afford investing in the technology.

A company that develops its own TO systems, and relies on a third party to integrate them into a vehicle, can also be the TO service provider. Roboauto, for instance, focuses on offering end-to-end TO solutions, relying on the retrofitting of vehicles to enable teleoperation. A current system aggregator could potentially become a TO service provider as well. As a system aggregator, V-TRON integrates the TO technology into vehicles, and aggregates OEM hardware into remote operator systems, such as the one from Roboauto in 5G-Blueprint.

It will also depend on whether TO is legally required as a support to autonomous driving. The entity that delivers a self-driving service may be required, in the future, to ensure there is a teleoperation process supervising the operations of the AVs and taking control when necessary. For instance, in order to assign licenses to operate AVs in public roads. In that case, AV software developers may prefer to develop their own teleoperation systems. Additionally, such companies may also see TO as a way to train and improve their autonomous SW systems and thus enable autonomous driving in the longer-term.

However, it is unclear whether these parties would be interested in setting up teleoperation as a service in environments of limited size, where the business case of TO remains unproven and other stakeholders are not yet officially on board. This would be seen as a more significant challenge if a TO center needs to be specific built because there is not an existing one that can cover the area. In such a case, we could face a chicken and egg problem in starting the deployment of TO.

In Scenario 1, i.e. in an environment that is limited to a particular port or logistics center, and therefore has a smaller scale, the TO service provider would probably be either (i) a specialized, generic TO SP that provides many locations as a service, (ii) a local logistics company investing in having its own TO center, or (iii) a joint venture of local transport and logistics companies (possibly in combination with the local port authority). The third option would be motivated by the objective to reach a larger scale and hence more cost-efficient operation.

Regarding inland navigation, a TO service provider like Seafar took the risk to start the service without other elements being in place, offering an E2E solution. They were led by the conviction that the problem of the shortage of qualified personnel would require novel processes like supervision from a remote location, together with the belief that full autonomy was still far-fetched even in the next decade, and that remote supervision and control will be required to allow (semi)autonomous shipping. In addition, they were convinced of the need for remote operation for using resources more efficiently, and of the long-term business opportunity of TO in the specific area covering the Belgian and Dutch coasts and ports; including the ports of Antwerp, Zeebrugge, North Sea Port, Rotterdam, and Amsterdam, this area represents a huge amount of operations. In addition, barges offer more flexibility: TO can reduce the crew on board of the ships, while in trucks removing the driver on board is a dichotomous problem.

5.3.1.3 The role of OEMs in allowing TO of their vehicles

A question regarding OEMs is whether they would facilitate different service providers to remotely operate their vehicles. OEMs may be reluctant to give third parties access to the vehicles they manufacture, but such access could potentially be given by system integrators that enable the vehicle to be teleoperated after retrofitting TO systems and equipment in it. The goal of system aggregators is to be able to provide after-market kits for any vehicle. But depending on the kind of integration they do, they may need approval from the vehicle manufacturers. And collaboration with OEMs could also lessen the required engineering efforts and potentially enhance the safety of the retrofit system.

OEMs also have a lot of sensitive data they may not want to make public or give to competitors, such as how to access the vehicle’s system. Nevertheless, these data would be directly shared with the specific company that provides the TO service or with the integrator. For instance, if V-TRON would start offering TO as a service today, they would do it first with OEMs whose systems they already know well; afterwards they would need bilateral service agreements with each OEM, implying that they would only be able to do TO with those specific vehicles. Therefore, the described data sharing would be done at the individual SP-OEM level but not across the entire value chain.

OEMs may prefer and opt for a business model in which they are the only ones that expose their vehicles instead of having their vehicles exposed with third party equipment in order to make them 'teleoperatable' by an external service provider. As per this approach, the TO SP would become a tier 1 provider of the OEM, and the system integrator a Tier 2 that brings the TO system through the TO SP.

From a service provider perspective, there is also the issue of facing liability in case of accidents or damages. To avoid potential liability claims, a TO may be less willing to remotely operate a vehicle with a certain TO kit in certain brands only, for which the system has been proven to work well. Another option would be that the TO SP has agreements with specific OEMs before offering the service.

5.3.1.4 Road permits for TO

Another aspect related to the business model topic is related to the allotment of permissions to deploy TO-based services in open roads. For a transport company to integrate the role of TO service provision, there should be a convincing business case. Authorities could establish a concession model for transport, allocating concessions to operate freight services based on autonomous or remote driving in specific routes, for instance for routinary ones. More than one company could receive a concession to operate on the same routes, and they may share the TO center facilities. It may also be that logistics companies and other parties (e.g., a specialized TO service provider) bid for a concession as a consortium. This approach would imply a change to the current situation, but it would resemble the case of public (passenger) transport. For authorities, this deployment model could provide a more controlled way to introduce TO or AVs on public roads.

5.3.2 TO Center deployment and management

The number of costly remote control centers that need to be set up to cover a specific area would greatly influence the business case. Ideally, a single TO center would provide European-wide coverage to teleoperate all kinds of modes of transport. However, because of latency, the TO center will only be able to perform teleoperation safely within a limited radius. In the deployment scenarios considering a limited area (i.e., a logistics site or short milk runs), this factor will affect whether a TO center needs to be built in each site or a TO service provider is able to cover multiple ones from a single, central location. And it will also affect governance if there need to be handovers between TO centers.

In current operations, Seafar's shore Control Center is able to cover a long trajectory, from Liege to Antwerp. And in the Netherlands, they have done a test between Enkhuizen and Urk, controlling a vessel remotely from their offices in Rotterdam and transferring control to their office in Antwerp while the vessel was in operation in the Ijsselmeer. This suggests that the location of the shore TO center is not important for this use case, and that it could be anywhere, in terms of latency. At least when not facing constraints to scaling up or in terms of vessel traffic blocking 5G signals.

However, this was not considered feasible for road transport, because of latency. Although, at this stage, the consulted experts were not able to estimate how large the coverage of each single center could be.

Another important question relates to the deployment, ownership and management of the TO control center. Seafar, as service provider of TO for inland and maritime shipping, deployed, owns and manages its own TO center. But for road transport, it is unclear who would set up and manage it. The model of the TO SP deploying its own infrastructure brings the risk that deploying TO in practice is dependent on the willingness or capability of a single service to offer it on a sustained basis. This challenge is more relevant in Scenarios 1 and 2, given the chicken-egg problem with 5G investments and the challenge to convince other parties to join the ecosystem. Different options are possible:

- First, a logistics service provider could take the responsibility for setting up the TO center infrastructure. Then a teleoperator service provider would be contracted to install the remote station and offer training to the transport company's employees, providing the service on an exclusive basis. The motivation for the logistics company would be, besides the potential benefits of TO, to have control over the driver and thus over the impact on the delivery time.

- Second, a consortium of (local or regional) logistics companies could also assume this responsibility. Other local or regional stakeholders could also participate in the partnership. This was initially perceived as a less realistic option, although it still needs to be explored in more depth. On a business model level, relevant unknowns would be how to share the costs and how to sort out the complexity of implementing it.
- Alternatively, a central party in a specific area or region could (partially) undertake the investment, offering the TO center premises to different service providers in exchange of fees or a lease. In scenarios 1 and 2, this party could be a port authority or the owner of a large warehouse or manufacturing plant. In scenario 3, this could be done by a road operator. This option is discussed more in depth below.

Next to the work of keeping ports operational and related tasks like customs, port site owners like North Sea Port and the Port of Antwerp-Bruges collaborate with mobile network operators to make sure there are coverage upgrades, for example by convincing MNOs to focus on their port when deciding on which areas to upgrade, giving them access to real estate to build masts, etc. Similarly, conditional to the economic benefits of TO becoming clear, a port site owner could be expected to take up the role of being a catalyst to enable TO within a port area: making sure that new infrastructure is there, that different sides of the market find each other, etc. But taking up the additional responsibility of setting up a teleoperation center would require extra efforts and costs from finding the personnel and expertise. It was considered unrealistic to expect an authority of a large and diverse port like North Sea Port to be the main responsible party to invest in the TO center. This was argued to be up to private companies to arrange, while the port would rather remain independent than intervene in the logistic processes.

In general, however, it would depend on each port and its characteristics in terms of size, traffic, type of cargo handled, location and isolation (i.e., if no one else is able to do it in that specific location). Problems are port area specific. Furthermore, how the ‘transport business’ works for the seaside, canals and road, respectively, can be all different, even within a single port. Regarding the cargo, it depends on whether it is breakable, liquid, container-based, etc. Lastly, even if a site owner would invest in the TO center, there is still a risk that a TO SP would not find a business case in covering that specific area on a sustained basis.

Currently, in Belgium, road authorities are not yet establishing specific obligations of deploying technology to enable CCAM when assigning long-term contracts to construct public roads. A reason is that the design procedure for new roads considers a long life cycle, and adapting procedures takes a long time and would require a thorough understanding of whether such requirements are worth it. The same holds for roads within ports. In Belgium, the port authority is, by law, the manager of the road within the limits of the dedicated port area, and has authority to make decisions on local roads, unless they are considered to have a status above ‘local’ road (e.g., motorways).

5.3.3 Recap of business model options for the TO service provision

Scenario	Customer(s)	TO service provider(s)	Pricing strategy	Party investing in the TO center*	Distinctive added value	Input required from other parties
Scenario 1	Logistics service providers; shippers; port manager (cranes, reach stackers); warehouse/site owner (forklifts)	- Transport company - TO systems developer - System aggregator - Specialized firm - JV of local transport and logistics companies (maybe with port)	Except if SP has own TO center: - Subscription (fixed + or per volume) - License model - E2E with connectivity, training, etc. - Spot pricing (per ride), if on-demand	- TO SP itself - Port or industrial site owner (TO center located in own site) - Neutral host (e.g. infrastructure investor) - Consortium of local logistics service providers	- Cost savings (general) - For E2E, convenience from multiple things included in single offer - For spot pricing, flexibility	- Either TO kit (if system is retrofitted) or TO-enabled trucks and vessels - Employee training - TO Center (if not owned by the SP itself) - Licenses to allow TO (maybe only for Sc 2&3, i.e. for public roads) - Collaboration for (un)loading (see 5.2) - Digitization of transport documents and ID recognition of trucks and containers (see 5.2)
Scenario 2	Logistics service providers; shippers; automakers; fleet owners	- OEM - Transport company - TO systems developer - System aggregator - Specialized firm		- TO SP itself - Port or industrial site owner - Neutral host (e.g. infrastructure investor) - Terminal or logistics SP	- Cost savings and lower insurance premiums (general) - For E2E, convenience from multiple things included in single offer - For spot pricing, flexibility	
Scenario 3	Logistics service providers; shippers; automakers; (AV) fleet owners	- OEM - Transport company - TO systems developer - System aggregator - Specialized firm - AV SP (AV fleet owner)		- TO SP itself - Traffic manager (TO center co-located with traffic control center) - Neutral host		

Table 9. Comparison of business model options for the provision of TO services, per scenario.

* Additionally, the TO Center can be monetized in different ways. For instance, via long- or short-term leases of office space (where the TO SP can install one or multiple TO stations), or via the rental of individual TO stations per hour. The use of short- or long-term leases will be most likely used when the TO Center owner is not a TO service provider (it could be, e.g., a port, traffic manager or neutral host). These entities may also offer flexible rental per hours, while a TO service provider may also choose to rent individual TO stations if it has excess capacity at a given point in time.

5.4 Deployment options for teleoperation

Considering our three deployment scenarios, the relationship of TO with automation, and a feasible timeline, this section explores what would be the most realistic and economically beneficial role of teleoperation in the foreseeable future. This implies assessing in which scenarios and use cases TO will be more likely to be used first, and whether the role of TO will be limited to a transition phase or, on the contrary, there will be a business case for TO on a sustained basis.

5.4.1 Role of and value proposition of teleoperation vs autonomous driving

It is often assumed that the final goal of TO is to help make AD feasible in the future. In practice, a combination of teleoperation and automation might be the most technically and financially feasible approach to scale up the deployment of both technologies. TO and AD can complement each other: on the one hand, highly (but not fully) autonomous vehicles would likely require the intervention of teleoperation in challenging situations, or in case of occasional disengagements; on the other hand, a high level of automation would provide a safety net by enabling the vehicle to perform the fallback task in case of emergency.

There are five degrees of driving automation, based on the taxonomy described by SAE [68]. Automation levels are classified based on three concepts: (i) what operational and tactical functions the system, instead of the human driver, performs; (ii) under what design domain the vehicle can drive autonomously; and (iii) who performs the fallback task when needed. Levels 1 and 2 include advanced driver assistance systems that can automate either the longitudinal (e.g., accelerating and breaking), or lateral (e.g., steering) operational control function (in Level 1), or both simultaneously (in Level 2). An example of L1 is adaptive cruise control, in which a vehicle adapts its own speed to the speed of other vehicles in front of it. However, in the first levels human drivers must still continuously monitor both the system and their road environment. In contrast, in L4 and L5, i.e. high and full automation, the vehicle performs the entire driving and fallback tasks. What distinguishes L5 from L4 is that the AV can autonomously drive in all potential situations on a sustained basis (i.e., it has an unlimited operational design domain). In contrast, in L4 the vehicle is able to drive itself in certain environments, such as pre-defined geo-fenced areas or a range of weather conditions. While a safe and large scale deployment of L5 vehicles is not expected in the foreseeable future, in L4 teleoperation can complement AD where a vehicle is not able to drive autonomously, for instance in areas where road infrastructure is not good enough or in complex traffic conditions.

Because of the mentioned reliability and (ultra-low) latency requirements, performing teleoperation represents a challenge even when using network slicing and 5G technologies. Enabling TO would require densifying the network with more equipment and smaller cells, which also represents an economic challenge in terms of financial investment. In practice, this challenge will depend on the scale of deployment, both in number of vehicles and area size, and on the role of teleoperation as well. While covering a local area where one or two teleoperated vehicles are present would not be a problem, having, for instance, 20 vehicles simultaneously teleoperated would generate substantial issues. Scaling up to support many vehicles in long stretches of highways would carry the need to install additional cell sites every few hundred meters along the road, increasing the deployment challenge.

However, if direct TO would play a supporting role, exceptionally assisting highly autonomous vehicles in areas where the on-board AI systems would not be able to cope with the complexity of the traffic, rather than being used for 100% of the trip, then it may not be needed to densify the network along highways. Sources of higher traffic complexity include situations in which frequent lane changes and overtakings are required, or where there are many vulnerable road users (VRUs). An example of VRUs are on-site workers walking around in port environments. In contrast, low traffic complexity areas could be highway corridors in scenarios 2 and 3, which may even rely on a single lane for teleoperated trucks. Therefore, a limited operational design domain, such as local milk runs and getting vehicles on and off the highways or helping out stranded AVs on a highway, would be more financially feasible, all else equal. But in that case, the rest of the trip would need to rely more on vehicle automation.

