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D3.5: Governance models and recommendations

Roadmap for Deployment and Governance

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Abstract

This report elaborates on the analysis performed and the challenges identified regarding a viable and safe deployment of (direct control) teleoperation in transport and logistics based on 5G communication technologies. The deliverable provides recommendations and guidance on actions required for enabling teleoperation deployed at scale in a societally acceptable and economically viable manner while also briefly summarizing key findings reported in preceding deliverables under work packages 'WP3 - Governance and Business models' and 'WP5 - 5G connectivity' of the 5G-Blueprint project.

Keywords: teleoperation, road map, governance

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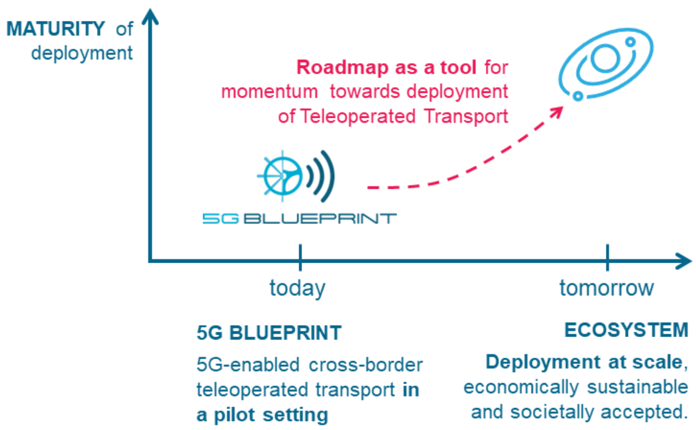
EXECUTIVE SUMMARY

In the 5G-Blueprint project, partners have made significant progress in overcoming the technical challenges related to 5G-enabled and cross-border teleoperated transport, both over land and water. In parallel, extensive research has been undertaken on the business-related aspects of teleoperation and the 5G network required to run it.

At conclusion of the project, however, one crucial question remains: **how can we build on the technical achievements of the project to realize a healthy ecosystem** in which teleoperation is deployed at scale in a societally acceptable and economically viable manner? This deliverable aims to provide concrete answers to that question and more specifically **translates the technical outcomes and business model analyses into a deployment roadmap with an associated governance structure**.

This deliverable aims to **present a roadmap and associated governance structure** which could provide **guidance** for the first steps in the deployment of Tele-operated Transport and **generate momentum** towards the "*dot on the horizon*": a Teleoperated Transport ecosystem.



Key findings and recommendations are summarized in sections 2 & 3, whereas more extensive analysis and reporting can be found in the sections 4 -7.

DOT ON THE HORIZON

Before we can identify the concrete steps on the roadmap towards viable teleoperated transport, we first need to think about the intended target of the roadmap – the **'dot on the horizon'**. In other words, we have to identify pragmatic ambitions for teleoperated transport, in the short term as well as in the longer term. These ambitions take into account the potential use-cases to which teleoperation can add value, as well as the hard constraints identified which limit its operational domain.

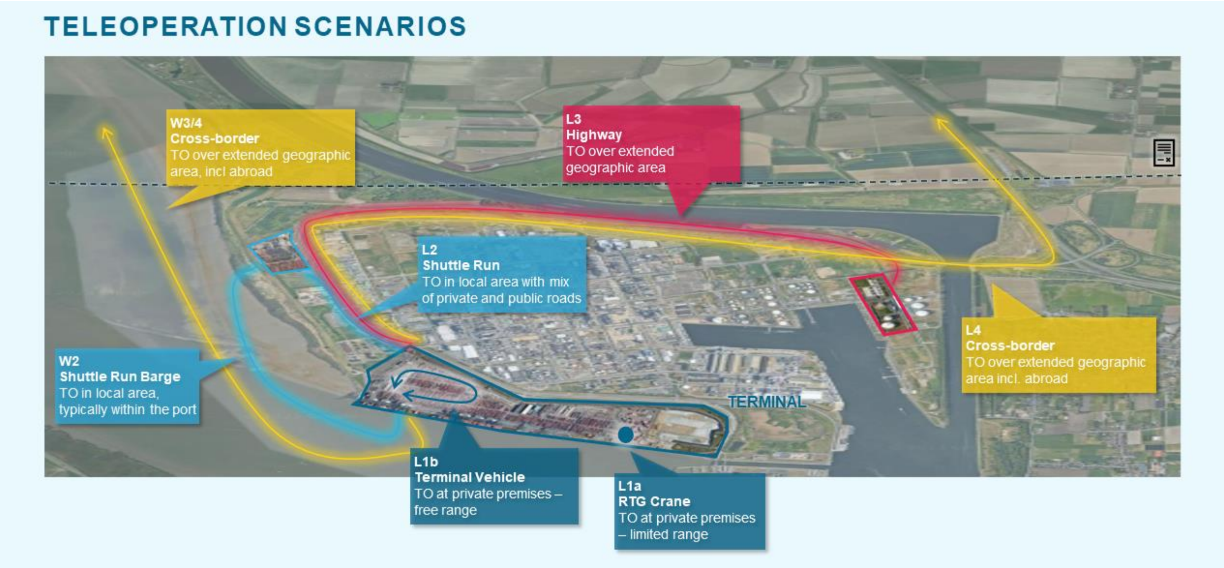
First, with regard to the **potential use-cases**, we identified 7 applications ('scenarios'), schematically presented in the diagram below, which differ in the geographic scope of their deployment (on private premises, in a local area with a mix of private and public roads, over an extended geographic area, or cross-border), and in whether they involve transport over land or over water. Within these scenarios teleoperation can be applied in either **direct control**, meaning that the teleoperator takes on all crucial driving tasks, **or hybrid**, where the teleoperator oversees an automated driving system and takes over only when the vehicle ventures beyond the operational domain of the automated system.

Second, **limitations** (in the form of short-term challenges and long-term hard constraints) shape the deployment path of these scenarios.

In the short term, teleoperated transport will be commercially viable in applications with a limited geographic scope. These are deployments where:

- the business case is clear: low complexity with a limited number of stakeholders involved;

- the regulatory and safety concerns remain limited: teleoperation in a controlled environment on private or semi-public roads;
- the connectivity provision is relatively straightforward: typically a private network operated by a single private network operator, over a small geographic area where connectivity weaknesses can be easily identified and addressed.



**The title of each scenario refers to a typical application of teleoperated transport within that scenario: L1a RTG Crane – teleoperated fixed-range rubber-tyred gantry cranes (used to pick-up containers); L1b Terminal Vehicle – teleoperated free-range terminal vehicles such as terminal tractors or reach stackers; L2 Shuttle Run – teleoperation of frequent runs between warehouse nearby and port terminal; L3 Highway – teleoperated transport over highway; L4 Cross-border – teleoperation of cross-border transport over highway; W2 Shuttle Run Barge – teleoperated barges within the port; W3/4 Cross-border – teleoperated barges over longer trajectories, potentially cross-border.*

From our analysis, it appears likely that the first commercial deployments will focus on **small-scale, niche deployments**. Whereas, considering the regulatory and connectivity-related complexity increases with the scale of deployment, more ambitious teleoperation deployments may emerge only through gradual innovations and maturation of the business and technology.

In the longer term, it is unlikely that teleoperation in its most ambitious application, direct control, anytime and anywhere, will materialize. Teleoperated transport indeed faces **two main challenges** which, considering the concurrent timeline for truly automated driving systems, imply that by the time these challenges are cleared (if ever they will be cleared) the maturity of automated driving systems most probably will be such that these present the preferred option over such ambitious application of direct control teleoperation:

1. **Roll-out of high-quality 5G will take time and may not be realized everywhere:** The roll-out of 5G expected in the next 10 years is unlikely to meet the stringent coverage and quality requirements implied by a ‘Direct Teleoperation Anytime Anywhere’ form of teleoperated transport. The considerable investments in 5G infrastructure indeed may not be realized in low-activity areas where the business case for MNOs is questionable; and even if so, MNOs may not be able to fully meet the stringent quality requirements in terms of uplink capacity everywhere. Direct teleoperation therefore may remain limited to areas where it makes sense for MNOs to invest in the required infrastructure.
2. **Type-approval of teleoperated vehicles is a strict prerequisite** for the roll-out of mass-produced ‘direct control teleoperation’ enabled vehicles on public roads. Considering it is not yet on the agenda of the relevant regulatory bodies it is highly unlikely that these type of teleoperated vehicles will be available on the EU market within the next 10-15 years. From our assessment we foresee that it could easily take a decade before the full regulatory process can be finalized, once properly kicked-off.

These challenges suggest two important consequences:

- **Direct control teleoperation may be reserved for niche applications** – at least in a first instance, with teleoperated vehicles produced on a smaller scale and targeting dedicated use-cases. However – as pointed out below – our assessment suggests that teleoperation functionalities may find their way also in type-approved and mass-produced fully automated vehicles in light of providing a potential fall-back solution when automation fails.
- **Teleoperation at a larger scale most probably will be hybrid**, where a human teleoperator supervises a fully automated vehicle and intervenes in case the vehicle strays beyond the operational design domain of the automated driving system – for either providing waypoints to the system (indirect support) or for taking over direct control.

  This conclusion reveals an interesting interplay between teleoperation and automated driving. Both technologies are complementary in that they provide solutions to each other's shortcomings: Automated driving systems do not require a high-bandwidth low-latency connectivity but may require human intervention when the vehicle moves outsides the system's operational design domain. On the other hand, direct control teleoperation systems have the benefit of human control in situations that may be difficult to navigate for an automated driving system, but do require a high-quality 5G network.

ROADMAP

A healthy teleoperated transport ecosystem, the 'dot on the horizon', will not emerge without coordinated action. The roll-out of teleoperated transport faces challenges which, if unresolved, will block the evolution towards a truly mature and widespread ecosystem. These challenges can be broken down in two groups:

Stringent 5G connectivity requirements from teleoperation: Teleoperated transport demands a lot from the communications network and the latter may not always be able to deliver the performance required. This makes network saturation issues likely (i.e. when demand for network resources exceeds supply) which could hamper the potential of teleoperated transport. Teleoperation service providers may be reluctant to roll-out their service in the face of degraded network quality and spotty coverage.

Resolution of this challenge involves making 5G networks smarter for teleoperation. Besides the expansion and densification of the 5G network, work needs to be undertaken towards a smart interaction between connectivity supply and connectivity demand from teleoperation. We also need a governance framework that can provide transparency on the quality of the 5G network in a spatiotemporal context, so that teleoperation service providers and regulators can assess where and when teleoperated transport can be safely deployed. Finally, new customer-focused business models are needed for sophisticated customers of 5G services. Service level agreements between customers and MNOs could help manage expectations and handle liability for adverse effects of network saturation issues.

Concerns for operational safety of the teleoperation setup (vehicle, control centre and operators): On the vehicle side, it is difficult today to commercially deploy or even pilot teleoperated vehicles on public roads as regulation is lagging behind. At the same time, oversight of teleoperation service providers is needed to keep them accountable for safety and to ultimately ensure that teleoperation is as safe, if not safer, than on-board operation.

Resolution of this challenge involves the introduction of a standardized and harmonized teleoperation licensing system, a procedure that certifies that a prospective teleoperation service provider meets all the requirements for safe teleoperation. These requirements are related to the vehicle used, the control room setup, the operator and the connectivity. In that system, teleoperation service providers will be given a license to operate a particular trajectory or bounded area, with a particular vehicle type and with a particular control room setup. In addition, any adjustments to the current logistic process to accommodate teleoperated transport should be kept to a minimum, in particular with respect to cargo handover points (i.e. points at which the responsibility over the cargo and/or the vehicle shifts from one actor to another). This ensures that challenges related to liability and governance are limited and clear, therefore strengthening the business case and willingness to deploy.

A more comprehensive overview of the challenges and solutions is provided in the ***table*** at the end of this executive summary. The table also lists the recommended first steps on the roadmap – actions that should be undertaken sooner rather than later to gain and keep momentum towards commercial deployment of teleoperated transport.

GUIDELINES

When executing the Teleoperation Roadmap, a number of overall guiding principles do apply.

Avoid a Teleoperation disruption. The introduction of teleoperation functionalities in the existing logistics ecosystem should be gradual. Drastic changes to how this ecosystem functions from an operational, regulatory, and business perspective have in our view limited chance of success. Instead, we recommend a gradual evolution towards more ambitious forms of teleoperation, focusing first on applications where the benefits from teleoperated transport are clear without disrupting the logistics chain.

Involve all relevant stakeholders. The impact from the introduction of teleoperated transport goes beyond those that are directly involved with setting it up (such as teleoperation service providers, fleet providers or logistics companies). In order to avoid a coordination problem later down the road, it is best to involve all stakeholders from an early stage during the piloting or deployment phase. For a comprehensive list of stakeholders, we refer to Deliverables 3.2 and 3.4.

Teleoperation follows connectivity. While teleoperated transport presents an interesting business opportunity for connectivity providers, it is unlikely that individual teleoperated transport deployments will trigger significant investments in the 5G network infrastructure. When considering a deployment at a particular time, teleoperation service providers should therefore assess the potential of the deployment with the (5G) network at that time as a given – or at least with the projected evolution in connectivity absent the deployment. In other words, a teleoperation service provider should look at the connectivity that is currently being provided (or that is projected to be provided) to assess whether the service offering is viable and safe, rather than count on MNOs to make the necessary investments to fill in any gaps in connectivity.

That being said, it should be emphasized that 5G is the most suitable communication network for teleoperation. While some forms of teleoperation can today be deployed without requiring 5G network connectivity, a 5G-focused deployment strategy when considering the provision of direct teleoperation services is recommended.

Tag along with Automated Driving. Automated driving faces many challenges that also count for teleoperated transport, in particular those linked to unmanned transport. For example, issues related to liability (who is in control), type approval and pilot exemptions are similar for teleoperation and automated driving. The latter however has the advantage that many regulatory initiatives already have been kickstarted. We therefore recommend to duly consider and integrate teleoperation technologies in relevant analyses and decision-making processing on automated driving, and applaud recent initiatives to that effect. This has the additional benefit that solutions for both technologies will be immediately aligned, which minimizes coordination issues later on.

Theme	Roadblocks to Deployment of Teleoperation	L1 TO @ Terminal	L2 Shuttle Run	L3 Highway	L4 Cross-border	W2 Shuttle Barge	W3/4 A to B Barge	Solution	First steps
Teleoperation	Reduced **situational awareness** could undermine safety of teleoperation	☺	😐	😐	😐	😐	😐	Define set of mitigating requirements (under the umbrella of a licensing system)	(TO Service Providers) Devise a set of best practices on how to deal with reduced situational awareness
	Specialised **fuelling** or charging infrastructure is needed [for long-haul transport]	☺	☺	😐	😐	☺	☺	Fuelling or charging stations operated by third parties along main transport corridors, with fuelling protocol in place	Involve potential providers of services at an early stage to resolve chicken-egg problem
	Insurers are reluctant to provide **insurance** for teleoperated vehicles as they cannot assess the risks involved	☺	😐	😐	😐	☺	☺	Mandate a Vehicle Data Recorder which would make it easier to attribute fault and assess risk; deploy novel insurance schemes	(Insurance companies) Explore innovative insurance schemes for teleoperation service providers
	Teleoperators may lack the **legal certainty** (in particular when operating in support of automated driving systems)	☺	😐	😐	😐	😐	😐	Change jurisprudence to better protect the teleoperator from adverse effects beyond his control	(Lawmakers) Consider how criminal and civil liability should be adjusted in the wake of unmanned, automated and/or teleoperated transport
Legal	**Exemption process** is tedious, untransparent and costly	☺	😐	😐	😐	😐	😐	Standardization and Harmonization of Exemption process.	(TO Service Providers) Push exemption granting bodies to harmonize and standardize procedures
	Creation of **type approval process** for teleoperated vehicles has not started yet in the EU [only for large-scale deployments]	☺	☹	☹	☹	☺	☺	Regulatory change to enable type approval of teleoperated vehicles	(TO Vehicle Providers) Push to put direct control teleoperated vehicles on the UNECE agenda
	Lack of accountability by service providers could have detrimental effects on safety of teleoperation	☺	😐	😐	😐	😐	😐	Introduction of licensing system for teleoperation, harmonized at EU level	(Regulatory Agencies) Create a roadmap towards a teleoperated transport licensing framework
5G	**Network saturation** and **coverage** issues may hamper potential of Teleoperation	😐	😐	☹	☹	😐	☹	Expand network infrastructure; develop network awareness; create governance framework; introduce novel business models	(Telecom Regulators) Investigate how transparency on 5G coverage should be adjusted to the needs of teleoperation
	The MNO has limited control over quality of service provided by **roaming** MNOs	☺	☺	☺	☹	☺	☹	Optimized Steering of Roaming; Automated Driving fallback; Coverage on Demand; Agreements between Roaming partners	(MNOs) Investigate: Optimized Steering of Roaming, scalability of Inter-PLMN handover, Dual SIM, Service Level Agreements between MNOs
	The solutions enabling seamless **handover** need to mature before large-scale deployment can take place	☺	☺	☺	☹	☺	☹	Hybrid control teleoperation at border crossings Maturation of inter-PLMN handover.	(TO Service providers) Use dual-sim for first cross-border deployments at limited scale and investigate the need for seamless handover at scale.

LEGEND

☺	No issues related to the topic and the scenario
😐	Either issues are minor or easy to solve
☹	Issue is both major and hard to solve

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Sections highlighted in blue constitute the core sections of this deliverable.

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REFERENCES

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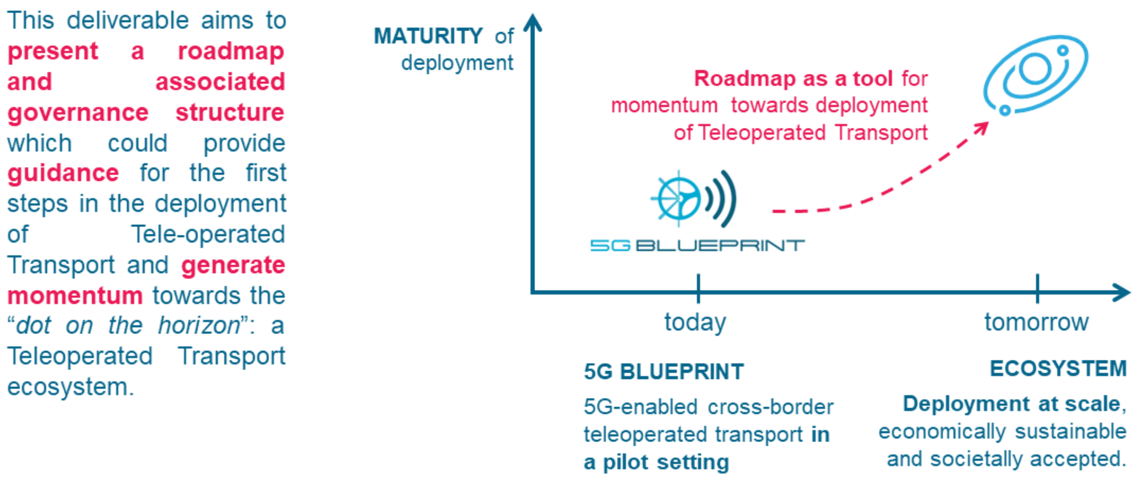
1 INTRODUCTION

This deliverable aims to provide concrete answers to the question "**What's next?**". In the 5G-Blueprint project, partners have made significant progress in overcoming the technical challenges related to 5G-enabled and cross-border teleoperated transport, both over land and water. Work Package 3 evaluated business and governance-related aspects of both teleoperation and the required 5G network. In particular, it explores what future teleoperation ecosystems could look like from a business model and techno-economic perspective.[1] However, there remains a gap between the technical accomplishments of the project (and more generally the current state of the art) and the "dot on the horizon", the future ecosystems in which teleoperation is deployed at scale in a societally acceptable and economically viable manner. How to close that gap, or at least to make the first inroads toward closing the gap, is the topic of this deliverable.

More specifically, the objective of the deliverable is to translate the technical outcomes and business model analysis into a deployment roadmap with an associated governance structure. This deliverable aims to provide the reader with solutions on how to overcome the remaining challenges for realizing the teleoperation ambitions underpinning the 5G-Blueprint project as well as with a clear path towards deployment.

Figure 1: Schematic view of the objective of this deliverable



In this deliverable we will cover the following topics:

- Dot on the horizon [**Section 2**] – What are the pragmatic ambitions for teleoperated transport: Earlier in the 5G-Blueprint project, seven deployment scenarios have been identified with varying levels of sophistication and maturity. The scale, nature and order of their implementation will be driven by the potential use-cases to which teleoperation can add value as well as by the hard constraints which limit the operational domain for teleoperation.
- The Teleoperation Roadmap [**Section 3**] – What is the path towards the dot on the horizon: The Roadmap considers a number of expected technical or legal evolutions (such as 5G) and adds to this a series of required coordinated steps to be taken in the domain of teleoperation, legal, connectivity or business to establish a Teleoperated Transport ecosystem.

These two topics are the core of this deliverable, providing a succinct overview of what we believe

[1] For more details, see previous WP3 Deliverables – D3.1, D3.2, D3.3 and D3.4.

to be the major considerations regarding future deployments of teleoperated transport.

Further details on the roadmap are provided in the *deepdive* sections (**Sections 4 to 7**). These *deepdives* will tackle individual components of the roadmap in greater detail along four themes – Teleoperation (Section 4), Regulation (Section 5), 5G Connectivity (Section 6) and Business (Section 7). **Section 8** provides some concluding considerations.

The assessment presented in this Deliverable is guided by what we postulate to be the core characteristics of a healthy Teleoperated Transport ecosystem:

- Efficiency: The Teleoperation business case can be realized, at least in the longer term;
- Buy-in: All required stakeholders are willing to cooperate within the ecosystem;
- Prosocial: The ecosystem benefits the wider society, in terms of e.g. job market, fair competition and the environment;
- Safety: Teleoperation should be as safe or safer as current logistic operations;
- Legal certainty: A transparent and enforceable legal framework has been established.

We therefore ensure that the potential efficiencies and prosocial effects from teleoperated transport can be realized without jeopardizing the safety and legal certainty of all stakeholders involved.

2 THE DOT ON THE HORIZON

Throughout the course of the 5G-Blueprint project, the consortium partners have had lively discussions on what they consider to be the **dot on the horizon**: the version of a future Teleoperated Transport ecosystem that is both realistic and desirable, taking into account (i) useful applications of the teleoperation technology and (ii) the hard constraints faced when deploying teleoperation in particular operational domains. This section provides a consolidated view of these discussions, presenting the base scenarios, the likely implementations of these scenarios and the order in which these implementations are likely to materialize.

In the partners' view, the dot on the horizon consists of teleoperated transport which:

- **is deployed at a smaller scale for niche applications**, as opposed to mass-produced standardized direct control teleoperated vehicles which we consider to be unlikely to materialize; and
- **coexists in a mutually beneficial relationship with automated driving systems**, in which automated driving functionalities provide fallback options for teleoperation in case connectivity is disrupted, and in which teleoperation functionalities support and are integrated in automated vehicles for tackling situations that the automated driving system cannot handle (yet).