Even when the role of remote direct control is limited to highly challenging traffic situations, we assume that fully automated driving in simpler design domains would require a continuous monitoring of the vehicle. This may be either a technical requirement or be mandated by legislation. Such monitoring would require an ultra-low latency connectivity service, and having an infrastructure in place that allows for the vehicle to be taken over as a safety measure. Assuming TO would be used to handle just a few vehicles that are in need of assistance in a given area, this connectivity service could be supported by nationwide coverage instead of purpose-specific densified networks.

As mentioned before, highways are more limited in terms of commercial opportunities for 5G connectivity providers; hence it may be also more realistic to assume that 5G connectivity on highways will rely on low bands, in order to have a larger coverage area relative to the degree of densification. While these would still be higher reliability networks compared to previous-generation networks, there would still be quite limited in terms of capacity, at least in the coming years.

In the case just described, a potential issue would arise if several vehicles would simultaneously need assistance at the same location, resulting in a spike of demand for teleoperation. This could happen because of road conditions, for instance due to road works. If that were to happen, this may be solved at the application layer, orchestrating how these requests are handled. These vehicles could also help each other out in different ways. First, by connecting to the same server, in order to optimize the video uplink. Second, they could do a sort of coordinated platooning in combination with TO for the platoon leader, so that not all vehicles would need individual assistance. In such a setting, a remote operator would directly control the platoon leader from the TO Center, while providing indirect control (i.e., path setting) for the other vehicles, which would share the same set of waypoints that the leading vehicle would communicate using short-range connectivity. In this way, platooning could help scale teleoperation in the long haul, reducing the teleoperator-to-vehicle ratio. As a limitation, this approach would be, realistically, limited to small platoons.

We must also consider the role of CACC-based platooning. With the driver still present, the financial benefits of platooning are limited to fuel consumption reduction. But with teleoperated and autonomous driving, savings from CACC-based platooning also arise from more operational efficiency and uptime. Based on the role of TO, two main setups are possible:

- First, when the remote driver controls the leading truck. Here, follower vehicles are automated, although still remotely supervised in case the teleoperator needs to intervene.
- Second, that there is a manual driver on-board of the first truck, with the followers being teleoperated or remotely monitored where AD is proven to be safe.

Lastly, it is important to note that the actual functionality of TO will depend on its technical feasibility. The performance of the 5G network will determine the maximum driving speed at which a vehicle can be safely operated from a distance [41]. Therefore, it is still possible that TO would be limited to low speeds, which would have a major impact on the studied business models. It is challenging to use direct TO at high speeds without highly reliable 5G infrastructure: it would require an automatic safety fallback from high autonomy or advanced Active Collision Avoidance systems, in order to stop the vehicle in case the connection with the teleoperator gets cut.

5.4.2 Evolutionary path for TO business models

In the matrix below, there are 2 axes: vertically, the complexity of the scenario, based on the 3 scenarios described in section 2.3. Horizontally, the level of automation, which we assume to be directly linked to the timeline in terms of feasibility. While the ideal goal is using TO on long routes combined with automation, which is expected to offer the clearest business case, it would be interesting to know for which scenario TO would be interesting to either service providers or customers. Other important questions are (i) which is the most feasible evolution with time?; and (ii) how does this differ between road and water transport?

	<L4 (short-term)	L4 (mid-term)	L5 (long-term)
Scenario 1	Full direct TO of cranes, TO supporting truck docking, platoon forming, direct TO for short "milk runs"		If mandated by legislation as support to AVs
Scenario 2	Direct TO of barges with captain on board for complex maneuvers; TO to reduce ship crew; Possibly direct TO to join and leave truck platoons;	Direct TO of barges as complement to AD, with remote captain and very limited crew	
Scenario 3	Direct TO of barges with captain on board and reduced crew; Possibly direct TO to join and leave truck platoons;	Direct TO of trucks as complement to AD, e.g. in complex roads or after sudden fallback; Direct TO of barges	

Table 10. Feasible TO deployment options by automation level and deployment scenario.

Starting from the leftmost columns of the table, we provide first a discussion on the possible deployment options relying on lesser than L4 automation across the scenarios.

- Scenario 1. Teleoperation of cranes and reach stackers or forklifts within a densified area of a Belgian or Dutch port was seen as a feasible application to start with the deployment of TO. Having a very advanced network available only in a limited scope in terms of geographical area is something that fits within the current growth path of an MNO, even though it may require co-investment with local actors in certain locations where alternative revenue streams are not so obvious to find. In addition, direct TO for platoon forming within the port area would leverage that same network infrastructure. Another deployment option is the use of direct control teleoperation for milk runs with trucks in public roads within the port environment. As a second step of scenario 1, TO could be used for these longer (but still local) transports, whose high frequency might already provide a good business case for deploying TO.
- Scenarios 2 and 3, for longer national or international roads. One possibility is using remote driving to join and leave a truck platoon in the short term, where joining and leaving platoons are still challenging actions. A feasible setting would be one where the leading truck is manually driven, for safety matters, with follower trucks relying on on-board software. Direct TO would be used to form and leave a platoon, and while the semi-autonomous vehicle is in the platoon, the remote operator would keep monitoring it, but no active direct interventions in the driving task would be required. In the context of scenario 2, teleoperated platooning can be beneficial when doing point to point driving within or between big operational hubs and big industrial sides. While not representing dense and complex traffic environments, vehicles would have to interact with road users

and cross intersections. From a telecommunications network perspective, this would entail similar requirements to the ones in the example above for scenario 1, even for long haul. However, some potential legal challenges may need to be addressed when having a first vehicle that is manually driven, because the manual driver could be considered the driver of the whole platoon.

Beyond the platooning example above, scenarios two and three are more challenging. More ambitious applications would likely only be feasible some years further in the future. First, direct TO would need the network to be improved. One of the biggest challenges for the long haul is having sufficient networking capability along all major roads. The challenge is not in just having coverage but in providing different service levels, including the high QoS required for TO. The geographical expansion of the network that's required for <L4 will probably not only come from the single business case of TO, and typically, enhanced nationwide coverage by MNOs grows as additional business cases are clear. However, it is difficult to identify alternative use cases that require full national coverage, extremely high bandwidth, and extremely low latency. Therefore, these upgrades may only come in a later time when higher automation is already available. Second, for safety reasons, scenarios 2 and 3 would also be much more feasible when adding higher automation, especially if network upgrades are not pervasive.

In L4, if the connectivity is lost, the automation software which runs on board of trucks and vessels allows to bring a vehicle to a safe stop position until connectivity is restored and the teleoperator can take control again. This appears to be more challenging in a road environment, because of the number of surrounding vehicles, which increases the chances for collusion. In addition, the automated safe stop can be handled much easier in a port environment than in roads with higher speeds and more complex environments. Therefore, performing TO with lesser-than-L4 vehicles and without solid connectivity is especially dangerous on highways. Consequently, deployments of teleoperated driving in open roads for scenario 3 would likely start with L4. In contrast, closed areas with multiple short distance trajectories and where driving speeds are lower are seen as much more feasible in the shorter term.

Therefore, a feasible evolution for teleoperated road transport would be scaling up to long haul with direct TO only once higher automation levels are available for driving in public roads, whether local roads or highways. That would mean starting direct TO from L4, which would imply that the business potential of TO is probably highest as a complement to autonomous driving. While this discussion relies on assumptions that still need to be researched further at the technical level, we should already explore the economic potential of potential business models relying on the mentioned approach. Two options of using direct TO as a complement to AD for long-haul seem most promising, a priori: (a) one where direct TO is used in more complex last-mile areas (e.g., local roads), while AD is the default for driving during the highway part of the trip; and (b) one where direct TO is used after sudden fallback to help stranded AVs on a highway, either because AD systems fail or because weather and road conditions suddenly become unmanageable. Similarly, in this setting remote driving could also be used to help trucks enter a highway before they start driving autonomously at a certain location. The next section will focus on these deployment options of TO as a complement to L4 AVs for the long haul, providing a more in-depth assessment.

A final caveat regarding teleoperated road transport is the feasibility of long-haul platooning. While using TO to help form platoons was identified as an a priori possible deployment option from a financial perspective, its technical feasibility needs to be investigated further: safely forming a platoon on EU roads was identified as a complex task, due to the short distances between highway entries/exits and the subsequent challenge of safely mixing platoons with normal traffic when the trucks in these platoons leave short inter-vehicle distances.

In the case of waterways, TO of barges is only expected to start being technically and economically feasible from scenario 2. TO makes sense for longer journeys, while the economic benefits of doing direct TO only in a port site area are seen as quite limited. Seafar's TO services already involve automation, with up to 70 or even 80% of the trip along a canal being done automatically by the vessel, with the supervision of a captain in the TO Center. With a captain on-board, TO can take over when the captain rests, which already increases uptime. And the captain on board can take over for the more difficult parts of the trip, for instance around the port. Direct TO can also help reduce the required crew on board, by using idle or resting time more efficiently for certain tasks. The longer-term goal is to remotely operate the vessel without the skipper on board and with just one helmsman on board who can interfere when an emergency happens. Potentially, milk runs with barges could make business sense for a large port environment where a lot of short “sails” happen (e.g. getting containers from the left to the right bank). However, financial benefits would be more limited and the business case would need to be explored in more detail, taking into account all the required infrastructure investments.

Compared to road transport, the waterways use case makes it more feasible to scale operationally towards more complex scenarios before upgrading in terms of automation. Compared to roads, direct TO for cross-border trips seems to be a more realistic target because the operational design domain in waterways is less complex. In addition, it is possible to reduce crew size while still keeping part of the personnel on board for safety purposes.

But allowing TO in waterways also entails challenges regarding 5G networks. First, exploiting the full capacity of autonomous platooning in maritime would entail huge CAPEX from upgrading current infrastructure. Second, ports and waterways are challenging environments for any radio network because the coverage provided with land sites along the banks can be blocked if, for instance, a big container ship passes between them and the teleoperated barge, standing in the way of its reception. 5G can have multiple active connections to different cells of the MNO to address that, so if connection from a main cell is lost, the barge immediately connects to another. But then this means densifying along the waterway to provide that redundant and expensive coverage. Third, if there is a high concentration of barges in the same area, all of them would be sharing the limited network resources unless dedicated coverage using higher frequencies (e.g., 3.5 GHz) is deployed along waterways. This would translate into a much more densified network compared to the use of 700 MHz bands, including substantial small cell and fiber deployments. Therefore, network deployment costs need to be explored further to evaluate the business case of waterway teleoperated transport, especially in those cases where the added value would be lower, such as short trips and situations where a large percentage of the crew must remain on board (e.g., in case of low automation or small vessels).

5.4.3 In-depth assessment of a business model for automated road transport with TO

Assuming that fully autonomous trucks will not be widely available within the foreseeable future, business models should take an evolutionary approach. From the discussion above on the role of TO with respect to AD, in terms of potential and technical feasibility, it becomes clear that both technologies can reinforce each other: TO can support and thus enable AD, while AD offers higher potential economic benefits from operational efficiency and uptime compared to direct remote control. In addition, relying on automation will reduce the strict network requirements that teleoperating many vehicles simultaneously would entail.

We propose an L4-ready business model for low complexity highways with huge freight volume in terms of goods flow. In addition, we perform a cost-benefit analysis to evaluate, quantitatively, its economic feasibility. This model resembles the concept of the ‘exit-to-exit’ scenario presented in [69].

The present model involves L4 autonomous trucks driving in predetermined geo-fenced routes, such as specific highway corridors. A truck is driven to a transport hub or pick-up point by a human teleoperator, and then for the pre-defined highway part it operates without a driver. The self-driving domain is further restricted in case of certain low-frequency but high-impact weather conditions, such as heavy snowfall or storms. To govern that, a control center gives clearance for the routes in advance. We argue that this business model will allow to reap the benefits of AD from higher cost and traffic efficiency sooner, while also yielding better work conditions and a quicker market adoption of TO as well as AVs.

This business model is assumed to be feasible with high but not full automation (L4), which entails self-driving but only under limited domains and environments [68]. Therefore, it involves opting for a quicker deployment of AVs in the face of the tradeoff between waiting for further technological advances (L5) —which are uncertain in terms of time, development costs and feasibility— and exploiting a business case that offers less of the potential benefits but also less technical complexity. It also implies the underlying assumption that fully-autonomous vehicles will not be market-ready for the foreseeable future. In consequence, we argue this business model to be a feasible one for the medium term, since it is closer to current capabilities and allows for a quicker roll out on a step by step basis, as the demand of each potential deployment area becomes clear.

The role of the traffic control center. To safely scale in terms of areas and operations, we propose a control or operation center that "clears" the route, i.e., that decides if the climatic, connectivity and road traffic conditions are permitting to allow AD at a specific moment in time. Such a control center would be responsible for several routes and a large number of trucks passing through them. Moreover, by having a real-time overview of the road situation and the vehicles traveling a specific route, it would also have the role of facilitating truck platooning. By coordinating with different logistics providers, it would increase the chances and number of vehicles joining a platoon. We assume that this traffic management center would not be co-located with the TO center, although this would be a theoretical option, subject to latency needs.

It remains unclear who would invest in and operate this center. Different stakeholders, such as traffic management authorities, truck OEMs or freight providers, have a potential interest in doing so, and could even invest in it as a consortium. For automakers, AD will reinforce a trend towards after-sales service business models. However, while some logistics companies have the expertise of operating large fleets of thousands of trucks across Europe, OEMs would need to acquire these capabilities. In any case, this role could be supported by backend software provided by AD systems developers.

Since operational design conditions (e.g., weather or road status) are not completely predictable, even with a control center, the reliability of this L4-based service would be lower than in the case of fully autonomous systems. As per the definition of L4, the fallback task would be performed by the vehicle. The driving fallback task is the response action to minimize the risk of an accident when the system cannot drive autonomously on a sustainable basis, which may entail stopping or driving away from active lanes of traffic. In such a circumstance, vehicles left stranded in the middle of their trip could be remotely driven to a pickup point. However, while remote operation would increase productivity by limiting the amount of time a trip is halted, it would entail further infrastructure costs; the need for ultra-low latencies may require teleoperation centers to be located closer to the vehicles, besides the need to densify current telecommunications networks.

Rethinking the driver role. While highly-autonomous systems can radically change the current role of the human driver, this does not mean drivers will be entirely substituted. First, drivers will still be needed to perform other tasks, such as handling the cargo, interacting with the customer, or doing other administrative-type work, which poses a challenge for the last-mile. Second, in the foreseeable future, a human (remote) driver will still be able to perform the driving task in a safer way in complex traffic situations, such as local roads or in case of bad weather conditions. In this model, remote drivers would pick up and leave trucks at specific locations, leaving vehicles to drive autonomously during predefined highway routes. This would already be possible in L4, where human drivers are not needed for the driving nor the fallback tasks in simpler, geo-fenced parts of the trip. Therefore, the direct TO function would only happen for the ‘short haul’, on a more local basis, and in case trucks need assistance.