The road towards this dot on the horizon will run in first instance via deployments with a limited geographic scope, for example around terminals or logistic hubs. Local deployments are less complex in terms of connectivity and regulatory requirements and allow for incremental innovation in a context where the business model is more straightforward than for deployments with a more extended geographic scope.

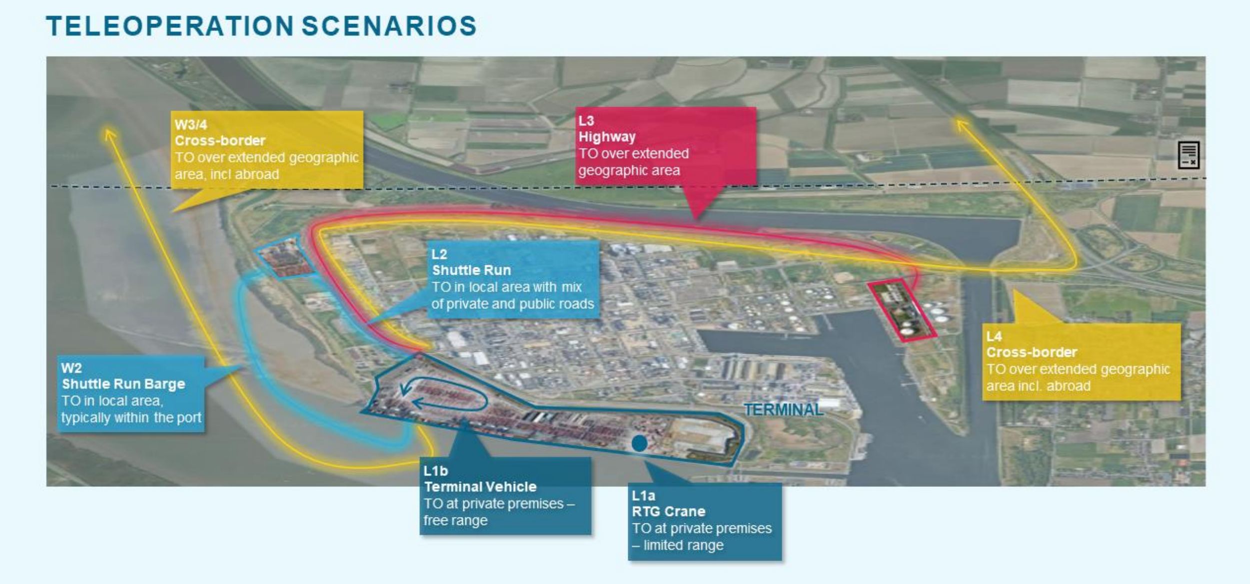
2.1 Seven Teleoperation Scenarios

In previous Work Package 3 Deliverables D3.2 (Business Models), D3.3 (Techno-economic Analysis) and D3.4 (Validation of Business Models), a number of scenarios were identified, analysed and discussed. We shortly recapitulate these scenarios, introducing a coding system that will be re-used in following sections: each code contains a letter (with L, for land-based deployment, or W, for water-based deployment) and a number (the higher the number, the greater the complexity).

The differentiating factor between these scenarios is the geographic scope of the deployment. We consider four different geographic scopes – illustrated in the diagram below[2]:

[2] The depicted area is only an illustration and does not represent a 5G-Blueprint pilot environment.

Figure 2: Visual presentation of teleoperation scenarios considered



- **Scope 1**: Teleoperation is **limited to private premises** (e.g. at a port terminal or a logistic hub). Within this scope, we can make a further distinction between teleoperated transport with a limited range (Scope 1a) and teleoperated transport with free range within the private premises (Scope 1b).
  - Typical application for 1a – **L1a RTG Crane**: A rubber-tyred gantry (RTG) crane at a port terminal is remotely operated from a control centre on-site;
  - Typical application for 1b – **L1b Terminal Vehicle**: A vehicle used exclusively at a port terminal is remotely operated from a control centre on-site. A range of terminal vehicles could be teleoperated, such as a terminal tractor (used to transport containers between container stack, warehouse and quay), a reach stacker (used to move containers between a container stack and a terminal tractor), or a skid steer (used to move bulk goods such as sand).
- **Scope 2**: Teleoperation is **limited to a specific local area** that includes a mix of private and (semi-)public roads (e.g. a port terminal and surrounding area) or local waterways. Typically, for these transports the number of origins and destinations will be limited.
  - Typical application for land – **L2 Shuttle Run**: The transport of containers between a port terminal and a warehouse nearby is teleoperated. This transport with a fixed origin (either the container stack at the terminal or the docking bay at the warehouse) and a fixed destination takes place multiple times per day.
  - Typical application for water – **W2 Shuttle Run Barge**: Bulk goods are transported via teleoperated barges, from one side of the port to the other, or, more generally, over short stretches of waterways overseen by a single authority. The skipper will no longer be on board the vessel but will operate the vessel from a control centre.
- **Scope 3**: Teleoperation takes place **over an extended geographic area** with (in theory) unlimited amounts of origins and destinations.
  - Typical application for land – **L3 Highway**: The transport of containers between two warehouses via a major national transport axis is (at least partially) teleoperated.
- **Scope 4**: Teleoperation takes place over an extended geographic area with (in theory) unlimited amounts of origins and destinations, **including origins and destinations that are in different countries**.
  - Typical application for land – **L4 Cross-border**: The transport of containers

between two warehouses via a major international transport axis is (at least partially) teleoperated.

- Typical application for water – **W3/4 A to B Barge**: Bulk goods are transported over (inland) waterways via teleoperated barges, potentially cross-border. Specifically, the role of the skipper is transferred from the vessel to a control centre.

The geographic scope drives the type and extent of the (5G) network that will need to be deployed to establish communication between the teleoperated vehicle and the remote control centre. Applications that are limited to private premises (**Scope 1**) may be enabled via a private network. This network could be fixed (in the case of scenario L1a) or cellular. Applications deployed in a local area (**Scope 2**) can be enabled via a private network, a public network or a mix of both (where roaming on a public network is possible). Use of public networks is most logical when applications are to cover an extended geographic area (**Scope 3**). The same holds for applications that take place in an international cross-border context (**Scope 4**), where network providers additionally will have to enable and agree on roaming.

The table below summarizes the differences between the various scenarios considered.

Table 1: Characteristics of each scenario

	L1a RTG Crane	L1b Terminal Vehicle	L2 Shuttle Run	L3 Highway	L4 Cross-border	W2 Shuttle Barge	W3/4 A to B Barge
Geography	One particular site	Terminal or warehouse	Port plus hinterland	National	Inter-national	Port	National or inter-national
Road type	None	Private	Private/ Public	Public	Public	Waterway	Waterway
Origins/ Destinations (O/D)	Very local	Fixed O/D on local premise	Fixed O/D	Flexible O/D	Flexible O/D	Fixed O/D	Fixed O/D
Type of Network	Fixed or Cellular private network	Cellular private Network	Private or public network	Public network	Public network and roaming	Private or Public network	Public network and roaming
Typical Vehicles	RTG Crane	Terminal Tractor / Skid Steer / Reach stacker	Single- or double-articulated vehicle	Single- or double-articulated vehicle	Single- or double-articulated vehicle	Barge	Barge
Typical Goods	Container	Container / Bulk goods	Container	Container	Container	Bulk goods	Bulk goods

2.2 Three types of teleoperation

We distinguish three types of teleoperation, depending on the level of control assigned to the teleoperator.[3]

- A teleoperator could be in **direct control** of the vehicle (in the same way a driver of a non-teleoperated vehicle is in control today): the teleoperator takes on the dynamic driving task (DDT) in which the operator has sustained lateral and longitudinal control (steering,

[3] See Sections 3 and 4 of 5GAA (2020a), as well as Chapter 3 of UK Law Commission (2023a).

braking and accelerating) as well as takes care of object and event detection and response (OEDR). During direct control, it could still be the case that parts of the DDT are supported or performed by an automated driving system (e.g. via adaptive cruise-control or lane keeping).

- Alternatively, the teleoperator may only have **indirect control**: he is not responsible for the DDT and OEDR but takes care of the strategic (route-planning) or tactical (speed selection, lane selection, manoeuvre planning) aspects of driving the vehicle. An example of indirect control would be a remote operator giving instructions to the automated on-board system on how to bypass an obstacle on the road ("*switch lanes and pass on the left*").[4]
- A **hybrid** control version is also possible where the teleoperator takes on the role of a remote driver supporting SAE Level 4 or Level 5 automated driving systems.[5] The teleoperator in this case will monitor the strategic and tactical side of the transport, but could also take over via direct control. This could be needed when the automated driving system has reached its operational limits, or when an unexpected situation occurs (e.g. failure of the automated driving system) and the vehicle needs to be driven to a safe place.

While for direct control one operator per operated vehicle is needed, in 'indirect control' modus (and to a lesser extent, hybrid control modus) one operator can be assumed to be able to handle more than one vehicle. This for sure will be beneficial from a cost-efficiency perspective.

In this Deliverable, we only discuss direct and hybrid control teleoperation, as these are the most relevant types of teleoperation in the short to medium term. In any case does direct control teleoperation present the most challenging version of teleoperation.

2.3 In the short to medium term: small-scale niche applications with limited geographic scope

As is typical for a cutting-edge innovation, teleoperated transport will first be commercially deployed in niche applications where the business case is clear, the regulatory and safety concerns are limited, and connectivity provision is relatively straightforward. The business case considerations are discussed at length in the 5G-Blueprint deliverable D3.4, in which it was concluded that any future teleoperation ecosystem most likely will originate from small deployments in a controlled environment. This is also evident from the applications that are already commercially deployed today. We discuss two such examples from 5G-Blueprint consortium partners in the table below.

[4] See 5GAA (2020a) for a description on how this would technically go. For an example of a (foreseen) application of indirect control teleoperation, see the Hi-Drive project.

[5] These refer to a taxonomy for six levels of driving automation (see here). SAE Level 4 refers to a fully automated vehicle (i.e. not requiring any intervention by the passenger or operator) though with a constrained operational domain, whereas SAE Level 5 refers to a fully automated vehicle that can drive under all conditions.

Table 2: Overview of deployed applications of teleoperated services

	Teleoperated RTG Crane at the Lineage terminal in Vlissingen	Seafar vessels on Belgian inland waterways, teleoperated from Antwerp
Scenario	L1a	W2
"The business case is clear"	Lineage[6] sees real benefits in a teleoperated crane: staff is kept away from the dangerous container stack area in the comforts of an actual office; switching between crane jobs is more straightforward than before. In addition, the benefits accrue to the same party (i.e. Lineage and its employees) that decides on crane infrastructure.	Seafar is an independent ship management company (offering vessel and crew to transport goods over water) who offers efficiency improvements to its customers through crew-reduced or unmanned navigation. By moving the skipper to the remote control centre, crew time can be more efficiently used with expanded time of operation.
"Regulatory concerns are limited"	None to limited oversight is needed by a regulator as teleoperation takes place on private premises.	Seafar deals with the waterway regulator directly, though this process is not without concerns (see section 5.1).
"Safety concerns are limited"	Teleoperation takes place in a controlled environment with no or limited public access.	Inland waterways are less complex environments than public roads with less (and more uniform) traffic.
"Connectivity provision is straightforward"	RTG Cranes are operated via a fixed network.	Vessels are operated via a 4G connection involving multiple sims (when the service level of one network drops, connection is made with another network).

Subsequent deployments involve incremental innovations relative to the teleoperation deployments already observed today. An example of such incremental innovation would be to move from a fixed network to a cellular private network for teleoperation on private premises (essentially from L1a to L1b, Table 1). This would make connectivity provision a bit more complex (a private 5G network would have to be set up with sufficient quality of service to enable teleoperation), though the other parameters mentioned above would remain unaltered. Another example is the one of Seafar currently experimenting with cross-border transport (within the 5G-Blueprint project and also independently): all parameters remain the same, but one degree of complexity is added by requiring roaming. The lessons learned at one rung of the innovation ladder are then taken onboard when moving up to the next rung of the ladder. As such incremental innovations reinforce the business case, provide solutions for particular challenges and change the public and regulatory perception of teleoperated transport.

Such incremental innovations imply that commercial deployments in the short to medium term probably will have **a limited geographic scope** (**Scope 1 - private premises** or **Scope 2 - local area**; except for water based transport where the geographic scope could be more extensive). The leap from local deployments to deployments covering a wider area faces regulatory and 5G hurdles which, according to our assessment, will take time and are therefore unlikely to be resolved in the short term. Incremental innovations are therefore likely to focus on developing mature deployments of Scenarios L1 and L2. In addition, commercial deployments will likely be **limited to small-scale, niche deployments**. When the scale of a teleoperation application increases (both in terms of number of vehicles per deployment, as in the number of simultaneous deployments in the same area), so does the regulatory and connectivity-related complexity. More details on this are provided in Section 3, and in Sections 5 and 6.

2.4 In the longer term: teleoperation and automated driving in mutually beneficial coexistence

There are limits to the commercially viable deployment of teleoperated transport.

[6] In the course of the 5G-Blueprint, Kloosterboer was acquired by Lineage. The information here is provided by former Kloosterboer representatives who now represent Lineage.

Teleoperation in its most ambitious application, direct control anytime and anywhere without support from automated driving systems, indeed is unlikely to materialize. In such an application a teleoperator is able to directly control a teleoperated vehicle at ‘normal’ speeds across an extensive geographic area (e.g. along the European TEN-T traffic axes) between flexible origins and destinations at all times without any concerns on safety nor relying on advanced automated driving systems (requiring continuous high-quality 5G coverage). The obstacles faced, in combination with the concurrent timeline for roll-out of automated driving systems, imply that by the time these obstacles are cleared (if they are ever cleared) the maturity of automated driving systems will most probably be such that it will be the preferred option over such ambitious application of direct control teleoperation.

We identify two obstacles which put hard constraints on the scope of deployment of teleoperated transport.

First, the expected roll-/out of 5G in the next 10 years will likely not be of such nature to meet the quality and coverage requirements of a ‘Direct Teleoperation Anytime Anywhere’ form of teleoperated transport. Such form of teleoperation will require a consistently high quality of connectivity across an extensive geographic scope, which is problematic for three reasons (for more details on these, we refer to Section 6):

- <u>Direct teleoperation is very uplink-intensive</u> (with multiple high-definition video streams that are sent to the remote control centre): Considerable investments in network infrastructure will be required to be able to provide a consistently high level of service.
- <u>Coverage will need to be foreseen also in low-activity areas</u>: The investments in network infrastructure will have to be made across the whole envisioned road network, including in areas with limited demand for connectivity services (i.e. with limited population or economic activity). In these areas, the business case for making 5G network investments is weak as there are no additional applications which can share the cost of the investment in the communication network.
- <u>Connectivity cannot be guaranteed</u>: Even if all investments are made, MNOs will still not be able to fully meet the expectations of teleoperation service providers, especially when teleoperation is rolled out on a large scale (with many simultaneous teleoperations in a specific area). Connectivity can still break down for reasons beyond the control of the MNO, and fully guaranteeing connectivity comes at a prohibitively high cost. Either connectivity is provided on a best-effort basis or via a service level agreement. In both cases will the teleoperation service provider need to anticipate that direct teleoperation may not always be possible, necessitating secure fallback options.

Direct teleoperation will therefor only be feasible in a select number of areas where it makes sense for MNOs to invest in the required infrastructure (because demand from teleoperation service providers or other parties is high enough). So a transport may be directly teleoperated in and around port terminals or logistic hubs, but once the transport hits a long stretch of road, connectivity will likely not meet the requirements needed to enable direct teleoperation (or at least not within the next 15 years). And even in those places where the 5G network would be able to service teleoperation, one needs to account for the possibility that connectivity may be disrupted at times, necessitating an automated driving system which ensures a safe stop as a fallback solution.

Any transport involving direct teleoperation over an extended geographic area (i.e. Scenarios L3, L4 or W3/4) will therefore require automated driving systems, both as an alternative for areas without coverage and as a fallback for areas with coverage but where connectivity may be disrupted. For example, a plausible application of Scenario L3 would be one where a vehicle is driven by an on-board operator to a parking close to the highway entry, where a teleoperator takes over and drives the vehicle onto the highway; there the vehicle is automatically driven (potentially as part of a platoon) with a teleoperator potentially only intervening in specific circumstances (e.g. bad weather conditions or accidents). For Scenario L4, border crossings will likely require hybrid control teleoperation: while 5G-Blueprint showed the technical feasibility of seamless handover protocols, a commercially viable and scalable solution may take a considerable time; in the meantime it seems likely that any border crossing of teleoperated transport (in a highway environment) will have to be supported by automated driving.

Second, it is highly unlikely that, within the next 10-15 years, mass-produced 'direct control teleoperation' vehicles will be available on the EU market. Mass-produced vehicle types need to be 'type approved' before they are allowed on public roads, which is essentially a process that checks whether the vehicle type meets a large number of stringent requirements. EU regulators, together with the UN, have only recently started making inroads on type approval for fully automated vehicles produced in small series. Direct control teleoperated vehicles are as of yet not on the agenda at the relevant regulatory bodies. As per our estimates, it will easily take more than a decade to go from putting type approval for teleoperated vehicles on the agenda to actual implementation.

Therefore, even in the longer term, direct control teleoperation will likely only take place in niche applications, with vehicles produced on a smaller scale. Approval can be done on a vehicle-by-vehicle basis in the context of a teleoperation service provider obtaining a license for rolling out its services. As it is explained in more detail below (section 5.4), while such a system is not yet fully available, setting it up (or adapting the existing but imperfect system of exemptions) does not pose a major roadblock.

All this being said, direct control teleoperation functionalities are likely to find their way in type-approved and mass-produced fully automated vehicles. As mentioned earlier, regulation on the type approval of fully automated vehicles is underway and the EU's ambition is to have SAE Level 4 automated vehicles on highways by 2030.[7] Direct control teleoperation functionalities will have their role in those vehicles: SAE Level 4 vehicles still have a constrained operational domain; in unmanned vehicles, teleoperation will still be required in case these vehicles stray beyond their operational domain. That is why current EU type approval initiatives also foresee (admittedly limited) teleoperation functionalities as part of the set of requirements for an SAE Level 4 vehicle. Beyond SAE Level 4, the timeline is a lot more blurry.[8]

In conclusion, mature teleoperated transport will coexist with automated driving systems in a mutually beneficial relationship. The two systems are complementary in that they provide solutions for each other's shortcomings, while safeguarding the business case for unmanned transport. Automated driving systems do not require a high-bandwidth low-latency 5G but may require human intervention when the vehicle moves outsides the system's operational design domain. Direct control teleoperation systems have the benefit of human control in situations that may be difficult to navigate for an automated driving system, but do require a high-quality 5G network. So, on the one hand will we likely see niche deployments of direct control teleoperation where the automated driving system acts as a fallback in case of degraded connectivity quality. On the other hand can automated driving systems be supported by hybrid control teleoperation functionalities where a human operator may intervene in case the vehicle strays beyond the operational design domain of the automated driving system.

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[7] See for example here.

[8] A discussion on this is not in scope of this Deliverable. See, among others here: "*Fully self-driving cars unlikely before 2035, experts predict*". The complexity of Level 5 automated driving is considerably higher than that of Level 4 automated driving: it needs to account for less predictable environments (urban vs highway) with a lot of technical challenges related to the urban environment (e.g. how do you interpret a hand signal from a pedestrian); it has considerably regulatory hurdles; and current focus of the industry has been on Level 4 driving on highways.

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3 TELEOPERATION ROADMAP

A healthy teleoperated transport ecosystem will not emerge without coordinated action. The roll-out of teleoperated transport faces challenges which, if unresolved, will block the evolution towards a truly mature and widespread ecosystem. **The roadmap presented provides an overview of the coordinated actions required, and as such provides a blueprint for how stakeholders should proceed to make teleoperated transport a reality**.

Our analysis points to two major challenges – the requirement for **vehicle type approval** to have teleoperated vehicles deployed at a larger scale; and issues linked to extended **coverage of 5G networks**. As explained in Section 2.4, these challenges, rather than being resolved in a timely fashion, constitute hard constraints shaping the future teleoperated transport ecosystem.

Besides these major challenges, there are other challenges which can be resolved within a reasonable timeframe. These challenges break down in two groups:

Stringent 5G connectivity requirements from teleoperation. Teleoperated transport demands a lot from the communications network and the latter may not always be able to fulfil the connectivity requirements. This makes network saturation issues and coverage gaps likely which could hamper the potential of teleoperated transport. Teleoperation service providers may be reluctant to roll-out their service in the face of degraded network quality and spotty coverage.

Resolution of this challenge involves making 5G networks smarter for teleoperation. Besides the expansion and densification of the 5G network, work needs to be undertaken on a smart coordination between connectivity supply and connectivity demand from teleoperation. We also need a governance framework that can provide transparency on the quality of the 5G network in a spatiotemporal context, so that teleoperation service providers and regulators can assess where and when teleoperated transport can be safely deployed. Finally, new customer-focused business models are needed for sophisticated teleoperation customers of 5G services.

Concerns for operational safety of the teleoperation setup (vehicle, control centre and operators). On the vehicle side, it is difficult today to commercially deploy or even pilot teleoperated vehicles on public roads as regulation is lagging behind. At the same time, oversight is needed of teleoperation service providers to keep them accountable for safety and to ultimately ensure that teleoperation is as safe, if not safer, than on-board operation.

Resolution of this challenge involves the introduction of a standardized and harmonized teleoperation licensing system, a procedure that certifies that a prospective teleoperation service provider meets all the requirements for safe teleoperation. These requirements are related to the vehicle used, the control room setup, the operator and the connectivity. In that system, teleoperation service providers will be given a *license to operate* a particular trajectory, with a particular vehicle type and with a particular control room setup. Ideally, the system is set up, or at least harmonized, at EU-level, providing all parties with legal certainty even for teleoperated transport across borders. In addition, any adjustments to the current logistic process to accommodate teleoperated transport should be kept to a minimum, in particular with respect to handover points (i.e. points at which the responsibility over the cargo and/or the vehicle shifts from one actor to the next). This ensures that challenges related to liability and governance are limited, thus strengthening the business case and willingness to deploy.

In what follows we provide a high-level overview of the challenges related to the deployment of the teleoperation scenarios considered and the coordinated actions that would in our view be required to overcome these challenges. For more information on the challenges as such, we refer to the **deepdives per theme** in Sections 4 to 7 – challenges related to (tele)operational aspects, to legal aspect, to 5G aspects, and finally to business aspects of teleoperation. We also identify the first key steps to be undertaken to gain momentum and provide some key recommendations from the deepdives and the work carried out in the context of 5G-Blueprint in general.

3.1 Challenges & Solutions

The table below groups the **main challenges** according to the themes considered (teleoperation, legal, 5G and business). The Business theme is different from the first three in that there is no specific challenge that requires a strict resolution related to it. Either business challenges are resolved through resolution of challenges of other themes, or a resolution is not possible and the challenge constitutes a hard constraint which impacts the dot on the horizon.

For each challenge and scenario we indicate whether (i) the challenge does not apply to the scenario; or (ii) the challenge is either minor <u>or</u> easy to solve; or (iii) the challenge is major <u>and</u> hard to solve. We consider a challenge minor if it only affects the timeline and extent of deployment of teleoperation. A major challenge has the potential to derail the roll-out of teleoperation for the specific scenario.