Deployment areas. The decision to deploy geo-fenced AV routes would be driven by the capability to cover demand for road goods transport in a cost-efficient manner. To help scale the volume of operation and increase asset utilization and thus vehicle uptime, it is important to deploy the transportation service in repetitive, incessant routes from a defined pick-up point to another. Therefore, a specific challenge of this business model is finding commercially-viable deployment areas, which will require sufficient scale. Such areas would consist of roads where traffic is not too complex for the software to handle, and at the same time there is enough demand for the service. Compared to urban areas, highways offer simpler environments and traffic patterns and less presence of vulnerable road users. Since helping scale TO solutions throughout the EU is a main goal of the 5G-Blueprint project, we focus on highway corridors such as those planned in the European TEN-T network, which are a realistic example where this model could be deployed. This international road network is of high economic importance, with high quality infrastructure, linking the continent's most important transport hubs, including its busiest ports. Therefore, they would offer enough goods flow demand for constant, repetitive routes.

Revenue sources. The business models options to charge for the TO service discussed in section 5.3 are also relevant here, for the complex part of the trip in which the use of TO is planned in advance. However, a pricing strategy for the overall service may be more feasible when using additional revenue sources as well. To monetize the building and operation of 'control centers', one option would be to charge variable tolls (i.e., usage fees) per distance traveled within the controlled route, which could be registered by the freight provider or TO fleet manager, who would indicate in which exiting pickup point the entering truck will end its autonomous trip. Moreover, this could be complemented by 'performance-based' spontaneous charges (also distance-based) if the vehicle is aided to join a platoon. Such a type of billing would also be relevant in case a vehicle is teleoperated in case of emergency, since the TO service would be unplanned and sporadic. If the same party offers a logistics service, however, it may be necessary to mandate neutrality vis-à-vis competitors, to ensure the service is carrier-agnostic; for instance, regulation could fight potential abuses of market dominance through marginal-cost-based price caps.

Regarding road and telecommunications infrastructure, there are two ways in which investments can be monetized directly. On the one hand, road authorities can charge logistics service providers ex post: for example, through highway tolls or vignettes and through a connectivity subscription, as a function of road and network usage. On the other hand, service providers can contribute financially ex ante, that is, offering a kind of sponsorship in the infrastructure building stage. In the latter case, the need to coordinate the spending and the commitments by different parties may help in bringing the mentioned security that the required investments will be undergone.

5.4.3.1 Cost-benefit analysis

To complement the qualitative evaluation of the proposed business model, we investigate its financial feasibility. We present a cost-benefit analysis to assess the incremental costs or benefits that can be expected compared to the status quo of manual driving. Previous studies show that automation of road freight transport brings substantial cost savings compared to manually driven trucks [70–72]. However, a variety of assumptions in terms of automation level, rate of adoption, truck design, and factors considered, among others, prevent a direct translation of previous findings into the present business model. Therefore, in the paragraphs below, we consider the main sources of incremental costs and benefits, and estimate their specific impact for three different scenarios, which we summarize in Table 11.

To give practical support to our calculations, we use two contiguous TEN-T road corridors in the core of continental Europe as examples of deployment areas. More specifically, we study (i) the 'North Sea-Mediterranean' corridor, which links, in two strings of highway, the port of Marseille and Paris with the ports of Rotterdam, the North Sea and Antwerp; and (ii) the North Sea Baltic one, which connects the aforementioned ports with those of Hamburg and Bremen, reaching towards Poland and the Baltic states. If we assume that a pick-up point would be located around each port and each main metropolitan area, or alternatively each urban node of the core network defined in Regulation 1315/2013 [73], this would be equal to one pick-up point per either 265 or 325 kilometers, approximately.

The first source of costs we consider is sensing hardware, a manufacturing cost that we assume will be passed to customers. We assume conventional truck designs on top of which sensing hardware and CAD technology is built. Since trucks will be partially manually-driven, they need to have a cabin. This will also lead us to ignore any potential fuel consumption benefits from more aerodynamic design. Estimating hardware costs is challenging. Special emphasis is usually placed on lidar, which has long been considered a crucial bottleneck to make AVs cost-competitive. Earlier generations of the technology were estimated at about $60,000 [39], while later estimates placed this cost at considerably lower levels between the hundreds or thousands [39,74,75]. Nevertheless, newer generations of cheaper lidars show a more limited performance, and therefore multiple ones are needed [39]. Moreover, the architectural approaches that different companies use are not identical, differing in terms of the number of lidars, sensors and cameras they use [72,76]. In addition, production costs can be expected to drop as technology matures, AV adoption unlocks economies of scale, and new suppliers keep entering the market, as several ventures [77] and big firms [78] do. For example, a premium of between 11.5 to 20 thousand GBP was assumed in Wadud [72]. We use the reviewed literature as a reference for costs and state-of-the-art road tests as a reference for architectures. These tests include those publicized by Waymo and Daimler, in which a total of four to six lidars, plus several cameras and radars, are built on the top of the cabin, as well as on side mirrors and the front of the truck. This way we arrive at the estimations per scenario presented in Table 11, which constitute one-time acquisition costs.

The main sources of operating costs for manually driven trucks are driver wages and fuel costs [38]. In the future, market forces may impact driver wages in either direction. On the one hand, lowering the driver shortage and making the job more attractive will reduce the current demand-supply imbalance and, all else equal, reduce wages. On the other hand, collective bargaining, amongst other factors, can increase them. Current wages per km for the US are reported in Murray & Glidewell [38]. Across Europe, different income levels and working conditions make salaries range widely [79]. Adjusting the figures in both sources for inflation and currency, and considering the income levels of the proposed deployment areas, we arrive at an equivalent of 0.4 euro per km, which we assume to be fixed in our cost model. What makes the scenarios fluctuate is the incremental uptime that the described geo-fenced business model will yield, which will depend on the average length of the automated part of the trip relative to the overall route. In the pessimistic scenario, we assume that the average automated part of the trip will be equal to just the average distance between any two pick up points (i.e., 295km); in the benchmark scenario, the automated part of the trip will be two pick-up points long (i.e., 590km, very close to the EU average for road freight journeys in which goods are carried [80]; lastly, in the pessimistic one, it will be three points long. If we assume an average speed of 80km/h on the highway corridors, the average automated trip will last about 4, 8, and 12 hours per scenario with pick up, inspection and re-filling times included. In addition, we assume that the local (remote) driving part of the trip, which includes delivery, loading of new cargo and return of the truck to the pick-up point, takes a full day (i.e., 8h) for each single entire route. Therefore, the total automated trip equals a third, half or 60% of the entire trip, depending on the scenario. In consequence, this represents the incremental uptime and, ceteris paribus, drives the wage reduction caused by this business model.

Regarding fuel consumption, we consider reductions due to the more efficient driving enabled by truck platooning. Based on recent studies and manufacturers' websites, we take the average consumption (in liters per km) for heavy trucks weighing between 16 and 40 tones, the general maximum permissible vehicle mass in Europe [81]. Since fuel prices fluctuate, we take the average diesel price over the previous year across the countries of the corridors considered. We use diesel as it is the most common fuel type for trucks. This yields a fixed cost of 0.54 EUR per km. To calculate the cost reductions caused by platooning, there is a wide range of possible assumptions in terms of how many trucks join a platoon, the relative portion of a trip the platoon lasts, the time gap between vehicles, etc. Moreover, there is a trade-off between coordinating driving times and speeds and uptime. We use the middle-case fuel consumption reduction in Al Alam et al. [37], consisting of 6.2% when two identical trucks are involved. Our most conservative scenario assumes that the control center will, on average and compared to the status quo, help one extra truck join a platoon per each trip and during the entire automated portion of it, thus resulting in a fuel cost reduction of 6.2%. In contrast, the most optimistic scenario assumes twice this impact, while the baseline effect falls in between.

Next, we consider the expenses from operating the traffic control center, which mainly consist of the rental of office space and personnel wages. Based on publicly available market prices in the countries of the example corridors, we assume an average annual rent of 250€ per sqm. Further, we assume 20 sqm per employee and an average gross salary of 38 thousand euro per year, the rounded average across the countries considered for the deployment areas plus an additional 20% due to the night shifts and training involved. Scenarios differ in the total number of centers needed, as well as the number of employees per center. In the best case, only one center is needed to control both corridors; in the worst case, 3 centers are needed per corridor (six in total). Last, in the baseline scenario three centers are required. In addition, we assume that 50, 35, 20 and employees per center (so 50, 105 and 120 in total) from optimistic to pessimistic scenarios. The implied assumption is that higher required proximity does not entail a proportional increase in complexity. Altogether, this yields the values in Table 11.

Finally, we must cover remote operation in case of fallback, which also involves workforce and office space costs. Regarding wages, the main source of uncertainty is how many trucks will each human operator be able to supervise at the same time, on average. Previous studies assume a range between one and fifty cars [82] and 5-40 trucks [71]. In both cases, higher bounds rely on more mature CAD technology, while lower bounds are influenced by more complex road deployments. Therefore, we assume a range of 10 to 30 trucks per operator, with the baseline scenario being 20. For this range, applying our previous assumptions regarding uptime per scenario and wages would result in salary costs between 0.03 and 0.05€ per km and vehicle. Moreover, we add the yearly office space rental OPEX of five thousand euro per employee, as assumed above. It must be noted that we assume remote operation centers not to be co-located with control centers, as latency needs of teleoperation may demand a closer distance to the vehicles. Lastly, with an assumption of 300 working days (explained later) and daily kilometers based on incremental uptime, the total rounded OPEX are presented in Table 11.

Cost category	Unit of measurement	Pessimistic	Baseline	Optimistic
Truck hardware	Vehicle, acquisition	20k	14k	8k
Fuel consumption	Km, vehicle	-0.034	-0.05	-0.068
Driver wages	Km, vehicle	-0.13	-0.2	-0.24
Control center	Total, annual	5.16M	4.52M	2.15M
Remote operation	Km, vehicle	0.10	0.08	0.05

Table 11. Incremental costs by category. All quantities are in euros.

First, we calculate the incremental TCO, per vehicle, for a truck fleet owner (e.g., a logistics company). At this stage, this company pays for the truck, fuel, driver and remote operation service, but does not pay for a control center yet. In addition, the control center is assumed to clear the route 99% of the time. As shown in the left side of Table 12, using L4 trucks according to the present business model leads to annual cost savings in each scenario, from year 2 onwards. However, in Year 1, when the truck is acquired, the pessimistic scenario results in an increase in TCO.

Second, we calculate the cumulative increase in TCO per vehicle. The right side of Table 12 plots net present values (using a 5% discount rate) for years three to seven. Assuming a current truck lifespan of ten years, we also assume (conservatively) that the useful life of L4 vehicles will be reduced by their increased utilization rate. For instance, for a 33% increase in uptime, as in the pessimistic scenario, we assume a lifespan of seven years. Accordingly, grey cells in Tables 1 and 2 show periods in which the first truck has been replaced, and thus a new truck has been acquired. For the pessimistic scenario, cost savings are experienced from year four onwards, implying a payback period of about 3.3 years. In the optimistic scenario, the NPV grows to thousands of euro over the useful life of the vehicle.

	Year 1	Years 2 to n	Year 3	Year 4	Year 5	Year 6	Year 7
Pessimistic	13917	-6083	1514	-3562	-8159	-12309	-16046
Baseline	-18314	-32313	-71646	-94818	-115620	-123780	-140352
Optimistic	-65561	-73560	-183722	-235491	-275645	-317112	-353991

Table 12. Incremental TCO per vehicle (in euros): annual (years 1&2) and cumulative (years 3-7).

Next, we consider the incremental costs that arise from the control center. We calculate the breakeven point, in number of vehicles needed for the above TCO savings to cover these costs. In addition, we perform a sensitivity analysis on the variable of 'route clearance'. More specifically, we lower the proportion of time in which the control center allows self-driving in the geo-fenced deployment areas. This will depend on the capabilities of technology (i.e., L4 automation systems) to deal with challenging weather or road conditions. In our model, lower clearance impairs the fuel and driver cost savings derived in Table 11, while all other costs are considered fixed and hence remain the same. Table 13 shows the impact of this sensitivity analysis on breakeven points for 99% and 95% clearance rates. In the worst case scenario, breakeven is only possible after several years of cumulative TCO savings and with thousands of L4-ready vehicles adopting the described business model. In contrast, in the other scenarios the breakeven is achieved in Year 1 with just 33 or 247 trucks. For reference, there are over six million trucks in circulation in the EU, according to ACEA. The breakeven point implies that the costs of the control center can be financed by the savings in vehicle TCO.

	99% clearance				95% clearance			
	Year 1	Year 3	Year 5	Year 7	Year 1	Year 3	Year 5	Year 7
Pessimistic	-	-	2769	1877	-	-	4250	2126
Baseline	247	175	172	175	279	189	185	188
Optimistic	33	33	34	35	35	35	36	37

Table 13. Breakeven point in number of vehicles, per year (cumulative NPV).

Finally, we list those costs that have been assumed to remain equal. Incremental insurance costs are uncertain and may not change with CAD, since less accidents will reduce premiums but higher vehicle and cybersecurity costs may offset these savings [71,72]. A similar reasoning applies to maintenance needs, hence previous studies have kept maintenance costs unchanged in likely scenarios [71,72]. Moreover, the electrification of fleets will both increase vehicle prices and reduce fuel consumption. In addition, other costs have not been considered, for simplification. On the one hand, self-driving or TO software systems may increase vehicle costs, while mapping routes and increased computation (i.e., higher energy consumption) can increase operational expenses. Similarly, there will be software integration costs at ports and for logistics SPs (e.g., related to terminal and gate operating systems). On the other hand, yearly depreciation has been implicitly assumed to increase, due to the conservative assumption that higher uptime will lead to a shorter useful life of the vehicle, ignoring that wear partly arises from time itself. Further, infrastructure costs may increase if dedicated lanes are needed and MNOs must upgrade coverage along roads. Similarly, the total costs from wages of remote drivers may be higher than those of current manual drivers, while here they have been assumed to remain equal, thereby ignoring them in the calculation of incremental costs/benefits. Finally, we have not quantified any positive externalities from the reduction of accidents.

5.4.3.2 Discussion of the proposed business model's impact

In short, the described business model involves geo-fenced highway routes where trucks drive autonomously, without a human on board, conditional to a control center guaranteeing that road and weather conditions are permitting. Trucks are driven to and picked up from a transport hub by remote drivers, who consequently perform the short-haul driving task in more complex roads, the rest of the trip being entirely driverless. If widely adopted, this model will generate a beneficial impact on several dimensions, discussed below.