Table 3: Challenges to roll-out of teleoperated transport

			L1	L2	L3	L4	W2	W3/4
Theme	Code	Challenge	TO@Terminal	Shuttle Run	Highway	Cross-border	Shuttle Barge	A to B Barge
Teleoperation	AWARENESS	Reduced **situational awareness** could undermine safety of teleoperation	🙂	😐	😐	😐	😐	😐
	FUEL	Specialised **fuelling** or charging infrastructure is needed [for long-haul transport only]	🙂	🙂	😐	😐	🙂	🙂
	INSURE	Insurers are reluctant to provide **insurance** for teleoperated vehicles as they cannot assess the risks involved	🙂	😐	😐	😐	🙂	🙂
	LIABILITY	Teleoperators may lack the **legal certainty** (in particular when operating in support of automated driving systems)	🙂	😐	😐	😐	🙂	🙂
Legal	EXEMPT	**Exemption process** is tedious, untransparent and costly	🙂	😐	😐	😐	😐	😐
	TYPE	No **type approval** process for teleoperated vehicles exists yet in the EU [for large-scale deployments]	🙂	☹️	☹️	☹️	🙂	🙂
	ACCOUNT	Lack of **accountability** by service providers could have detrimental effects on safety of teleoperation	🙂	😐	😐	😐	😐	😐
5G	SATUR	**Network saturation** issues may hamper potential of teleoperation	😐	😐	☹️	☹️	😐	☹️
	ROAM	The MNO has limited control over quality of service provided by **roaming** MNOs	🙂	🙂	🙂	☹️	🙂	☹️
	HANDOVER	The solutions enabling seamless **handover** need to mature before large-scale deployment can take place	🙂	🙂	🙂	☹️	🙂	☹️

[AWARENESS] Reduced situational awareness could undermine the safety of teleoperation. An operator's ability to safely operate the vehicle may be impeded when removed from the vehicle as situational awareness may be reduced due to imperfect visual, auditory and haptic feedback.

We consider this to be a **minor challenge** in all scenarios that are being deployed on public roads or public waterways – situations where the teleoperated transport is mixed with other traffic.

- Solution: A number of mitigating measures have been identified aimed at (i) approximating the 'realness' of driving in the teleoperation environment; and (ii) boosting the awareness by providing additional aids not available to an on-board operator; all while (iii) avoiding information overload. Mitigating measures include HD imaging with low latency, improved visual cues via virtual or augmented reality features, a spatial awareness view supplementing the camera images, auditive and haptic cues, workload management and operator training. These mitigating measures should be integrated into a set of requirements that a teleoperation service provider should meet before it is granted a commercial permit (see also the solution for ACCOUNT).

[FUEL] Specialised fuelling or charging infrastructure is needed. In the long term, and only for transports across long trajectories, specialised fuelling infrastructure should emerge which take on the task of (automated or manually) fuelling or charging the unmanned vehicle. A lack thereof may lead to reluctance to deploy teleoperation over longer distances.

We consider this to be a **minor challenge** for scenarios that involve long-haul road transport, such as L3 - Highway and L4 – Cross-border.

- Solution: The emergence of fuelling or charging stations operated by third parties with a fuelling protocol in place.

[INSURE] Insurers are reluctant to provide insurance for teleoperated vehicles as they cannot assess the risks involved. Lack of historical data on teleoperated transport (of any kind) means that insurance companies cannot make a proper risk assessment, resulting in insurance premiums that are higher than what should be considered appropriate for the actual risks incurred and ultimately than what a prospective teleoperation service provider is willing to pay. This may be specifically the case for the teleoperation scenarios that take place on public roads, where the risk and impact of adverse outcomes on third parties is highest.

We consider this to be a **minor challenge** for all scenarios that are being deployed on public roads.

- Solution: A Vehicle Data Recorder should be mandated in all teleoperated vehicles which would make it easier to attribute fault and assess the risks involved. Concurrently, novel insurance schemes should be developed specifically for TO deployment.

[LIABILITY] Teleoperators may lack the legal certainty (in particular when operating in support of automated driving systems). The combination of teleoperated driving and automated driving systems complicates the handling of individual liability, where, for example, it is not clear to which extent a teleoperator can be held responsible for adverse outcomes resulting from automated operation under his supervision.

We consider this to be a **minor challenge** for all scenarios that are being deployed on public roads.

- Solution: Jurisprudence needs to be adjusted to better protect the teleoperator from adverse effects beyond his control.

[EXEMPT] The exemption process is tedious, untransparent and costly. Today, small-scale (experimental) deployments of teleoperated transport are allowed on public roads through the system of exemptions, whereby a national authority grants an authorization to operate under specific conditions. The exemption request procedure is perceived as tedious and costly and varies per EU country. This hampers the rate of innovation and slows down the evolution towards commercially viable teleoperation deployments.

We consider this to be a **minor challenge** for all scenarios where deployment requires approval from a road or waterways authority.

- Solution: The exemption process needs to be streamlined by harmonizing the rules at the EU level and standardizing the approval process with a single point of contact at national level, a transparent flow and the possibility to appeal a decision.

[TYPE] No type approval process for teleoperated vehicles exists yet in the EU. There is a series of EU Directives and Regulations on vehicle type approval which have gradually set out what safety requirements (motorized) vehicles should meet before being allowed on public roads. Recent updates to existing regulations have taken place to account for type approval of vehicles equipped with SAE Level 4 automated driving systems, as long as it concerns a vehicle type produced in small series. However, the resulting legal framework for type approval does not address the technical and functional requirements posed by teleoperation in the envisioned scenarios. Even more concerning is the fact that teleoperation is currently not being discussed in the context of future versions of the EU type approval framework contrary to both driver assistance systems and automated driving functionalities.

We consider this to be a **major challenge** for all large-scale deployments of scenarios that take place on public roads.

- Solution: Advocacy work should be undertaken to put type approval for teleoperated vehicles on the agenda of the relevant regulatory bodies. As explained in Section 2.4, a type approval process for direct control teleoperated vehicles will likely take more than 10 years such that any deployment of teleoperated transport will need to work within the constraints of the absence of such a process, even in the longer term. So for the next 10-15 years or so, direct control teleoperated vehicles should be approved on a vehicle-by-vehicle or small-series-basis.

[ACCOUNT] Lack of accountability by service providers could have detrimental effects on safety of teleoperation. The safety challenges posed by teleoperated transport are not limited to the teleoperation system installed in the vehicle, but also involve connectivity, remote control infrastructure and personnel. Some of these challenges are out of scope of type approval and remain to be tackled at the level of the teleoperation service provider, in a Remote Control Centre. There is therefore a need to not only hold the vehicle manufacturer accountable (through type approval) but also the teleoperation service provider for the safety-critical aspects of the operation.

We consider this to be a **minor challenge** in all scenarios that are being deployed on public roads or public waterways – situations where the teleoperated transport is mixed with other traffic.

- Solution: A teleoperation licensing systems should be introduced which gives a teleoperation service provider a license to operate a particular trajectory, with a particular vehicle type and with a particular control room setup. The licensing process should verify that all requirements for safe teleoperated transport are being met. Ideally, the licensing system is organized (or at least harmonized) at EU level to facilitate cross-border teleoperated transport.

[SATUR] Network saturation issues may hamper potential of teleoperation. The demand for uplink bandwidth from teleoperated transport will put considerable stress on the available capacity. Network saturation episodes may occur in which demand for telecommunications resources exceeds capacity. If uncontrolled, these may have serious consequences for teleoperation as connectivity may be lost during operation. These episodes can be countered by dynamic adjustments to demand and supply of uplink bandwidth. However, for more advanced scenarios (L3 - Highway, L4 – Cross-border and W3/4 – A to B barge), network saturation episodes may be too significant, unpredictable and dangerous for these adjustments to present a workable solution. Average service levels could be seriously impacted to the extent that the business case, safety and ultimately viability of teleoperated transport is undermined. The problem is amplified by the potential existence of coverage gaps along the trajectory of the envisioned teleoperation deployment.

We consider this to be a **minor challenge** for deployments with a limited geographic scope (such as L1 – TO@Terminal, L2 – Shuttle Run and W2 – Shuttle Run Barge) where network saturation episodes and coverage gaps are relatively easy to control; and a **major challenge** for scenarios with a more extensive geographic scope (L3 - Highway, L4 – Cross-border and W3/4 – A to B barge) where the issue is more profound and more difficult to resolve.

- Solution: Resolution of this challenge calls for four parallel developments. First, network infrastructure needs to be expanded to accommodate deployments along relevant transport axes. Second, network awareness needs to be further developed, a fully automated system which gives a 5G network the ability to measure, predict and interpret the state of the network and dynamically and independently adapt the network when needed. Network awareness promises a smarter utilization of available capacity. Third, a governance framework is needed which maps the connectivity conditions required for a particular scope of teleoperation and provides insights into where these conditions are in place. Such a framework should oversee that teleoperation (within the right scope) is authorized only at the appropriate place and time. Fourth, service level agreements may need to be introduced to provide some reassurances to teleoperation service providers in advanced deployments. The operational and legal certainties linked to this type of agreements help overcome the business risks faced by teleoperation service providers.

[ROAM] The MNO has limited control over quality of service provided by roaming MNOs. End-users require a minimum quality of service, which the home MNO (i.e. the one end-users enter into a commercial relationship with) needs to provide abroad using networks it has no or limited control over.

We consider this to be a **major challenge** for all cross-border scenarios (L4 – Cross-border and W3/4 – A to B barge).

- Solution: Optimized Steering of Roaming should be developed which helps to ensure that subscribers connect to the most suitable roaming network for their needs. In addition, MNOs should opt to provide Coverage on Demand – instead of providing roaming connectivity across a whole trajectory, it is only provided at specific locations. These technical innovations should be made possible through the use of fallback from automated driving systems, the introduction of Service Level Agreements between roaming partners and a EU-wide governance framework on 5G corridors (see also SATUR).

[HANDOVER] The solutions enabling seamless handover need to mature before large-scale deployment can take place. While the 5G-Blueprint project convincingly demonstrated that handover can be done seamlessly in a controlled environment with no noticeable interruption and a latency of less than 100ms, the project partners consider that scalability of the developed inter-PLMN handover technology in a commercial setting poses various challenges such as operational challenges, security considerations and pricing. In addition, the same holds for Dual-SIM, a second solution that was implemented and validated in the 5G-Blueprint project in which handover is done by switching between different SIM cards: scalability is a challenge considering the actions a teleoperation service provider would need to undertake to deploy such solutions (in particular at a EU-wide level).

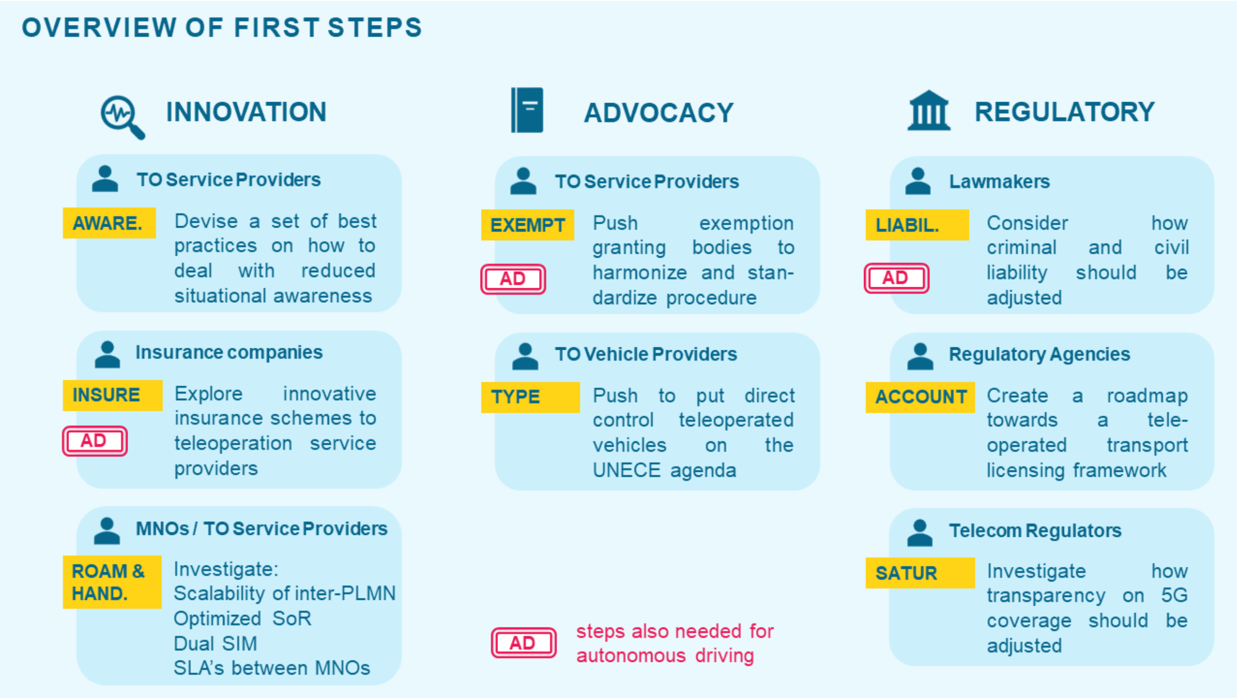
We consider this to be a **major challenge** for all cross-border scenarios (L4 – Cross-border and W3/4 – A to B barge).

- Solution: Hybrid control teleoperation should be the standard for every transport involving a border crossing. This requires that border crossings are located on stretches of road in which fully automated driving is feasible. At the same time, the proposed solutions (inter-PLMN handover and dual-SIM) should reach a sufficient level of maturity for deployment.

3.2 First steps

Based on the solutions presented in the previous subsection 3.1, we can identify a series of first steps – actions that should be undertaken sooner rather than later to gain and keep momentum towards commercial deployment of teleoperated transport. These actions can be grouped into three categories – Innovation, Advocacy and Regulatory. Some of these actions also overlap with what is needed to advance the roadmap towards the deployment of fully automated vehicles.

Figure 3: Overview of first steps on roadmap for teleoperated transport



Innovation[9]

- **[SA]** Teleoperation service providers and other stakeholders should sit together with experts from academia to **devise a set of best practices** on how to deal with reduced situational awareness. This should result in a roadmap for implementing these best practices to be added to the requirements for a licensing system.
- **[INSURE]** *[also for automated driving]* Insurance companies should **explore and assess how they would go about providing an efficient insurance** for teleoperation service providers. Ideally, insurance companies are involved in follow-up innovation projects on teleoperated transport.
- **[ROAM & HANDOVER]** MNOs should investigate the **scalability of the developed inter-PLMN handover solution**, focusing on the remaining operational challenges, security considerations and billing. In addition, they should consider the particular concerns of teleoperated transport in their **work on technical specifications for Optimized Steering of Roaming** in upcoming 3GPP releases.[10] Finally, already ongoing initiatives within the GSMA to **develop and incorporate Service Level Agreements between roaming partners** should be continued. [11] From their side, Teleoperation Service Providers should further investigate the practical feasibility of a **dual SIM solution** for cross-border (building on the work started in the 5G-Blueprint project)[12]. They should also investigate the feasibility of avoiding the need for seamless handover at scale by using automated driving systems at border crossings.

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[9] Work on this could be undertaken in the context of a follow-up project to 5G-Blueprint.

[10] 3GPP is a partnership that develops protocols for mobile telecommunications, such as 5G.

[11] Global Systems for Mobile communication Association, a global organization unifying the mobile ecosystem to discover, develop and deliver innovation.

[12] See Deliverable 5.5.

Advocacy

- **[EXEMPT]** *[also for automated driving]* Teleoperation service providers and other stakeholders should **push exemption granting bodies** and EU regulatory entities to harmonize and standardize the current exemption systems.
- **[TYPE]** Teleoperation vehicle providers and other stakeholders should **push to have direct control teleoperated vehicles put on the agenda at the UNECE** – the UN body that takes the first step towards designing and implementing a type approval process.

Regulatory

- **[LIABILITY]** *[also for automated driving]* Government agencies should **consider how criminal and civil liability should be adjusted** in the face of unmanned and automated transport. Work on this is already ongoing, though the potential involvement of a teleoperator should be explicitly taken into account.
- **[ACCOUNT]** Regulatory agencies (at national or EU level) should **create a roadmap towards a teleoperated transport licensing framework**, building on efforts undertaken by, among others, the UK Law Commission in the UK.
- **[SATUR]** National telecommunication regulators (such as BIPT in Belgium) and EU entities (such as the 5G Observatory) should **investigate how they can adapt their current efforts of providing transparency on 5G coverage** to the particular needs of teleoperated transport, and what is required in terms of data exchange from MNOs.

3.3 Guidelines

When executing the Teleoperation Roadmap, a number of overall guiding principles apply:

Figure 4: Guiding principles

Avoid a Teleoperation disruption. The introduction of teleoperation functionalities in the existing logistics ecosystem should be gradual. Drastic changes to how this ecosystem functions from an operational, regulatory and business perspective have in our view limited chance of success. Instead, we recommend a gradual evolution towards more ambitious forms of teleoperation, focusing first on applications where the benefits from teleoperated transport are clear without disrupting the logistics chain.

Involve all relevant stakeholders. The impact from the introduction of teleoperated transport goes beyond those that are directly involved with setting it up (such as teleoperation service providers, fleet providers or logistics companies). For example, the introduction of (unmanned) teleoperated transport has implications for the way insurers provide insurance to drivers and logistics companies. Similarly, unmanned transport creates challenges and opportunities for providers of fuelling or charging facilities. In order to avoid a coordination problem later down the road, it is best to involve such stakeholders from an early stage during the piloting or deployment phase.[13]

Teleoperation follows connectivity. While teleoperated transport presents an interesting business opportunity for connectivity providers, it is unlikely that individual teleoperated transport deployments will trigger significant investments in the 5G network infrastructure. When considering a deployment at a particular time, teleoperation service providers should therefore assess the potential of the deployment with the (5G) network at that time as a given – or at least with the projected evolution in connectivity absent the deployment. In other words, a teleoperation service provider should look at the connectivity that is currently being provided (or that is projected to be provided) to assess whether deployment is viable, rather than count on MNOs to make the necessary investments to fill in any gaps in connectivity.

That is not to say however that the 5G network shortcomings and complexities highlighted in Section 6 of this Deliverable imply that 5G is not the most suitable communication network for teleoperation. While some forms of teleoperation can today be deployed without requiring 5G network connectivity[14], the future potential of 5G network connectivity is such that it is our recommendation to prospective teleoperation service providers to roll out their services as much as possible over a 5G network.

Tag along with Automated Driving. Automated driving faces many of the same challenges that Teleoperated Transport faces, in particular those linked to unmanned transport. For example, issues related to liability (who is in control), type approval and exemptions are shared by teleoperation and automated driving. The latter has the advantage that many regulatory initiatives have already been undertaken to take away these issues. We therefore recommend to duly consider and integrate teleoperation technologies in relevant analyses and decision-making processing on automated driving, and applaud recent initiatives to that effect. This has the additional benefit that solutions for automated driving and teleoperated transport will be immediately aligned, which minimizes coordination issues later on.

[13] See Deliverables D3.2 and D3.4 for a comprehensive overview of who these stakeholders are.

[14] Notable examples are the two deployments presented in section 2.3: Seafar runs teleoperation over a 4G network; Lineage runs its teleoperated cranes via wired connectivity. The involvement of both partners in this project is partially driven by their curiosity in seeing whether 5G can bring these teleoperated services to a new level.

4 TELEOPERATION

This section discusses the challenges faced when removing the operator from the vehicle. In particular, we look into the extent to which the operator is still able to perform the tasks assigned to him while being no longer physically in or near the vehicle. We also assess how the removal of the operator complicates any attribution of fault. We explore these challenges and propose concrete solutions towards addressing them.

KEY FINDINGS

- The physical absence of an operator in or near the vehicle is not an issue for most tasks, insofar these tasks do not involve shifts in responsibilities among logistic parties. Teleoperation stakeholders should aim at addressing the issue of reduced situational awareness and should ensure specialised fuelling or charging infrastructure is in place when targeting long-haul teleoperated transport.
- Teleoperation complicates an assessment of liability and fault attribution. As a result, insurers may be reluctant to provide appropriate insurance, such that teleoperation service providers or individual teleoperators may not be properly protected against adverse outcomes beyond their control.
- Due to the more complex nature of teleoperation, product liability becomes more important. At the same time the standard way of product liability management (i.e. through homologation of a vehicle type) is not an option for teleoperated vehicles, at least not in the short term.
- These challenges overlap with numerous challenges also faced by automated driving systems – where more initiatives are already ongoing. Teleoperation stakeholders should piggyback on these initiatives which aim to address these challenges in the context of automated driving.

Table 4: Operational roadblocks to deployment of teleoperation

Roadblocks to Deployment of Teleoperation	L1	L2	L3	L4	W2	W3/4	Solution	First steps	Timeline of resolution
	TO @ Terminal	Shuttle Run	Highway	Cross-border	Shuttle Barge	A to B Barge			
Reduced **situational awareness** could undermine safety of teleoperation	☺	😐	😐	😐	😐	😐	Define set of mitigating requirements (under the umbrella of a licensing system)	(TO Service Providers) Devise a set of best practices on how to deal with reduced situational awareness	0-5 years
Specialised **fuelling** or charging infrastructure is needed [for long-haul transport]	☺	☺	😐	😐	☺	☺	Fuelling or charging stations operated by third parties along main transport corridors, with fuelling protocol in place	Involve potential providers of services at an early stage to resolve chicken-egg problem	5-10 years
Insurers are reluctant to provide **insurance** for teleoperated vehicles as they cannot assess the risks involved	☺	😐	😐	😐	☺	☺	Mandate a Vehicle Data Recorder which would make it easier to attribute fault and assess risk; deploy novel insurance schemes	(Insurance companies) Explore innovative insurance schemes for teleoperation service providers	5-10 years
Teleoperators may lack the **legal certainty** (in particular when operating in support of automated driving systems)	☺	😐	😐	😐	😐	😐	Change jurisprudence to better protect the teleoperator from adverse effects beyond his control	(Lawmakers) Consider how criminal and civil liability should be adjusted in the wake of unmanned, automated and/or teleoperated transport	5-10 years

LEGEND

☺	**No issues related to the topic and the scenario**
😐	**Either issues are minor or easy to solve**
☹	**Issue is both major and hard to solve**

The removal of the operator from the vehicle creates two potential hurdles to the evolution towards a healthy ecosystem for Teleoperated Transport.

First, the physical absence of an operator in or near the vehicle may complicate a number of tasks actually assigned to the on-board operator. For most tasks, the removal does not pose an issue as these could (i) still be taken on by the (tele)operator; (ii) automated or digitized; or (iii) handed over to an existing role within the same entity that employs the operator. However, for two tasks, teleoperation poses a challenge, though not of such nature to be a showstopper:

- Reduced situational awareness: An operator's ability to safely operate the vehicle may be impeded when he is removed from the vehicle as situational awareness may be reduced due to imperfect visual, auditory and haptic feedback. Mitigation should be achieved by (i) approximating the 'realness' of driving in the teleoperation environment; and (ii) boosting the awareness by providing additional aids not available to an on-board operator; all while (iii) avoiding information overload (as this may render points (i) and (ii) less effective).
- Lack of specialised fuelling or charging infrastructure (for long-haul transport): In the long term, and only for transports across long trajectories, specialised fuelling infrastructure should emerge which take on the task of (automated or manually) fuelling or charging the unmanned vehicle. A lack thereof may lead to reluctance to deploy teleoperation over longer distances. We therefore recommend to involve providers of such fuelling services at an early stage.