- First, by making autonomous road freight financially feasible prior to the commercial readiness of full automation, the benefits of AD in terms of reducing road accidents and increasing traffic efficiency could be felt earlier.
- Second, automating a large highway portion of a freight trip would increase the health and well-being of (remote) drivers compared to the status quo. Since the driving task would be done from an office, it would mitigate the negative consequences of long-haul trips, such as mental health issues from social isolation.
- Relatedly, the proposed business model will bring a positive impact on the job market. Better work conditions will lead to the truck driver job becoming more attractive, while self-driving alone would reduce demand for drivers, all else equal. Both aspects will help mitigate the current problem of unfilled vacancies. Moreover, rethinking the driving role avoids the potential negative side of an abrupt substitution of drivers, helping ensure that the longer-term transition towards full autonomy is smooth.
- Furthermore, it would have a positive economic impact for Europe, beyond lowering the current driver shortage. As we mentioned before, exploiting early commercialization prospects can lead to a quicker rollout of autonomous trucks. Moreover, automating a large portion of the trip would substantially decrease the overall operational downtime of vehicles. The resulting increased productivity will provide cost-efficiency gains for logistics companies, and these benefits could be passed to end customers in the form of cheaper goods and delivery costs. Given the weight of road transport on the European economy, it can also contribute to economic growth.
- In addition, the combination of repetitive, continuous routes and a control center coordinating the trucks entering the geo-fenced area can help achieve scale with platooning. The centralized planning could result in more durable and larger platoons. The literature shows the positive effects of AVs and truck platooning on traffic efficiency and the environment; specifically, smoother driving can lower congestion and energy consumption.

Finally, we assessed the feasibility of the model via a cost-benefit analysis with three scenarios in order to account for uncertainty. Even though we focused on two given TEN-T corridors, the described business model is scalable to other deployment areas with similar characteristics in terms of road quality and complexity. Our results show that, in all scenarios, vehicle TCO decreases over the useful life of the truck. As in previous studies, the main source of TCO savings from CAD with trucks comes from driver cost reductions. In addition, we find that these savings are enough to cover the costs of control centers even if less than 1% of current fleets are adapted to enable CAD. The amount of potential savings from this model also suggests that monetizing them through road tolls would help subsidize roadside telecommunications infrastructure. Moreover, charging fees to counterbalance part of these savings could help mitigate the potential induced demand, and therefore the resulting increased emissions, from road transport becoming substantially more cost-efficient.

To conclude, while our sensitivity analysis accounts for uncertainty, our simplifying assumptions logically represent a limitation to the cost-benefit analysis. For instance, variables such as the wages of teleoperators compared to manual drivers, as well as the financial costs of adapting road infrastructure and upgrading network infrastructure, were assumed to remain equal in our cost model. Nevertheless, a quantification of telecommunications infrastructure costs will be further researched in later stages of 5G-Blueprint. In addition, the assumptions on the increased uptime (i.e., on the proportional part of the trip that is automated) were rather conservative, for instance by including the time of (un)loading in the overall trip. Since the extra uptime represents the most important driver of the calculated economic benefits, including more optimistic scenarios would provide a more accurate assessment of the benefits, albeit reinforcing the conclusion on the positive sign of the effect of TO on operating margins. Lastly, future research could extend the present analysis by replicating the analysis for intensively used transport routes within the same country (i.e., for deployment scenario 2). This would allow us to assess if this more limited scenario can already offer a positive business case for road transport with teleoperated trucks.

5.5 Overall business models and reflection

Having a deep understanding of the relevant business model options for several individual key roles in the value network, this section extends the analysis by delineating a series of business models for the different deployment scenarios. In addition, we address remaining challenges regarding infrastructure investments, discussing the potential role of several stakeholders in orchestrating the new ecosystem or kickstarting such investments. Lastly, we briefly discuss the role of and business models for teleoperated passenger transport.

5.5.1 Examples of overall business models per scenario

In the subsections below, we provide a series of examples based on feasible combinations of business model options for each scenario. These business model options are based on the more focused analyses of sections 5.1 to 5.4, so the business models below portray a more complete but less detailed picture. These business models are not meant to be exhaustive, as plotting any possible combination would yield a large amount of possibilities and add little value besides the enumeration of them. Rather, we identify those ones that, at this stage of the analysis, appear to be feasible in the context of 5G-Blueprint; a further narrowing down, impact analysis and validation will be provided in a following phase of the project.

To complement the written description of the business models, and make it clearer, we represent them graphically via simplified value networks that plot the main interactions among the key roles. These interactions cover the services and value provided, along with the main revenue streams and required investments in assets.

5.5.1.1 Scenario 1: geographically limited area with numerous (short distance) transports

This scenario refers to the most isolated deployment. It assumes that teleoperation services will be offered in and around ports and/or large industrial sites, which assumes to be the most feasible initial locations. Deployment would happen on an individual site-by-site basis, starting in major European ports and industrial zones with a high-frequency of transport flows. TO would be offered within the site and from the site to external (but local) distribution centers (and vice versa). Therefore, while deployment might start within the boundaries of the sites, it will also include public roads in the port or industrial area (e.g., including milk runs with trucks). Such transport flows could cross borders, although within the premises of the same site (e.g., North Sea Port's premises extend across Belgium and the Netherlands).

These smaller deployments can be expected to offer a rather limited potential for economic and societal benefits, mostly limited to optimizing first- and last-mile transport and local site operations. Nevertheless, they can be seen as an intermediary step towards larger infrastructure deployments. As such, they can help clarify the potential benefits of TO. In Section 5.4, the TO deployment options identified for Scenario 1 as feasible in the relative short-term included the following: (i) the full direct TO of cranes, (iv) TO as supporting the process of automated articulated truck docking, and (iii) direct TO to help trucks join or leave a platoon. All these were seen as being possible with lower than L4 vehicle automation.

For this first scenario where the teleoperated transport services will be offered in a limited geographical area, two different business models have been identified. The first one relies on a more locally-orchestrated deployment, with a private 5G network within the port area, while the second relies on attracting deployment of 5G and TO services by providers with a broader (inter)national focus.

BM1: Local deployment in port and local TO platform. This model relies on local collaboration and shared investment of resources. Here, a private 5G network is financed by the port authority, who will contract a connectivity provider to manage the deployment and operation of its private network and offer the ultra-low latency connectivity service to support TO within the port area. This party would be a micro operator that has coverage only within this site. In addition, the port would also help finance the deployment of a TO center, in collaboration with local logistics companies. This would take the form of a joint venture, which would take care of setting up the TO stations and, afterwards, perform the TO service. This new entity could gather additional revenue from leasing space in the TO center to other TO service providers, if the business case of TO becomes clear and its deployment is expanded to larger scenarios. Similarly, it could raise revenue from servicing additional freight service providers, besides the ones that would be part of the joint venture, which would be its first customers. It is also possible that, in this longer term future, the port authority exits the venture, selling its initial shares once the TO service is proven to be a stable, stand-alone business case and the port has already recovered the capital invested.

The advantages this business model would be the following:

- Due to the use of a private network, the port site owner would have full control of the 5G network, with data management being local and centralized. In addition, the private network should be adapted to cover the specific requirements of the different services that the port provides, beyond TO. The private network might issue multiple network slices, for example one eMBB slice to serve its employees. The resource allocation towards these slices can be realized dynamically based on the demand of its provided services, which would lead to a more efficient resource usage compared to leasing different network slices from MNOs, and hence might lead to a cheaper connectivity service.
- The development of a local platform for TO services, together with the deployment of a TO center by local actors, would also offer control over the timing of availability of TO solutions, avoiding the risk and uncertainty of waiting for more internationally-focused companies to be convinced to come and invest in the local area.

The downsides of this business model are mostly related to the up-front financial resources required from the port authority, to deploy infrastructure for both 5G and TO. Specific knowledge is required to maintain a wireless private network; the port would likely outsource this task, which would probably make it more costly compared to leasing network slicing from MNOs. In addition, the coverage of the network is limited to the port site, so the challenge of handover will need to be solved to ensure the continuity of service for teleoperation of trucks and barges. This issue will become more relevant as teleoperation deployments are expanded to Scenarios 2 and 3. In this model, this handover becomes an additional source of costs, as it is offered as a service by an MNO.

Figure 7 plots the model's main actors, roles and interactions, enumerated below:

1) The port authority is the crucial enabler of this model. Its assumed motivation to play this role is the prospect of increased operational efficiency and subsequent value creation for all the port's stakeholders,
   a) 1.a. represents the financing of the private 5G network.
   b) 1.b. represents the involvement of the port authority in the creation of the described JV by providing equity capital.
2) The handover between the private network and the public networks covering the areas around it will be offered as a roaming service by a national MNO. In exchange, the private network operator (PNO) would pay an entry fee and subsequent usage fees.
3) The connectivity service for TO would be provided by the micro-operator and paid directly by the TO service provider. Given that these parties would be the sole provider and customer of TO-grade QoS connectivity in the area–at least in the initial stage–, this payment would likely be made in the form of a recurrent subscription.
4) Employee training would likely be offered by a third party TO service provider that has previous experience in providing TO elsewhere. This service could also include setting up the TO stations, at least until the newly-formed joint venture acquires the relevant experience.
5) Both the deployment of the TO center and the provision of the TO service would be done by

the local joint venture of local transport providers and the port authority. The pricing of the TO service would probably be usage-based, relying on a software platform that records how the time spent by teleoperators in the required task. The customer of the service will depend on the specific use case: for instance, the port would pay for the teleoperation of cranes, while a logistics service provider would probably be the one billed for the teleoperation of platoon forming.

6) Container ID, VRU warnings & automated docking. The information services (i.e., container ID recognition and VRU warnings) are offered by specialized information service providers to both the TO service provider (who includes them in the dashboard to inform a remote operator) and freight service providers or terminals. These flows are represented by 6.a and 6.b, respectively. In the case of automated docking, this model assumes it to be offered as a service to logistics players by a specialized service provider. The first deployment scenario already offers a high potential for added value by these services.

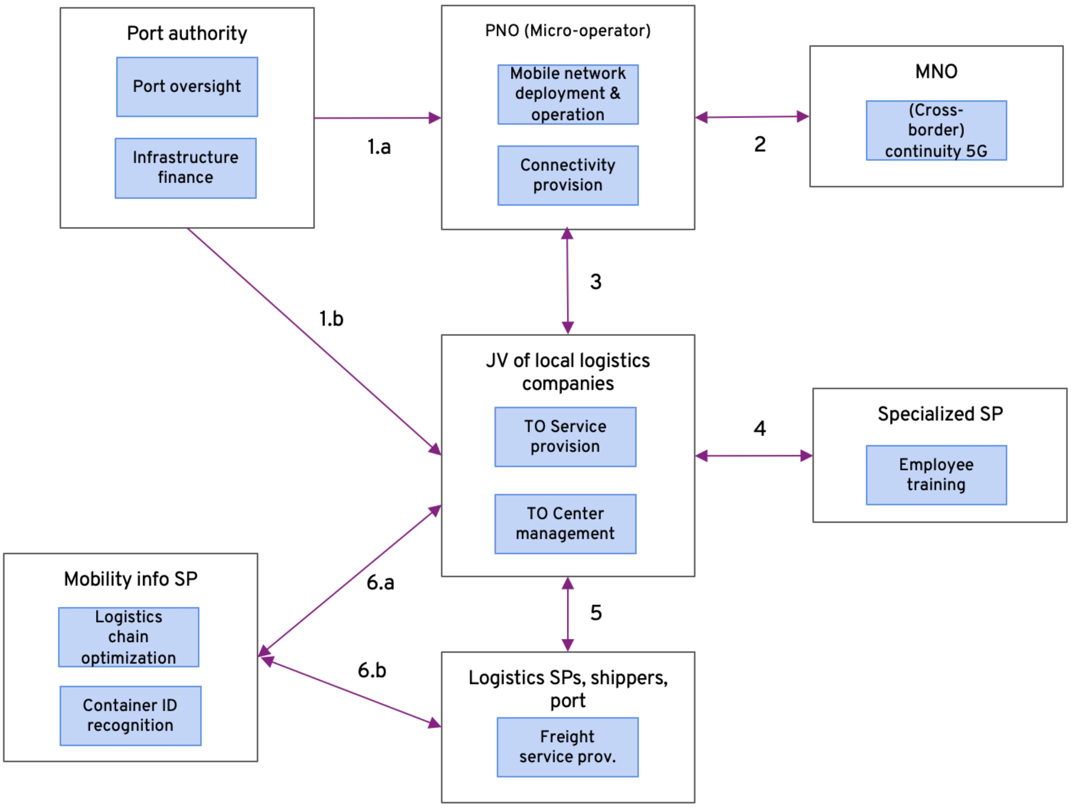

Figure 7. BM1: Local deployment in port and local TO platform.

BM2: Local deployment with public network coverage on-demand and independent TO provider. In this second model, the manager of the specific site remains a key enabler, although its financial contribution is not as high nor direct. Indeed, the port authority or large industrial site owner plays more the role of orchestrating than financing. Compared to BM1, here the port's financing of connectivity is limited to a possible contribution in the form of co-investing with the MNO (hence the dotted line in transaction 1.a in the value network below). Moreover, the contribution to finance the deployment of a TO center would be limited to offering real estate at preferential rental prices, at least in the initial stage; for instance, in the form of office space on existing buildings or in the form of land on which to build the Center. Via the offering of coverage on-demand, the MNO upgrades the capacity of its public network in the port and offers the connectivity service for TO. Similarly, the deployment of the TO center and provision of the TO service is done by an independent service provider, such as the ones mentioned in the market analysis of section 3.

In comparison to the previous model, the main advantages of BM2 are:

- A higher simplicity, since 5G connectivity is still customized to the KPIs required by TO, but the operation of the network is taken care of by the MNO.
- Less technical barriers for seamless connectivity roaming, since managing the handover between public and private networks becomes unnecessary when leaving the “ coverage on-demand area”.

On the other hand, the comparative limitations of this business model are the following:

- First, a lesser flexibly in term of network resource management, as the traffic levels supported will rely on agreements with the MNO.
- Second, the challenge of convincing companies with a broader geographical focus to come invest in the local area. This applies to both connectivity as well as TO service providers.

Figure 8 plots BM2’s main actors, roles and interactions, listed below. As it can be seen, this model yields a more integrated value network when considering the identified key value network roles, which are concentrated in just four different stakeholders:

1) The port authority possibly contributes to invest in the required network infrastructure upgrades (1.a) and finances the deployment of the TO center by providing office space or land at below-market prices (1.b).
2) The public networks of the MNO provide enhanced coverage on-demand, enabled by the required infrastructure upgrades. The proportion of co-investment will depend on the opportunities to find alternative revenue streams for the connectivity service in each port or site. The MNO is thus the connectivity service provider in this model, pricing its connectivity service based on the actual usage.
3) The TO service and the management of TO center offered are offered by the same party, namely an independent TO service provider. We assume that the likely value proposition would be an E2E service, meaning that employee training as well as other necessary aspects to remotely operate a crane or truck (e.g., SIM card, retrofitting of hardware) are taken care of by this party and priced in the TO service.
4) Container ID, VRU warnings & automated docking (same as in BM1).