Second, the attribution of fault in case of incidents is considerably more complex in a teleoperated transport context. Teleoperated transport requires the interaction between different innovative components (such as teleoperation software, connectivity systems and automated driving systems) which muddles the link between operator action and operation result. This has three consequences:

- Insurance uncertainty: Insurers may find it difficult to assess the risks involved with providing insurance to teleoperated service providers, and may on that basis be reluctant to do so (or they may charge prohibitively high premiums). Besides the involvement of insurance companies at an early stage of the (experimental) deployment of teleoperation, this may also require (mandatory) data sharing schemes to ensure that liability can be appropriately attributed.
- Role of automated driving systems: The combination of teleoperated driving and automated driving systems complicates the handling of individual liability, where, for example, it is not clear to which extent a teleoperator can be held responsible for adverse outcomes resulting from automated operation under his supervision. Changes in jurisprudence are required to provide a robust framework which may protect the teleoperator (or his employer) from adverse outcomes beyond his control.
- Increased importance of product liability: As teleoperators hand over operational control to the vehicle, or increase reliance on novel technologies and software to be able to exert operational control, the liability for damages caused by deficiencies in the hard- or software of the vehicle becomes more important. At the same time, the standard way in which product liability is dealt with in an automotive context (through government-supervised homologation of a type of vehicle) will not be feasible for teleoperated vehicles. Product liability will therefore be managed through a system of vehicle-by-vehicle homologation, at least in the short to medium term.

These challenges are not unique to teleoperated transport, as they also apply to automated driving functionalities. The recent initiatives on these matters in the context of automated driving should be leveraged by ensuring that teleoperated transport is taken into consideration in a follow-up of these initiatives.

In following sections we dive into the details on particular topics assessed.

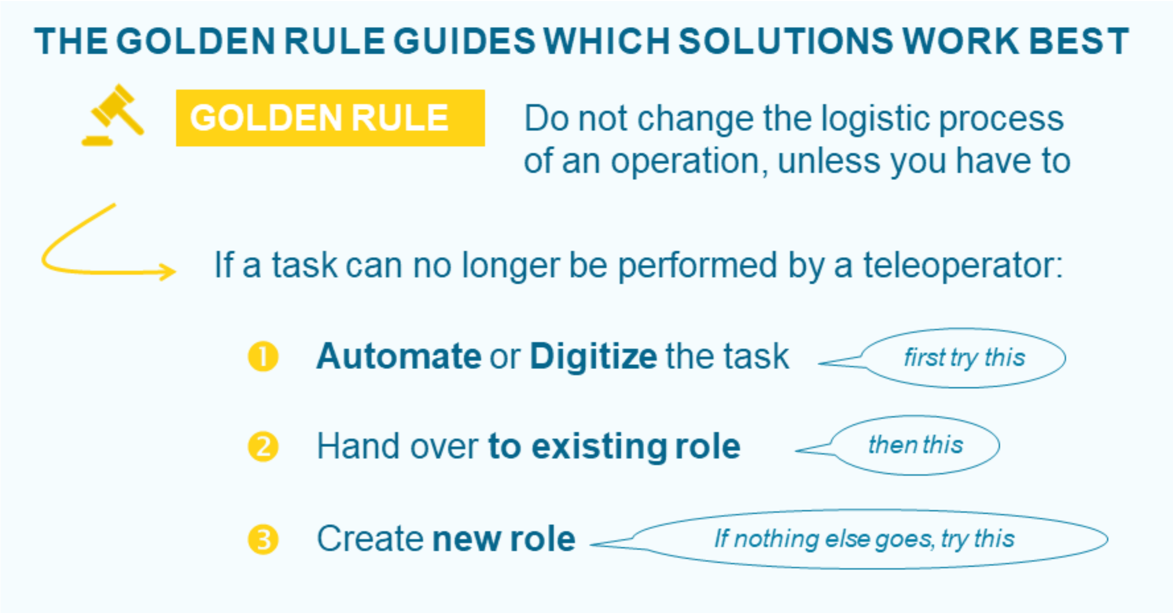
4.1 (Operator) Tasks

Today, an on-board operator of a vehicle or barge in a logistics context has a wide range of tasks, which may require the physical presence of the operator in or near the vehicle. Besides operating the vehicle (i.e. driving), operators are in charge of monitoring vehicle health, docking the vehicle, (de)coupling the trailer of the vehicle, fuelling or charging, monitoring cargo safety, (un)loading and providing the necessary documents to authorities. Removing the operator from the vehicle may pose a challenge as for some tasks a substitute needs to be implemented when the operator is not physically present.

For each scenario, we identified those tasks for which the operator is responsible in a non-teleoperated context and which requires the physical presence of the operator in or near the vehicle. We assessed whether the task can still be provided by the teleoperator and, if not, what solutions are available to substitute the teleoperator.

Crucially, these solutions should be such that changes to the current logistic process are kept to a minimum, in particular with respect to handover points (i.e. points at which the responsibility over the cargo and/or the vehicle shifts from one actor to the next). This ensures that challenges related to liability and governance are limited, thus strengthening the business case and willingness to deploy. This means that in the first place we will look to automation or digitization as a replacement for the operator to perform certain tasks. In second place we should look to hand over the task to an existing actor, who due to his presence near the vehicle at some point during the operation is well placed to perform the task. In the last place, we should look to create a new role for a new actor as this may make things more complicated and ultimately more expensive.

Figure 5: Schematic view of solution hierarchy



The table below provides an overview, indicating per task and scenario whether the task can be performed by the teleoperator ("**TO**"), automated or digitized ("**A/D**"), taken over by an existing role ("**ER**"), or whether a new role needs to be created ("**NR**"). When the removal of the operator from the vehicle cabin poses a challenge, the cell is highlighted in **red**; when the task is not relevant, the cell is kept white.

Table 5: Tasks for Teleoperated Transport

Task of Operator	L1a RTG Crane	L1b Terminal Vehicle	L2 Shuttle Run	L3 Highway	L4 Cross-border	W2 Shuttle Barge	W3/4 A to B Barge
Operation - Situational Awareness	TO	TO	TO	TO	TO	TO	TO
Vehicle Health	TO, A/D, ER	TO, A/D, ER	TO, A/D, ER	A/D, ER	A/D, ER	TO, A/D, ER	A/D, ER
Docking		TO, A/D	TO, A/D			ER	ER
Coupling/Decoupling		TO, A/D, ER	TO, A/D, ER				
Fuelling/Charging		TO, A/D, NR	TO, A/D, NR	A/D, NR	A/D, NR		
Cargo Safety			TO, A/D	TO, A/D	TO, A/D		
Loading/Unloading						TO, A/D, ER	TO, A/D, ER
Documenting			A/D	A/D	A/D	A/D	A/D

*Symbol legend: **TO** - the task can be performed by a teleoperator; **A/D** - the task automated or digitized (under the supervision of the teleoperator); **ER** - the task can be handed over to an existing role; **NR** - a new role may need to be created for this task.*
*Color legend: **BLUE** - there are no challenges related to this task; **RED** - there are challenges related to this task*

The operational challenges resulting from the removal of the operator from the vehicle or barge are limited to two areas: operation (situational awareness) and fuelling or charging (for the highway-based scenarios). The other tasks do not pose a specific challenge, in particular because there is no handover of responsibility to another party:

- Monitoring vehicle health: If the control centre is close to the area of teleoperation (as is the case for scenarios L1 – TO@Terminal, L2 – Shuttle Run and W1 – Shuttle Run Barge), the teleoperator could still check up on vehicle health at the start of the shift. In any case can the teleoperator be assisted in this task by monitoring and diagnostic systems which can measure health status and alert maintenance crews if action is needed, as well as by the maintenance crew itself.
- Docking: Docking a teleoperated vehicle does not present a challenge in the relevant land-based scenarios (L1b – Terminal Vehicle, and L2 – Shuttle Run).[15] Teleoperators will dock at large bays with simple familiar layouts, making docking a repetitive and straightforward manoeuvre that can be handled by the teleoperator. Teleoperation may even increase the efficiency, safety and comfort of the manoeuvre, in particular in combination with automated docking systems.[16] In addition, the combination of teleoperation and automated docking could make it possible to dock double-articulated vehicles (a truck with two trailers in sequence), which is not possible by an on-board operator. In the water-based scenarios, docking involves bringing the vessel alongside the dock, fastening the lines (in collaboration with on-shore crew), and connecting gangway, power and supply. While a remote skipper can fully execute the task of bringing the vessel alongside the dock, a physical presence on board the vessel is still required to fasten all lines and setup the necessary connections. This requires extra manpower to be provided by the teleoperation service provider, though Seafar does not consider this to be a significant financial hurdle.[17]
- Coupling/Decoupling: This task is only relevant for Scenarios L1b (Terminal Vehicle) and L2 (Shuttle Run) as in the other scenarios the role of the (tele)operator does not require

[15] In Scenarios L3 (Highway) and L4 (Cross-border), docking by the teleoperator may not be needed as, in the envisioned deployment, teleoperation only starts close to the highway.

[16] Such as the one piloted in the 5G-Blueprint project.

[17] Seafar is currently working on a fully automated docking solution, so in time vessels could be fully unmanned from start to finish.

coupling/decoupling.[18] For L1b and L2, there is no issue as: (i) coupling or decoupling is a relatively infrequent activity (in the case of L1b) which, due to the proximity of the control centre, could still be performed by the teleoperator; (ii) in the case of L2, warehouse crew could also take on this task;[19] and (iii) the vehicle could be equipped with automated coupling systems which are already available on the market today.[20]

- Monitoring cargo safety: The operator of the transport is responsible for the cargo, needing to ensure that the container seal is not broken during the transport. Visual inspection and monitoring by the teleoperator is still possible through the use of smart sensors and camera technology. A minor challenge would be the placement of the sensors and the cameras as (i) these cannot be placed on the container, which is a commoditized product that travels around the world; and as (ii) placement of sensors or cameras at the back of the trailer is also complex. The most likely solution will therefore be placement of sensors or camera technology at sites that are vulnerable to container breaches (most notably parking spaces), using for example technology piloted in Enabling Functions 6 (Container ID Recognition) and Enabling Function 8 (Scene Analytics).
- Loading/Unloading: For Scenarios W2 and W3/4, the loading and unloading of the container usually takes place under the supervision of the skipper. The skipper as teleoperator will still be able to supervise the loading using the video feeds at his disposal. Controlling the hatches, supervising the loading and monitoring the stability and strength of the vessel can still be done remotely, provided the vessel is equipped with the appropriate cameras and sensors.[21] A minor challenge for W3/4 would be the (un)loading of the barge if it needs to be done via an on-board crane. Three options exist: (i) the crane is teleoperated and the skipper can take care of loading; or (ii) if there is still crew on-board the vessel, a crew member can take over; or (iii) onshore crew comes on board. Which of these options is chosen depends on the relative costs of the options, however, none of these options pose a risk for deployment of these scenarios.
- Documenting: The process of providing documentation or identification is already heavily digitized or in the process of becoming so. While there are some particular challenges, e.g. related to standardization, we do not consider these to be particular hurdles to the deployment of teleoperated transport.

In what follows we discuss each of the tasks for which teleoperation poses some challenges.

4.1.1 Reduced situational awareness could undermine safety of teleoperation

Situational awareness refers to "*the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future*" ((Endsley 1988) taken from (Mutzenich 2021)). It "*fills the gap between what is known about the environment, what is happening in it and what might change*" (Mutzenich 2021). Situational awareness, or lack thereof, is an important determinant of traffic safety. Indeed, "*inadequate [situational awareness] is frequently implicated in crashes, [and] 'failed to look' [or] 'distraction' is the most common citation in insurance documentation*" (Mutzenich 2021).