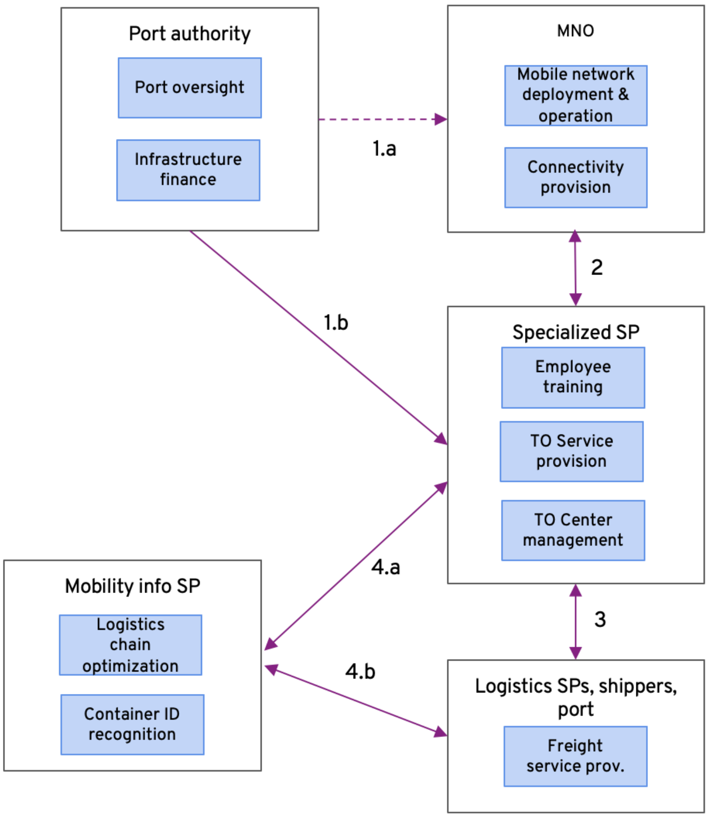

Figure 8. BM2: Local deployment with public network coverage on-demand and independent TO SP.

5.5.1.2 Scenario 2: major transport axis with significant transport flows

As indicated by its name, this scenario involves the deployment of TO services along a major transport axis, either by road or waterways, where a significant volume of transport flows is present. An example would be a canal between two ports in the same country. Here, we assume that Scenario 1 is incorporated as part of a larger deployment. And compared to scenario 3, this deployment would offer a more limited geographical scope both in terms of routes covered and the fact that these routes do not cross borders. The deployment options for teleoperation in Scenario 2 were identified in section 5.4, and included the following:

- For the shorter term, relying on automation levels beneath L4:
  - The direct TO of barges with a captain still on board, who would take care of complex maneuvers.
  - Also for barges, TO as support to other tasks besides navigation, which would help increase the operational time per manual worker and thus reduce the size of a ship's crew.
  - Direct TO of trucks when joining and leaving platoons. This scenario offers higher potential for platooning, in terms of the possible length of platoon journeys.
- For high but not full automation (i.e., L4), assumed to be feasible in the upcoming decade:
  - Direct remote operation of barges used to complement autonomous driving, with the captain located in the TO center on shore.

We will focus on the use case of direct TO of barges when used sporadically to support AD systems when these need assistance, for instance because they encounter a more complex situation that a remote human operator would be able to perform in a safer way. The main reasons are that (i) it is a more distinct use case to the ones considered in scenarios 1 and 3 (based on the feasible deployment options identified), (ii) it offers the highest economic potential among the feasible options, and (iii) it also shows higher complexity from a business model perspective.

BM3: Dynamic network slicing brokerage for TO of barges, with E2E TO services. This business model relies on the concepts of network Slicing-as-a-Service (NSaaS) and slice broker. In this model, port authorities (in the incorporated Scenario 1) as well as TO service providers lease customized slices from M(V)NOs, according to their specific QoS requirements. Therefore, they act as slice tenants. NSaaS can be provided dynamically, as network requirements vary in time, for instance if network traffic increases due to higher demand leading to a higher volume of vessels being teleoperated. The specific resources, priority promises, and liability contingencies incorporated in the slice are drafted into each bilateral SLA, based on templates. The M(V)NOs acquire virtual network resources on-demand via a slice broker role, who pools and assigns these resources from various infrastructure providers. TO service provision is again provided by a specialized service provider that offers an E2E, integrated service (i.e., similar to Seafar's current model in Belgium and the Netherlands) and deploys its own TO center.

On the connectivity side, this business model offers customized and flexible connectivity. Compared to subscribing to a general, public service for connectivity, NSaaS offers priority on network resources, as well as higher flexibility to both connectivity customers and providers. Customers like ports may contract different slice types for different uses (e.g., an mMTC slice for multiple devices requiring low throughput and a URLLC-type one for TO). To M(V)NOs, it offers the possibility to charge based on the actual QoS offered, for instance in terms of latency levels. This brokering model also allows for a fast assignment of the aggregated available network resources. Compared to private network deployments and coverage on-demand, the flexibility of NSaaS can provide a quicker time-to-market deployment of high QoS connectivity. Nonetheless, this business model also has limitations: for instance, the introduction of the extra brokering role also introduces an added layer of complexity.

On the TO service side, this E2E model, with everything integrated into a single offer, also provides a quicker deployment, presenting an easy-to-adopt solution to logistics customers. The TO SP is thus a key enabler of TO in each specific water-based transport axis. In addition, this model relies on a use case that already exists, albeit to a more limited extent, and for which TO SPs are already in the market.

Figure 9 plots BM3's main actors, roles and interactions, listed below:

1. The slice broker pools and aggregates resources from multiple MNOs or other infrastructure providers (such as non-operator network owners, i.e. neutral hosts). These deploy 5G networks alongside waterways, together with virtualized network infrastructures in their core networks. The price offered to these resource providers can be based on the dynamic auction prices that in turn arise from the bids of M(V)NOs, and in turn from the demand of connectivity for TO at each point in time.
2. The slice broker allocates resources or slices based on the aforementioned bidding process. It may be that the slice broker is actually the one that creates the NSaaS, and the M(V)NOs are the slice tenants, who sell connectivity to TO service providers and ports, thereby implying a B2B2B model. Alternatively, the connectivity customers may be the slice tenants, if they choose to have more control over the slice.
3. The connectivity service provision by M(V)NOs may be provided in exchange of a fixed subscription fee for the priority service to guarantee reliability on high QoS, together with usage fees.
4. Lastly, a specialized service provider would provide the TO service and the deployment and management of its own TO center. The integrated E2E service may be priced, for example, through a subscription with fixed rates per volume, or through dynamic spot prices, charged per ride and based on demand. The latter would make sense at a time where there is a spike of demand, because a limited availability of teleoperators would entail waiting times to be assigned to one. In that case, we assume that TO customers would show a higher willingness to pay for priority, and thus for the higher resulting uptime.

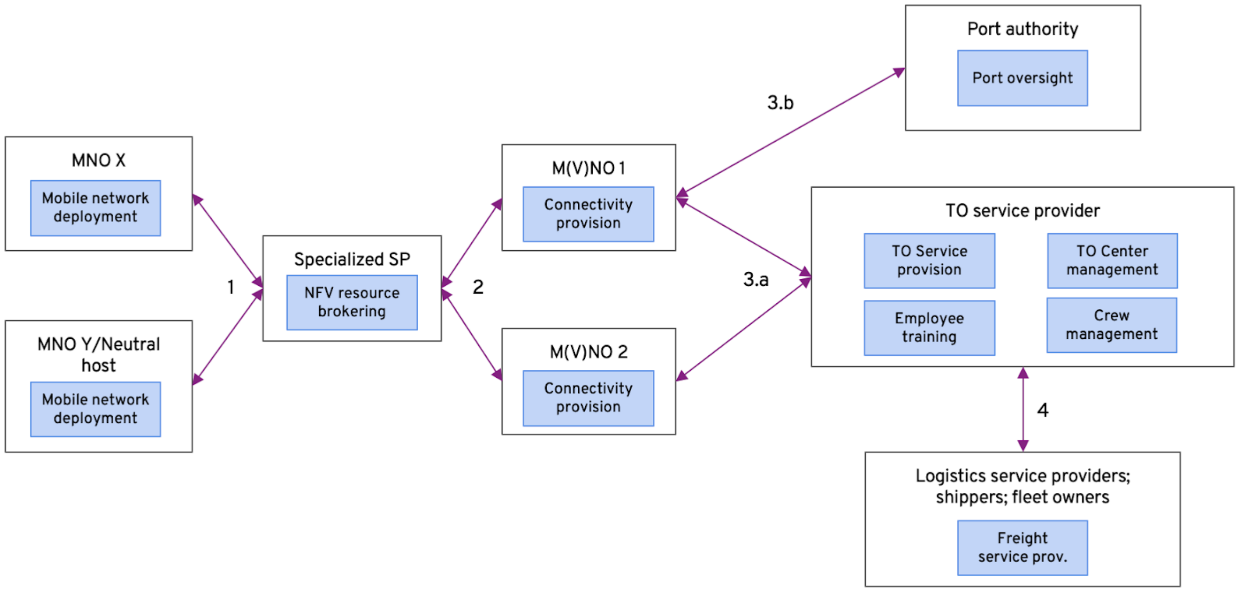

Figure 9. BM3: Dynamic network slicing brokerage for TO of barges, with E2E TO services.

BM4: Deployment based on 5G network sharing and a large transport company as TO SP. This model provides a variation on the levels of connectivity and TO service business model options. Here, MNOs densify their networks along waterways by relying on active network sharing to substantially reduce costs while building networks that support the high QoS. MNOs would enter agreements to jointly invest in masts, antennas and other RAN elements. An underlying assumption is that, in this scenario, such infrastructure deployments would mainly target the single use case of TO for water transport, for which MNOs, individually, would not see a clear return at an initial stage. Since MNOs deploy new networks (or network elements) based on multi-MNO network sharing, the relevant national or EU authorities will need to ensure that these agreements do not adversely affect competition beyond unacceptable levels, especially in case of bilateral agreement in those countries with only three competitive MNOs.

Regarding the TO service, the provider would be a transport company, similar to the case of BM2. However, in this model we assume that the transport company would be one with a larger geographical presence (e.g., a shipper with a large fleet). The reason is that substantial goods transport volume would be necessary to see a business case in deploying one or many TO centers and building the capabilities to provide TO services in this context. In an initial stage, if adoption by competitors in a certain area is slow, it would run the risk of only being able to provide services for its own operations. As new players become inclined to explore the market for TO services, this first-mover can lease its TO stations if it has excess capacity, which may incentivize scalability while allowing fair returns to investment for the deployment of the TO center. This may be more realistic, however, when the new TO providers focus on different use cases, since otherwise it could be seen by the first-mover as a threat to its competitive advantage.

Transportation companies may be interested in taking up the role of TO SP: they can retrain their current drivers or captains to be licensed to remotely operate vehicles. This could be considered a transitory solution, and over time be phased out, transferring this SP role to a third party. Alternatively, it could be a hybrid case, with the transportation company keeping some drivers on the payroll to cover its baseline workload and hiring a third-party TO service provider to cover temporary peaks in demand.

Once again, we map the main actors and interactions in a separate figure (see Figure 10).

1. The connectivity service provision may be provided by the MNOs in exchange of a fixed subscription fee in addition to usage fees. A possible variant is that MVNOs provide the connectivity service. Certain specialized MVNOs may be more ready to immediately sell attractive connectivity services or packages to TO service providers than nation-wide

MNOs, e.g. due to being specialized in B2B or URLLC use cases and services. MNOs would then sell wholesale access to these intermediaries; their network sharing agreements could contemplate revenue sharing in such cases.

2. It is likely that a more experienced independent TO service provider provides employee training as a service to the focal TO SP in the model, which is newer to the market. For similar reasons, crew management may be provided by the experienced SP as well, at least in an initial stage.
3. The transport company provides the TO service from its own remote control center.

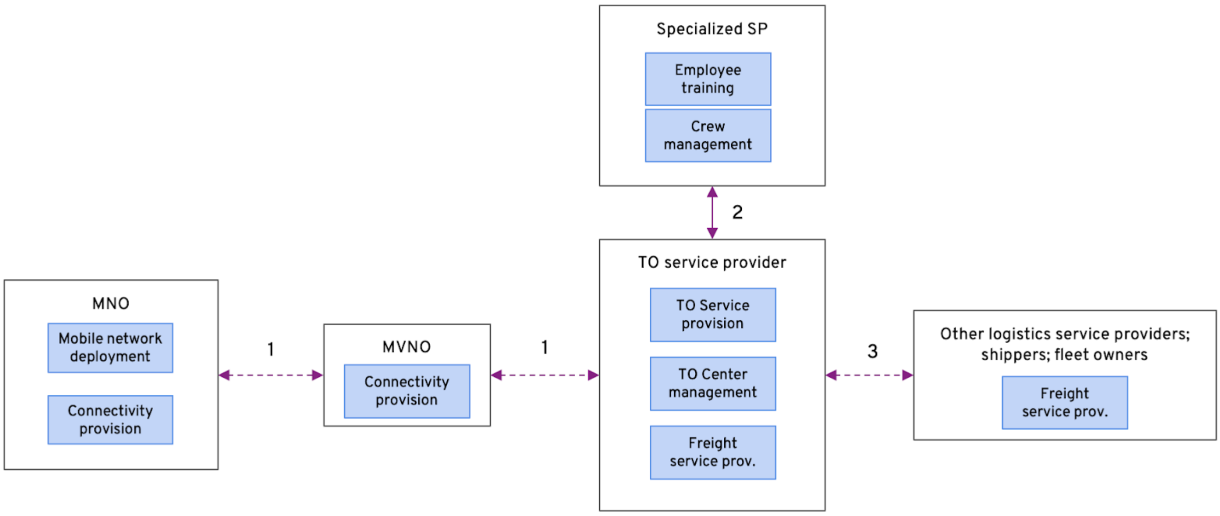

Figure 10. BM4: Deployment based on 5G network sharing and a large transport company as TO SP.

5.5.1.3 Scenario 3: public road or waterways, across national borders

This is the most ambitious scenario, with the largest scope in terms of geographical reach. It also entails the highest complexity for the continuity of service problem, involving handovers between public 5G networks and between remote drivers located in different TO centers. On the bright side, it also offers the greatest potential for economic benefits, in large part because it enables autonomous driving for large journeys, subsequently increasing operational uptime substantially. These potential benefits were exemplified by the business model for road transport with L4 AVs that was analyzed in section 5.4.3. Here, we will build on the already in-depth analysis of that model, extending it to consider 5G and TO service aspects to more extent. Therefore, the examples below focus on direct TO of trucks as a complementary process to AD, e.g. when safe driving requires human intervention in complex local roads or after sudden fallback. Again, we limit our analysis to the use case that offers the most distinct characteristics compared to the examples above and the highest uncertainty (out of the possible deployment options) from a business model perspective. The model in section 5.4.3 assumed the previous scenarios to be included as well, implying a wider deployment and the coverage of the entire transport journey from the continental port to the destination of the goods.

BM5: OEM as TO SP with traffic manager as neutral host of the TO center. In this model, a vehicle manufacturer integrates the role of TO service provider. At an initial stage, OEMs may prefer to take up this role to control the choice of what HW and SW systems are integrated into their products to perform TO, for security and/or interoperability reasons. They may also be reluctant to let a third party play this role if the OEM would retain the liability in case of overall system failure. In the longer term, TO capabilities would be included in the manufacturing process, and the TO service could be offered as an added value service in the value proposition of OEMs. In this model, the TO center would be co-located with a traffic management center; the traffic manager would be the infrastructure owner and lease office space for the TO stations.

Network infrastructure deployment will be done by either MNOs or neutral hosts. This will depend on each location: around main transport hubs and urban areas, it is expected to be more feasible that an MNO is willing to invest in deploying its own 5G SA network in the short to mid-term. In contrast, non-densely populated areas would be more likely to rely on ‘neutral’ infrastructure providers that host multiple MNO tenants, in order to speed up deployments.

This model could take shape in different variants or hybrid versions, leading to different outcomes in terms of the integration of roles. For instance, with the trend towards autonomy, and the driving task being outsourced to a remote driver, business models for vehicle ownership may also change, with OEMs keeping fleets of their branded AVs in their balance sheet to become (mobility or logistics) service providers. If current transport companies outsource the driving task and do not own their own fleet of trucks, their business model would resemble more that of a broker who indicates to the TO service provider where to pick up and deliver its client’s cargo. This would also make it more likely to be disrupted by a digital platform like the one in BM6.

Yet another variant is possible, yielding even more integration. Competing directly with freight service providers, the OEM may even become a capacity or logistics service provider itself. This could be more likely for newer companies that are born with a non-traditional strategy when approaching TO or vehicle manufacturing; for instance, as reviewed in section 3, Einride explores TO services for its own designed vehicles.

Figure 11 plots BM5’s main actors, roles and interactions, listed below:

1) The neutral host would lease access to the network infrastructure to different MNO tenants.
2) This refers to cross-border handover and continuity of service by the device’s home MNO, which is roaming into a visited network of another country’s MNO. The service would be provided between MNOs in exchange for a fixed fee plus a possible premium for priority of network resources in certain locations.
3) In turn, the MNO would sell wholesale access to MVNOs, or sell them customizable slices for them to operate as tenants.
4) The customer of the connectivity service provision for the SIM card attached to the vehicle may be the TO service provider in a B2B2B fashion (4.a). The TO SP would then include the connectivity costs for the actual usage due to TO in the transportation company’s bill. The end customer may be offered the choice of which M(V)NO to contract. Alternatively, the connectivity may be sold directly to the end customer (4.b). In the figure, the arrows point at either an MNO or MVNO simply for simplicity reasons; either party may provide the connectivity service in both 4.a and 4.b.
5) As mentioned above, traffic managers in each country deploy TO centers within their traffic control centers, and leases space to the TO service provider (5.a). To monetize the deployment and operation of the traffic control centers, they may use distance-based road tolls, collecting data from a truck’s OBU and GPS to calculate the relevant amounts and charging the freight provider for the use of automation in a country’s roads (5.b). This would be more likely when the traffic manager is–or is linked to–the road operator.
6) The OEM TO service provider would offer teleoperation of its own branded trucks or its own fleet of trucks to a transport company. The dotted arrow shows the variant discussed above in which the TO SP also offers the transportation service.
7) A more experienced TO SP, or a specialized company, would provide the training and licensing of remote drivers, which the OEM would employ and assign to a local TO center.
8) Logistics chain optimization messages (i.e., VRU warnings, ETA sharing, etc.) are assumed to be provided as a service by specialized information service providers to both the TO service provider (who includes them in the dashboard to inform the remote operator) and freight service providers. These flows are represented by 8.a and 8.b, respectively. Those services offered in terminals, such as automated docking and container ID recognition, can be assumed to be included–when scenario 3 incorporates scenario 1 as well– and offered as in BM1.

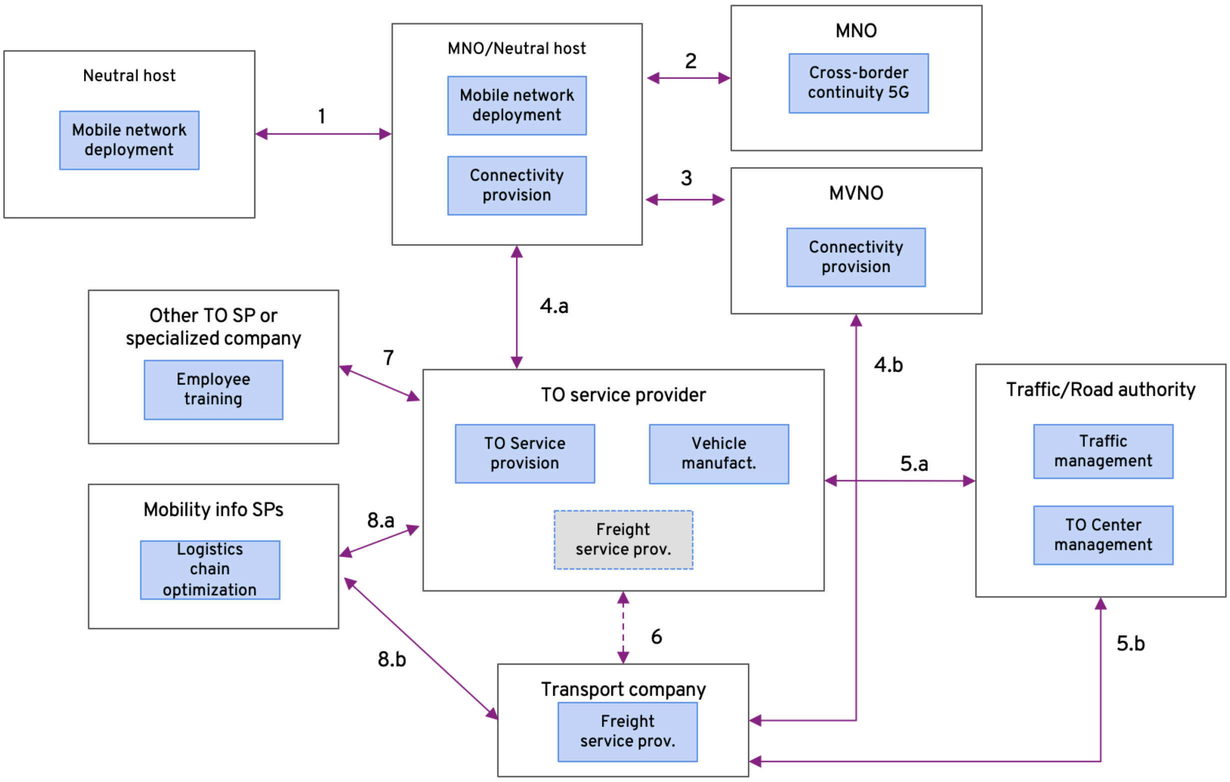

Figure 11. BM5: OEM as TO SP with traffic manager as neutral host of the TO center.

BM6: Large international TO SP platform. This last model is a simpler, more integrated one. Network deployment and connectivity aspects remain the same as in BM5, so here the main differences appear at the TO level. The focal actor of this model is the TO service provider, which takes the form of an intermediary match-making platform, owned by a large firm that offers this service across Europe. It owns its own TO centers and can therefore tackle demand for goods transport journeys throughout the continent, keeping any remote driver handovers internally. For the same reasons it is also able to anticipate demand for truck platooning and coordinate trips to optimize the chances that long-distance platoons are formed. The platform would employ its own certified crew of TO drivers, offering training in-house. It would not, however, own the trucks, adopting an asset light model that would allow it to scale with less financial resources. The ability to scale fast will be important in this business model, in order to be the first to enter new markets as the commercial viability of new deployment areas becomes clear.

Customers of the platform (e.g., transportation companies) would have a subscription for access to the service, and constantly send data on the location of their vehicles. Based on their AVs' ETA, the transport company would issue a request for teleoperation in a more complex local road, or when being notified that a truck has stopped, maybe after the traffic manager has 'uncleared' a route. The handling of requests in case of spikes of demand could be based on priority fees, possibly contracted via different subscription grades. In addition, the platform could leverage its AI software capabilities to offer freight trips as a service to shippers, efficiently matching their demand for goods transport with the available supply from transportation companies or other truck fleet owners. A similar revenue model already exists for road transport services, more specifically for the logistics spot market, and is offered by digital apps like Uber Freight and Convoy.

An important question would revolve around who buys the (autonomous) trucks in a future scenario. As shown in the cost-benefit analysis of section 5.4.3, the business case would depend on a minimum threshold in terms of volume of trips being automated/teleoperated. This threshold would be higher than the one initially estimated if connectivity-related expenses were to be taken into account. To reduce the risk of not having enough ROI, the platform would seek to incentivize fleet owners to renew their fleets. It would also try to incentivize new parties to become AV fleet owners; new truck fleet owners could act as asset providers, not needing to drive them themselves and relying on logistics companies to arrange the freight trip. Besides offering lower costs than conventional transport, it could cross-subsidize these target fleet owners by using slightly higher prices to those customer types with a higher willingness to pay (i.e., the shippers, fleet owners, transport companies).

Finally, we plot BM6's main actors, roles and interactions in Figure 12. Connectivity and roaming services (flows 1 to 4) remain the same as in BM5. The same holds for the information services that are ultimately displayed in the remote operator's dashboard (#8). The differences appear for the interactions around the TO platform:

5) Traffic managers are assumed to play the role of the control center in 5.4.3, allowing autonomous driving on roads at each given point in time. Compared to BM5, in this case they would charge the TO platform provider for their service.
6) The TO Service would be offered to transport companies as well as providers of passenger transport services, in order to scale up the volume of TO operations. This TO service would be offered in exchange of a subscription for access to the service, with higher price tiers for guaranteed priority.
7) The TO platform would match transport companies and other fleet owners (7.a) with a shipper's demand to bring goods to a specific destination (7.b). It would allow the shipper to book trips via the digital platform, probably via a 'surge pricing' revenue model.

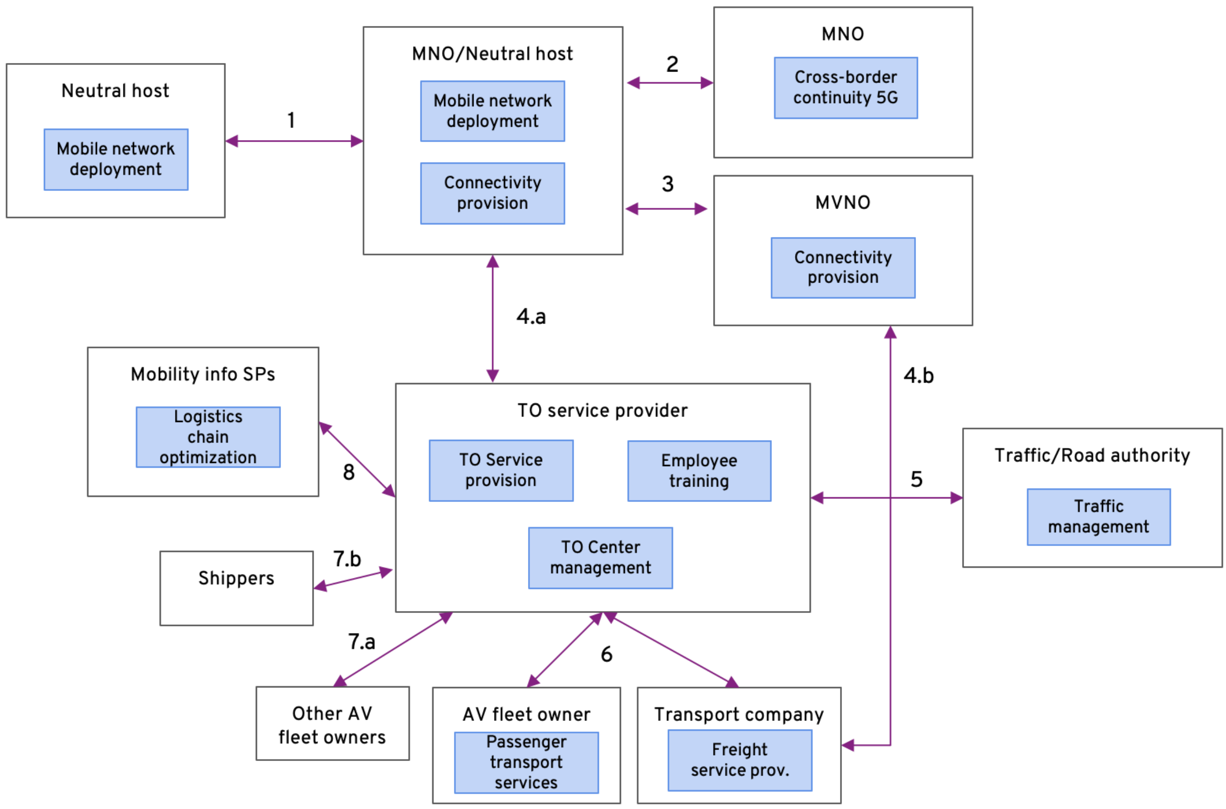

Figure 12. BM6: Large international TO SP platform.

5.5.2 Remaining challenges and the role of passenger transport

Enabling teleoperation (TO) requires investing in multiple elements. The main necessary investments we have considered include 5G network infrastructure deployments–whether upgrading or densifying current public networks or deploying new private ones to offer higher network capacity and stringent requirements–and setting up TO control centers. Such financial investments are large and subject to the risk of not being recovered or not yielding a sufficient return on investment. Therefore, these investment challenges can act as a barrier to the deployment of TO in practice.

The discussions in previous sections show that deploying TO solutions exhibits a mutual dependency among multiple stakeholders. It represents a big risk to bear the costs of undertaking any initial investments without the security that complementary elements will be deployed by other stakeholders. Due to the convergence of the 5G, transport, and teleoperation value chains, the resulting value network described in section 4 was a complex one. There is the risk that other necessary elements to enable TO are not available when an entity invests in one of them, which include vessels/trucks, TO technology, TO centers, 5G coverage, or even regulation to allow TO in certain routes. For MNOs, other elements also include use cases beyond TO: monetizing the rollout of 5G infrastructure will likely require finding alternative revenue sources, since the potential benefits of a single use case like TO are not likely to provide enough return for the required investments in 5G infrastructure deployment.

This uncertainty can disincentivize the different actors to move first to deploy a partial but yet crucial element behind TO use cases, thus taking a reactive approach and waiting for the business case of TO to be clearly demonstrated, which in turn is something that may only happen after the infrastructure investments have been made. This would result in a chicken-egg problem.

To help overcome this chicken-egg problem, it would be helpful to have an entity that acts as an orchestrator and/or kickstarter. An orchestrator would foster long-lasting relationships within the ecosystem, helping establish connections among different partners and encouraging them to work together and share their knowledge and resources. This would reduce the uncertainty that (i) TO is deployed and gains adoption and that (ii) there will be a long-lasting use of TO in an area, which will be important for firms to be able to recover their initial investments. Similarly, a kickstarter would take the lead in getting this ecosystem up and running by (partially) investing in TO and 5G infrastructure itself. This would help reduce the uncertainty about the different required elements becoming available.

Since it was unclear who would take up these responsibilities, 5G-Blueprint project partners engaged in a discussion to tackle the following questions: first, who could act as ecosystem orchestrator? And second, who could kickstart TO in a certain deployment area? In the paragraphs that follow, we discuss the concerns and potential role of several stakeholders in undertaking infrastructure investments or in collaborating in the form of co-investment.

Port authorities and industrial site owners. Participants believed that demand for teleoperated road transport will start locally, based on dedicated deployments at port or industrial sites before it can scale to a nationwide or a European-wide basis. Port authorities are a point of contact for many actors that operate in and around the port. They can identify what stakeholders are best placed to deploy TO in their area, and in certain situations may orchestrate and even kickstart deployments, with the longer-term goal to leave it up to market players with the specific knowledge to continue operations. From their central position and their long-term interest in increasing the efficiency of logistics operations within the area, they can be seen as a trusted partner to the different port stakeholders. In BM1 (see section 5.5.1), the port authority was assumed to contribute to the financing of a private 5G network and a JV that plays the role of TO service provider. In BM2, the port's role was more limited but still crucial, for instance in offering infrastructure elements that can be reused by many of its customers. To provide a relevant real-life example, the Port of Antwerp kickstarted a project with autonomous drones, in which the port authority owns the equipment but a third-party service provider performs the drone flights.

Logistics players. Related to the reasons given in the case of site owners, an entity that operates at a large scale and can 'divide the pie' would likely be more incentivized to orchestrate an incipient TO ecosystem. An example of logistics players fitting this description are freight forwarders, who usually handle cargo around the globe, taking care of documentation and other processes. They would have an immediate benefit from TO, especially if they can get a piece of the benefits that would accrue to inland road or water transports. In contrast, a single local transport company would likely not have enough operational volume, hence generate enough TO demand, to see a business case in investing on infrastructure alone. A freight forwarder may thus play a kickstarter role and share the resulting cost benefits with the different regional logistics companies that will make use of TO. An alternative option would be that local transport companies form a consortium to invest in infrastructure collaboratively, similar to the case in BM2, where it was assumed that local JV would take up the roles of TO center management and TO service provision.

Entities supporting regional economic development. These entities can inform and give advice to companies and ventures within their region, but they find it hard to convince these companies to invest in a particular technology before they can see a clear business case in it. These entities can incentivise deployment and adoption by:

- Setting up public-private partnerships with the objective of encouraging leading industrial incumbents to establish connections with regional startups.
- Similarly, they can set up public-private consortiums for research projects that explore the innovation in order to clarify its business case. For example, Impuls Zeeland advised regional companies to join the 5G-Blueprint's project consortium.
- In addition, they can provide tools that help find partners across sectors and establish networks of partners, both nationally and internationally.

Public authorities. Public agencies like governmental divisions and road authorities can help reduce uncertainty by coordinating and (partially) funding initial research projects, to help clarify the business case and technical feasibility of an innovation such as TO. They may also stimulate its deployment by orchestrating the new ecosystem, helping partners find each other and connect, as mentioned for the entities in the previous paragraph.

While partners should not passively expect a public entity to deploy TO technology and infrastructure elements, governmental financing can play a supportive role. This may include government grants and subsidies, tax incentives, etc. Public funding makes sense when there exist positive externalities that could cause market forces to undersupply. Public funding would thus aim to ensure the required investments are undertaken and the valuable services supplied. Positive externalities would exist if TO SPs were not able to price in the overall benefits that arise from TO use cases in their TO service offers; TO can yield safety, environmental and labor market benefits, and be a step towards autonomous driving for both logistics and passenger transport, but the anticipated benefits in terms of operational efficiency may not be enough for logistics customers to be willing to pay the premiums that the required infrastructure investments entail. For a public authority to invest, it would need to clearly envision the expected societal benefits of TO, which in turn would require to scale deployments to the wider scenarios 2 and 3.

Public (pre-commercial) procurement can also be a useful channel to kickstart a TO ecosystem. Recent governmental initiatives supporting large scale deployment of telecommunications and data infrastructure for CCAM include the Talking Traffic (2016-2020) and Mobilidata (2018-) projects in The Netherlands and Flanders, respectively. They both covered day 1 and 1.5 C-ITS use cases. Talking Traffic (2016-2020) was organized as a form of public procurement paradigm: the Innovation Partnership. This form of public procurement was introduced in Directive 2014/24/EU, more specifically in article 31. This procurement form is designed for situations where the contracting authority needs an innovative product or service that is not yet available in the market. Innovation partnerships shall aim at both the development and subsequent purchase of an innovative product or service for a limited amount of time, provided that the resulting products meet the thresholds agreed upon, in terms of performance and cost. In Talking Traffic, the public funding was brought together by about 60 national, regional and local authorities, and the participating private companies co-invested for the same amount as the funding they received. In Flanders, the Mobilidata project is organized as a so-called competitive dialogue. This is a form of public procurement explained in article 30 of Directive 2014/24/EU. This procurement channel is best suited for innovations with an already higher maturity level.

International TO service providers. An identified risk was the fact that no entity sees a business case in investing to deploy TO services in a specific area, especially if the possibility to scale towards wider deployment scenarios (i.e., long stretches of public roads or canals) remains unclear. A clear business case may be more obvious or available to an international actor that, via an integrated business model, pools demand and revenues from several customers across different locations and UCs. As in BM6 in the previous section, a kickstarter could be a firm that strives to dominate the value chain, integrating many roles within its digital platform. Such platform business models benefit from unlocking network effects from a wide customer base, and have the ability to cross subsidize between different customer segments, i.e. providing services to one side within the platform, at a reduced cost or for free, at the expense of another, more profitable side, in order to foster the growth of the earlier. This cross-subsidization can compensate for the lack of willingness to pay from one of the sides (e.g., fleet owners or transport companies). At the same time, customers enjoy the convenience of getting E2E TO services from a single source that deploys quickly in their area and takes care of all necessary elements (e.g., employee training, contracting 5G services, retrofitting vehicles with TO technology, etc.) However, this type of model carries the risk of yielding a less preferable economic outcome, in terms of market power and competition.

For such platform-based TO service providers, enabling passenger transport use cases would be interesting to pool demand from different customer segments. Servicing different transport types would give them the ability to more easily balance out peaks of requests across UCs, hence reducing operational downtime of remote operators and increasing volume of operations. The next section will discuss business models for TO services for passenger transport UCs.

Mobile Network Operators (MNOs). Section 5.1.4 listed different degrees of co-investment among MNOs and between MNOs and local stakeholders. The business model examples in the previous section incorporated some of them, but here we assume that the cost savings derived from neutral host models and network sharing are not enough by themselves for MNOs to invest on their own.

MNOs will aim to generate economies of scale by using their 5G infrastructure to service different use cases that benefit from an enhanced service and coverage. The ability to monetize network investments will depend on finding alternative revenue streams to TO in the same deployment area. Because an isolated use case like TO will be unlikely to provide enough return from the connectivity service alone, MNOs will be reluctant to single-handedly invest in increasing coverage in the short term only for TO services.

While 5G offers the opportunity to unlock new revenue streams from B2B applications, the availability–or reachability–of commercial opportunities is more limited along transport corridors. From a financial perspective, large-scale deployments of 5G infrastructure are especially challenging along highways and waterways, as well as in cross-border areas. In these areas, finding alternative revenue sources or co-investing will be more important than in ports or industrial areas, where there are more readily-available potential 5G connectivity users. MNOs face the risk that the ROI from teleoperated goods transport is not enough for the required deployment of cell sites to roll out upgraded 5G networks along highways in the upcoming years. The risk is thus that, until the business case is clear, MNOs consider it safer to wait for their roll out of 5G nationwide coverage, which is still expected to take a few years in Belgium and The Netherlands. Highways offer limited opportunities besides covering vehicles and passengers (in-vehicle infotainment services, remote diagnostics and maintenance, software updates or C-ITS services). However, TO for other use cases can bring an increased high-QoS traffic volume per cell site. Consequently, the next section will elaborate on business model considerations for teleoperated passenger transport UCs.

5.5.2.1 The role of passenger transport use cases

The discussion above shows how considering passenger transport use cases (UCs) is important, since they can provide an additional revenue source while sharing (some of) the same network and TO infrastructure resources. This could be potentially crucial to make 5G and TO deployments financially feasible, especially in inter-urban road scenarios. Both MNOs and TO service providers may need more volume of operations to see a positive business case in upgrading their networks and investing in real estate and setting up TO stations. The same argument may apply the other way around: passenger transport UCs could leverage the volume of operation and demand of the logistics sector.

Based on our findings so far, which focused on business models for road and waterway goods transport, we provide a brief discussion about TO for passenger transport. We start building on the generalization in D3.1 [8], extending it with some new business model considerations. D3.1 studied the opportunities and requirements of TO for taxi and bus services. Also for these UCs, TCO benefits–mainly from labor costs–can be expected from the same remote operator being assigned to multiple vehicles. These benefits can be further increased if remote operators could shift their focus between different UCs on the basis of their respective demand; for example, being assigned to a truck during periods of high demand for goods transport, assuming these coincide with off-peak hours for passenger transport. However, this entails the challenge of training remote operators to be certified to operate different types of vehicles.

Specifically for taxi services, the potential of TO arises from the idle time that taxi drivers have to spend waiting for a new ride. However, TO will not be able to fulfill customer needs for passengers that require physical assistance from the driver; a driver's help is valuable when helping passengers enter or exit the taxi and when carrying luggage, especially in certain locations like airports and with some customer segments like elderly people. Another caveat is that, compared to manual drivers, remote operators will not be able to provide first-aid to passengers [8].

In the case of bus services, the potential of TO to bring operational efficiency gains is low compared to logistics and taxi services, since idle times are generally much shorter. However, while PTOs may only increase the use of drivers' time by 1 or 2%, this can have a considerable impact on profitability due to current profit margins being very small. The benefits of TO would arise from, among others, enhanced route flexibility: for those PT lines where bus capacity is hardly used during off-peak hours, TO will allow PTOs to offer services that are more linked to the demand for rides [8].

Besides bus and taxi services, passenger transport consists of a wide array of other types of transport: ride hailing, car sharing, car rental services, rides with privately owned vehicles, valet parking, etc. In these cases, TO can add value in the following ways, among others:

- **Relocating vehicles**. Relocation can be done for geographical re-balancing (i.e., moving vehicles across areas to better match the demand in each location), as well as to drive a vehicle to a depot for maintenance and cleaning, to a pick-up point, to a charging station, etc. TO can do this more efficiently, saving the travel time that a user or employee would take to reach the vehicle's location. For ride-hailing urban services, rebalancing across neighborhoods also reduces waiting times for end users. For car-sharing, relocating can lead to higher convenience due to having a car available in a more nearby pick-up point. More generally, relocation can extend geographical coverage of services, potentially addressing accessibility to mobility services in areas that are less covered by current offerings.
- **Doing valet parking** with TO can also improve convenience by shortening total journey times, as it implies that the driver is freed from driving in the last mile parts of the trip.

Below we review possible business models for TO with 5G in passenger transport UCs. As better explained in the literature review of section 2.2.1, previous European projects already described different business model possibilities.

The 5GAA Automotive Association [53] considered the following two types of TO services for passenger transport:

- First, a TO service for private cars where car owners pay for the service. In the proposed business model, the TO service provider owns and operates its own TO center, and invests in the network infrastructure upgrades. TO services for private cars can address several purposes or functions:

    - Enabling drivers to work while on their journey
    - Driving a person without a driving license or with a disability
    - Performing valet parking
    - For drivers who suddenly become unfit to drive (due to illness, alcohol consumption, etc.)
- Second, a TO service as support to AVs for fleet owners such as enterprises with corporate cars or urban ride-hailing platforms. These fleet owners may perform the remote operation of their own vehicles and manage their own TO center. The fleet operator role charges end users for the transport services, and contracts the connectivity service, insurance, and the TO service, which is performed by a dedicated service provider.

Similarly, Kettwich & Schrank [83] discuss the use of TO centers to monitor operations of highly automated shuttles used for public transport. Via the HMI, the remote operator monitors the locations of all shuttles in the fleet in real time, streams live video images of the shuttle, and is notified about emergencies (such as technical malfunctions or accidents). This relies, therefore, on indirect control, which entails setting waypoints on a map to define a trajectory for the vehicles, which the shuttle follows automatically. This entails that the intervention of remote operators is more sporadic and that the approach is less sensitive to latency and connection reliability requirements.

The startup Imperium Drive [84] recently advertised the intention to bring a TO service to market in the UK. In the envisioned business model, passengers request a ride via a mobile app, and a remote operator brings a vehicle to their location. The customer then drives the car manually to his/her destination, from where a remote vehicle operator takes over again and relocates the car to a depot or the next user. For car rental and car sharing services, the cited economic benefits include the ability to relocate cars more quickly at periods of high demand, which in turn increases utilization rates. Another benefit is flexibility: more efficiently relocating cars allows fleet operators to extend the reach of their operations and allows them to more cost-efficiently offer interurban one-way trips. This is a similar model to that assessed in d'Orey et al. [85] for urban taxi services, where also a remote operator drives a car to its pickup points, with the end user driving to his/her destination.

Technical hurdles aside, leveraging the demand of logistics use cases would make these models more financially feasible, since the investments in TO and 5G infrastructure could be shared among different parties, and MNOs would also see a clearer business case to take care of the upfront capital outlays.

Lastly, 5G-MOBIX [44] discusses a business model for TO to aid AVs in complex road situations. More specifically, it addresses a service by transport and tour operators in which autonomous buses drive between two cross-border municipalities. In this model, either the transport operator has its own control centers or, alternatively, an AV fleet operator offers the TO service to transport operators and takes up the costs of the TO center and the 5G service.

This last model is compatible with the deployment options and business models for our third deployment scenario (see sections 5.4.2 and 5.5.1). Offering TO services for passenger transport would help reach a higher scale of TO operations for cross-border long haul road freight. While, all else equal, this would risk putting additional stress on 5G networks, there would be the possibility to balance out the different peaks of demand to some extent, since tourism-motivated trips between the two cities would more likely happen during the day, while transport operators would want to maximize the uptime of their trucks by driving at night as well.

6 CONCLUSIONS

Teleoperation (TO) can help increase the operational efficiency of goods transport by enabling remote operators to take control of a different vehicle or machine while the current one must remain idle or when another operator or driver needs to rest, thereby increasing operational uptime. Teleoperation can also help enhance safety and reduce the current challenges in finding truck drivers and captains by helping improve working conditions. However, TO also imposes stringent requirements on the network, especially regarding latency and uplink capacity. 5G networks can alleviate this problem, but their pervasive deployment is expensive and guaranteeing service continuity with seamless cross-border roaming is challenging. Therefore, business models need to consider feasible options to monetize these deployment costs to enable TO in practice.

Delivering the value of teleoperation will also require stakeholder involvement in several roles and responsibilities, and collaboration in sharing data or liability, and possibly in co-investing as well. The business model challenges that can act as a barrier to the adoption of TO relate, chiefly, to uncertainty: uncertainty regarding the legal framework around remote driving or navigation, uncertainty regarding liability claims, uncertainty regarding the parties who will be responsible for the upfront investments in deploying or upgrading 5G networks as well as other TO technology and system elements, and uncertainty regarding when a wide deployment of TO will be technically feasible. Moreover, it is uncertain how the new use cases will be monetized. The risk this uncertainty carries not only affects the profitability prospects and thus the attractiveness of the investment, but compensating for it raises the costs of raising external capital from investors.

To be able to assess the economic impact of teleoperation in cross-border logistics settings, as well as to draft sensible business and governance models, we need to first understand the entire value network. In the value network analysis, we plot the main business roles whose involvement is crucial to enable the use cases of the project, providing a comprehensive description of the entire value network. Since 5G-Blueprint covers different deployment environments (i.e., roads and waterways) and aims to explore different use cases, the relevant value network is a complex one. We have identified six different layers, which in turn include several specific roles and responsibilities each. We have also allocated these roles to the specific stakeholders that are potentially willing and capable to fulfill them.

Building up on the identified value network, we discuss the main necessary interactions amongst stakeholders/roles in terms of liability shifts and data flows. Since teleoperation will bring new sources of risk, for instance from the malfunctioning of software or from an unstable 5G connection, it may imply a liability shift from traditional liable actors–largely, human drivers or captains on board of a vehicle–to new ones, affecting which entities will be responsible to contract insurance to cover liability claims in case of damage to the vehicle, the cargo or third parties. Ensuring stakeholder involvement may depend on future contractual arrangements to share liability: achieving an attractive business case may require MNOs, vehicle manufacturers, system integrators and TO service providers alike to assume part of the liability. However, a lot of uncertainty remains around legislative mandates as well as on multilateral agreements by market players in order to distribute the responsibilities. For instance, MNOs may assume liability, to some extent, for damages caused (indirectly) by the underperformance of their networks in terms of reliability and latency. While SLAs between TO and 5G service providers cannot guarantee the QoS required by TO with absolute reliability, they may include promises and associated penalties based on the service levels that the network can provide in each given area.

On the one hand, regulation regarding liability will affect the resulting business models, for example if OEMs choose to integrate all the enabling hardware and software themselves–or even integrate the TO service provision role–in order to avoid assuming responsibility for damages caused by retrofitted third-party systems. Currently, providers are responsible for the safety of the entire systems delivered to customers, being liable for any situation in which the vehicle or machine is used within its operational design domain. This means that truck manufacturers are the responsible actors for the safety of the vehicles they sell, even if they integrate components from other parties. On the other hand, business model choices will also affect how liability is distributed within the value network. For instance, with the introduction of remote operation, transportation companies will face the following choices: will they prefer to have their own trucks and employ their own drivers, or rather contract the entire TO solution from a service provider? A negative answer would not only entail changing their traditional business model to become a kind of broker–one that indicates the TO service provider where to pick up and deliver its client's goods–but also their willingness to remain the responsible party for the integrity of the cargo.

Data transactions are also relevant to consider. The sharing of data stemming from multiple sources–including within vehicles, road user devices, and road infrastructure–is key to support or enhance remote driving. We have provided an understanding of the main data sources and types that need to be shared, aiming to give clarity regarding which specific actors will be responsible for providing them. In addition, we highlighted the main data that are required to perform several key roles in the value network. At the center are those data streams that are sent from transport, information and connectivity service providers to the teleoperation service provider, as well as those shared between the remote control station and the remotely operated vehicles.

In addition, it is important to identify any potential bottlenecks to the adoption of the different value network roles and responsibilities and, consequently, to the adoption of 5G Blueprint's use cases. We discuss the challenge of providing uninterrupted high QoS connectivity, which relies on seamless session handover between a private and a public network or, when a vehicle crosses a border, between public networks of different countries. From a business perspective, this entails a coordination challenge among MNOs, and would require much more complex roaming agreements than the current available ones. Standardizing future handovers will require defining new international templates, the specifics of which remain a topic of further research.

We also explored what would be the most economically feasible and beneficial role of teleoperation in the future, in relation to automation technology and the geographical scope of deployment. TO solutions will likely be deployed gradually in different areas as technical capabilities, regulation and demand become clear. Therefore, we identify three deployment scenarios varying in geographical reach and complexity of the driving/navigation environment. The first scenario assumes the deployment of TO in large port and industrial sites, while the third one considers teleoperated water and road transport across member state borders. The last scenario is the most challenging one, but it offers the greatest potential for economic benefits, because enabling the use of TO (in combination with autonomous driving) for large journeys has the potential to substantially increase the operational uptime of vehicles.

The identified deployment options relying on lesser than L4 automation, hence the most feasible ones to start with, were the teleoperation of cranes, reach stackers and forklifts, as well as using direct TO for short milk runs within or around a logistics terminal. This would require having an advanced 5G network but only within a local area where other use cases would also use the upgraded network resources. Teleoperation for waterway transport is seen as feasible to scale up beyond port sites before upgrading in terms of automation: it would be possible to reduce the size of the on-board crew while still keeping some personnel on board of the barges for safety purposes, and the remote captain would take over for the more difficult parts of the trip. This would already allow transport companies to use the idle or resting time more efficiently.

In contrast, wider deployments of TO for road transport would likely only be feasible once higher automation levels are available for driving in open roads, for safety reasons. On open roads, the largest benefits may arise when AD and TO complement each other: TO can enhance safety by ensuring a human driver can take over control remotely when the AD functionality fails, while automation helps guarantee the safety of remote driving if the wireless connection is interrupted. In addition, automation would increase the cost-efficiency of TO by lowering the ratio of required human operators per supervised vehicle. We hypothesize that TO would be used as a complement to autonomous driving (AD) in (a) more complex local roads, and to (b) help (highly but not fully) autonomous vehicles get on and off highways or if they suddenly become unable to continue driving autonomously on the highway.

In line with this, in section 5.4.3 we have proposed and quantitatively assessed a business model for long-haul road freight through European highway corridors. In this model, L4 (i.e., highly but not fully) autonomous trucks are driven to a location near a highway by a human teleoperator, and then drive autonomously until they exit the highway, subject to a traffic control center giving clearance for the routes on the basis of road and weather conditions. This business model would result in benefits from higher productivity and traffic efficiency prior to the commercial readiness of full automation, while also yielding better work conditions for truck drivers; TO would help mitigate the negative consequences of long-haul trips, such as mental health issues from social isolation, and in turn could help reduce current labor shortages. Similarly, TO can increase safety, since fatigue from long-haul journeys is a main cause of accidents. Our cost-benefit analysis also shows there are large potential economic benefits from decreasing the operational downtime of vehicles, even after accounting for the additional costs of adding sensor components in trucks and deploying traffic and TO control centers. The total cost of ownership over the useful life of a vehicle would be reduced in any deployment scenario. The cost savings would initially accrue to transport companies but could also be translated into economic benefits for other stakeholders, for example in the form of cheaper delivery costs.

The business model analysis in sections 5.1 to 5.4 delineated a wide set of specific options regarding the following crucial roles in the value network. These roles are enumerated in Table 14.

Governance and connectivity roles	Transport roles	Teleoperation roles
Cross-border 5G continuity (roaming agreements)	Automated docking	TO service provision
5G connectivity services	Container ID recognition	TO center deployment and management
NFV (network slicing)	VRU warnings	TO service provision
Network infrastructure deployment	Logistics services	TO center deployment and management

Table 14. Business model options for the key roles of different value network layers.

The discussions about discrete business model options revolved around, among others, (i) who will be the customers and (ii) providers of the services, (iii) the pricing models and (iv) value propositions offered, (v) the identified specific challenges, and (v) possible co-investment arrangements. The identification of the underlying granular choices behind these business models offers more flexibility to the analysis and facilitates its reuse, hence providing a blueprint for implementation beyond the geographical scope of the project (i.e., beyond the specific context of Belgium and The Netherlands).

Next, based on possible combinations of the identified business model options per role, section 5.5.1 proposed a series of complete business models per deployment scenario.

For scenario 1, consisting of a port or industrial area with numerous short distance transports, the following two business models were discussed:

- BM1 relies on a more locally-orchestrated deployment, with a private 5G network financed by a port authority. In addition, the port would also help finance the deployment of a TO center, in collaboration with local logistics companies. These logistics companies would form a joint venture to offer the TO service within the area.
- The second model (BM2) relies on attracting deployment of 5G and TO services by providers with a broader (inter)national focus. With coverage on-demand, an MNO upgrades the capacity of its public network in the port or industrial site. The TO service is

done by an independent service provider. Compared to the previous model, here the site owner plays more the role of orchestrating rather than financing.

For scenario 2, consisting of a major transport axis within a country, we focused on the use case of teleoperation of semi-autonomous barges.

- In BM3, port authorities as well as TO service providers lease customized network slices-as-a-service (NSaaS) from M(V)NOs, who in turn acquire virtual network resources via a slice broker. TO service provision is provided by a specialized service provider that offers an integrated service and deploys its own TO center. The resulting higher flexibility from NSaaS and using a broker for the allocation of network resources can provide a quicker time-to-market. Similarly, offering TO integrated into a single offer can also make deployment in each area more agile.
- In the fourth model (BM4), 5G network deployment is based on network sharing; MNOs densify their networks along waterways by relying on active network sharing to substantially reduce costs by jointly investing in masts, antennas and other RAN elements. Regarding the TO service, the provider would be a large transport company with a wide geographical presence and substantial volume of transports. This company would retrain their current captains (or, by extension, drivers) to be licensed to remotely operate vehicles.

For scenario 3, consisting of goods transport across national borders, we extend the aforementioned business model in which TO is used to support L4 trucks in complex local roads and when road and climatic conditions become unmanageable for the self-driving systems.

- In BM5, a vehicle manufacturer integrates the role of TO service provider, offering it as an added value service. This is motivated by the OEM's preference to control the choice of what HW and SW systems are integrated into their products to perform TO. In this model, the TO center would be co-located within the premises of a traffic manager, who would lease space for the TO stations. The OEM may even own its own fleet of trucks, implying that the business model of logistics service providers would change to resemble that of a broker.
- In the last model (BM6), the TO service provider is a large international match-making platform that owns TO centers across the EU. It would not, however, own the vehicles. The customers of the platform (e.g., transportation companies) would pay a subscription to access the service, complemented with additional optional fees for a priority allocation of a teleoperator in periods of high demand (i.e., premium fees to reduce waiting times). To incentivize fleet owners to renew their fleets, the platform would have the ability to cross-subsidize these fleet owners by charging slightly higher prices to those customer types with a higher willingness to pay (e.g., shippers or transport companies).

Next, we discussed the potential role of several stakeholders in orchestrating the new ecosystem or kickstarting investments in order to help overcome the chicken-egg problem of investing in 5G network infrastructure and setting up TO control centers. Such infrastructure deployments offer an unclear return on investment and exhibit a mutual dependency among multiple stakeholders.

Finally, we have also provided a brief discussion of business models for teleoperated passenger transport. Since MNOs indicated that they do not yet see a business case in upgrading and expanding their telecommunications networks to service teleoperated goods transport only, passenger transport use cases can provide an additional revenue source while sharing the same infrastructure resources.

To validate and improve the present study, further research is needed. The upcoming business and economics-related tasks of the 5G-Blueprint project will extend and complement this deliverable by considering the following topics.

- First, the feasibility and impact of the proposed business models needs to be evaluated further. The delineated business models are based on what the project partners have considered more feasible a priori, but this needs to be validated. In practice, the resulting business models will depend on individual company choices as well as regulatory changes. The preferences of different stakeholders need to be better understood after incorporating all the costs and revenue projections from the ongoing techno-economic analysis. In addition, the perceived societal advantages and disadvantages of each business model also need to be explored.

- Second, the mentioned techno-economic analysis is being conducted in another task of the project. This includes, among others, quantifying the expected connectivity costs and the required investments for 5G network deployment under each scenario. This analysis also complements the present study by using the identified value network and the delineated business model options as a basis.
- Third, many aspects related to the governance value network layer will also be tackled. For instance, this can include reviewing the current state of regulatory frameworks and identifying the required legislative changes to allow teleoperation in the contexts and with the business models explored in the present study. As identified above, potential value network bottlenecks include (i) that no party sees a business case in assuming liability for damages arising from teleoperated actions, and (ii) the challenge of MNOs to seamlessly handing over high-QoS sessions for cross-border TO. Therefore, regulation needs to give more clarity regarding liability, and the relevant experts need to identify what specific commercial terms need to be included in scalable SLA templates for international roaming. Lastly, cybersecurity is another important topic that requires more research. TO carries a risk from cybersecurity vulnerabilities in the system being exploited. These vulnerabilities may not only come from the vehicle but from other parts in the value network as well.

To recap, the present deliverable has provided several interconnected types of analyses. First, it provided a basis to understand the advantages and challenges of teleoperation and to build on previous work from previous related projects. Second, it provided a market assessment for teleoperation as a stand-alone service, comparing the value propositions of the companies that are currently advertising their offering of remote operation services. Third, it defined the overall value network for cross-border teleoperated transport based on 5G connectivity, studying the main roles and responsibilities as well as data and liability interactions and potential bottlenecks. Third, it discussed the different feasible deployment options of teleoperation, based on the role of complementary automation technology and the geographical scope of deployment. Last, it provided a thorough discussion of underlying business model options for several key roles in the value network, in addition to delineating a series of overall business models for 5G-based teleoperation solutions.

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