[18] Note for example that for scenario L3 and L4 we have assumed that teleoperation only starts after an on-board operator (or automated driving system) has dropped off the vehicle close to the highway.

[19] This assumes that warehouse crew and transport company are part of the same entity, which is typically the case for shuttle runs. For example, in Vlissingen, warehouse owner MSP Onions is also responsible for the transport to the terminal.

[20] See for example JOST's KKS-system: "*The JOST KKS enables the driver to couple and decouple the semi-trailer via remote control […] which saves time when coupling, as well as increases safety, efficiency and ergonomics.*"

[21] At Seafar vessels, the remote captain has multiple cameras at his disposal, one of which is positioned on a large pole and can be rotated 360 degrees, allowing full view on the cargo deck.

Situational awareness of a remote (tele) operator may be reduced as a result of not being present in the vehicle. The teleoperator "*is likely to suffer from a degraded state of [situational awareness] as they are being transmitted indirect cues unlikely to replicate the full range of visual, vestibular, auditory and temporal information that is available to [an on-board operator]*" (Mutzenich 2021). Visual information conveyed by cameras may lack depth and sharpness and the camera system may create image distortions, such that it does not perfectly capture the combination of sensory perceptions of a driver on the road. Further, teleoperators "*may also be deprived of the sensation of acceleration or other clues about the environment*" (UK Law Commission 2023b).

The reduced situational awareness creates a three-pronged risk:

- Direct safety risk: The teleoperator may fail to pick up on potentially dangerous events ahead, creating potentially dangerous situations.
- Discomfort risk: The teleoperator may need to exert more effort to ensure a safe operation. The perception that what the teleoperator sees is not 100% reliable and that important cues may be missed creates additional fatigue and stress. This makes the teleoperator more prone to errors.
- Detachment risk: Teleoperators may suffer from a sense of detachment, as they are in no personal danger.[22] Indeed, "*an [operator] who is not at risk from a collision may have less instinctive understanding that what they do matters in the 'real world'*" (UK Law Commission 2023b). This may lead them to underestimate the risks involved with teleoperation (i.e. the likelihood that things go wrong), or attribute insufficient weight to these risks (i.e. the perceived impact if things go wrong). The risk of detachment is further exacerbated via reduced situational awareness, as it confirms a teleoperator's perception that the situation is not 'real'.[23]

A mitigation (or prevention) of the loss in situational awareness in teleoperation should be achieved by (i) approximating the 'realness' of driving in the teleoperation environment; and (ii) boosting the awareness by providing additional aids not available to an on-board operator; all while (iii) avoiding information overload (as this may render points (i) and (ii) less effective). Indeed, "*in [a teleoperation setting], it may be beneficial to make a [teleoperator's] driving experience as realistic as possible whereby visual, auditory and haptic cues are provided as if they were [on-board]*" (Mutzenich 2021). But, "*many of the suggestions for improving [situational awareness of teleoperators] involve presenting additional information. Their benefit must therefore be carefully weighed against the additional [cognitive] workload that they will impose*" (Mutzenich 2021). Academic research is currently underway to explore the issue of cognitive overload in the context of remote driving.

We therefore see the following steps towards mitigating degraded situational awareness and its impact on the safety of teleoperation:

HD imaging with low latency. A low-latency connection is not only important to reduce the direct safety risk, it is also vital to reduce discomfort and detachment risk. Instantaneous HD images will contribute to the perception of 'realness' which draws the teleoperator in and makes him perceive

[22] Of course, the lack of risk for the teleoperator also constitutes one of the main advantages of teleoperation, in particular in extreme impact cases (transport of dangerous goods, signal vehicles at road works, etc.).

[23] Detachment risk has been widely documented: "*Remote operators have cited a sense of driving 'deaf' or feeling like it is a game, when the reality is that they are potentially driving real passengers with the resulting consequences if they crash only borne by those*"; "*Although they may have access to a wider range of sensors from the AV system than if they were manually driving the car at the location, [teleoperators] have no vestibular feedback and so may misunderstand the conditions 'outside' or attribute greater significance to one piece of information than another*"; "*[Detachment] may also have a deleterious effect on speed perception; without force feedback pushing you back into the seat or information from the tyre friction on the road, it is difficult to accurately judge how fast you are driving and to remain engaged in the driving task*". Sourced from (Mutzenich 2021, p.12)

risk appropriately. Studies have shown that image resolution matters, with "*low resolution leading to overestimation of distances and reduced quality of lateral control*" (UNECE 2020). This highlights the importance of having a stable, reliable 5G connection (see also Section 6).

Improved visual cues. It may make sense to go beyond HD camera streams and explore the usage of virtual or augmented reality features. First, as regards virtual reality, "*a naturalistic experience of driving even in [teleoperation] contexts could be supplied by using a virtual display headset, allowing the operator to control their field of view just by moving their head*" (Mutzenich 2021). Hyundai is supposedly working on a virtual reality prototype that can be used for remote operation, though its current status is unclear.[24] A particular challenge related to teleoperation via virtual reality is motion sickness "*which develop[s] as the vestibular input does not match the visual motion experience of the user*" (Mutzenich 2021). Second, as regards augmented reality, the idea is to superimpose additional information over the visual information provided via camera streams. This could take many forms: from highlighting potentially dangerous situations on the camera stream to "*placing AR virtual markers overlaid onto a map to allow [teleoperators] to 'see' [relevant] information coming up which may be occluded by forward terrain or buildings*" (Mutzenich 2021). Enabling Function 4 on Distributed Perception, piloted in the 5G-Blueprint project, provided a proof of concept of such a solution whereby objects in the field of vision of a lead vehicle were shown to teleoperators operating a following vehicle.

Add spatial awareness view. "*Poor spatial and navigational awareness will reduce [situational awareness] so providing [teleoperators] with pre-loaded terrain data with the [teleoperated vehicle's] current position superimposed on it [i.e. real-time maps] will give [teleoperators a] better comprehension of 3D spatial relationships*" (Mutzenich 2021). The video-centric interface should therefore be complemented by a sideview with a map-centric interface. This was the focus of Work Package 6 of the 5G-Blueprint project: functionalities were piloted which enhanced the awareness of the teleoperator by providing additional visual and textual cues of potential dangers on a map-centric interface, while limiting information overload. For example, Enabling Function 2 piloted technology which detects vulnerable road users (pedestrians or cyclists); when the system predicts that these users will pass the teleoperated transport at close distance, a visual and textual cue is shown on an 'enhanced awareness dashboard' provided in Enabling Function 1.

Add auditive and haptic cues. The 'realness' of the teleoperation context can be further enhanced by adding other cues that approximate sensations and perceptions experienced in on-board driving. For example, teleoperation service providers are actively looking to adding sensory feedback to the operator seat or steering wheel.

Avoid distraction. Detachment risk may still occur when teleoperation takes place in an environment that does not look like the cockpit of a vehicle (even if visual, auditive and haptic cues are on point). A desk in an office landscape, with three screens, a headset and a chair with haptic feedback may not be sufficient to prevent detachment. Good HMI and cockpit design are therefore essential to bring the experience as close as possible to on-board operation. Overall, such design "*may benefit from asking questions such as: how to gain [and keep] operator attention, how to allocate jobs to operators, how to ensure the operators are attentive*" (UNECE 2020).

Manage workloads. The combination of a video-centric interface with AR or VR enhancements, a map-centric birds-eye view interface and potentially other interfaces showing vehicle system status "*may create new demands on the operator and task-switching requirements*" (UNECE 2020). How this information is presented and how to support the operator in prioritizing the information needs to be carefully considered. Teleoperator workload "*could be very high, leading to a need for more rest periods or shorter shifts*" (UNECE 2020).

Train the teleoperators. Teleoperators should be made aware of the risks inherent to

[24] Mentioned in (Mutzenich 2021) – no information on this has been found online as the link is dead.

teleoperation, in particular the risk of reduced situational awareness and detachment. Training can help in raising such awareness. In addition, "*as with other types of safety critical shift work, the organization and its employees can benefit from health checks, e.g. for sleep apnoea*" (UNECE 2020).

These mitigating measures should be integrated into the set of requirements that a teleoperation service provider should meet before he is granted a commercial license (see also Section 5.4). In other words, a teleoperation service provider should not receive a license if it cannot demonstrate that appropriate actions along the aforementioned dimensions are taken to mitigate the risk of reduced situational awareness.

As a first step, the mitigating steps should be further developed, with detailed specifications on how these steps should be filled in and what the minimal requirements are before the step can be considered reached. These steps have been described in academic and regulatory literature.[25] However, a consolidated view is missing which provides a set of guidelines towards mitigating the risk of loss in situational awareness. The ISO certification on flight and train simulators could prove a fruitful basis for specifying these mitigating steps. These simulators are built in such a way that they accurately mimic real-life situations (including vibrations, movements, sounds, …). As a sidenote, the fact that a lot of effort was put into making these simulators as 'real' as possible, further underlines the importance of 'realness' for eliciting the appropriate behaviour from the operator.

4.1.2 Specialised fuelling or charging stations should emerge in the long term

We discuss in turn the case for the land-based scenarios and the water-based scenarios.

Land-based scenarios

Operators are responsible for ensuring that the vehicle has sufficient fuel or battery charge to operate. In a non-teleoperated context, it is their task to fuel the vehicle or plug in the battery. In a teleoperated context, there are three options with respect to fuelling or charging. Whichever of these options is preferred is a matter of cost and depends on the scenario and the scale of deployment.

- By the teleoperator: Provided the remote control centre is close to the fuelling or charging station, this task can be carried out by the teleoperator.
- Automated: Automated systems exist for both fuelling and charging, with the commercial prospects for the latter being more promising.[26]
- By dedicated staff: Fuelling or charging stations can be equipped with dedicated staff whose sole task is to operate the station, including fuelling and charging of unmanned vehicles.

For Terminal Vehicle (L1b) and Shuttle Run (L2), all three options are viable and none of these options presents a challenge to the deployment of the scenarios. Which option is

[25] See among others (Mutzenich 2021) and (UNECE 2020) which were the main sources for this section.

[26] With respect to fueling, there are several systems commercially available which allow automated fueling (see among others Autofuel (autofuel.eu) or Rotec Engineering (rotec-engineering.nl). The commercial exploitation of this technology is still in its infancy (a limited number of gas stations in Scandinavia are equipped with the Autofuel technology; Rotec has a bespoke automated fueling solution for mining dump trucks but does not yet seem to have deployed its automated gas station product anywhere), and it remains to be seen whether the technology will ever break through. With respect to charging, multiple technologies are being developed which allow for automated charging: wired systems which simply automate the act of plugging in the vehicle (Rocsys, Siemens), conductive systems where conductive charging hardware is put on the vehicle (typically roof-mounted or in the underbody) which can then connect with a charging pad mounted overhead or integrated into the floor (Schunk, Easelink), or wireless charging systems (inductEV, Volvo, BMW).

preferred depends on the scale of the deployment and whether fuelling or charging investments can be shared across multiple deployments.[27] For larger deployments and/or deployments with the potential for shared amenities, it may make sense to invest in automated fuelling or charging infrastructure, or stations with dedicated staff. In any case, the chosen option will be a business decision without any technical or legal challenges.

The same holds for Highway (L3) and Cross-border (L4), provided the distance travelled along the highway is not too high. In that case, fuelling or charging close to the remote control centre, or at least in stations (co)controlled by the teleoperation fleet manager, remains possible. It is likely that the first deployments of L3 and L4 will involve transport over shorter distances. For example, one such envisioned deployment could be teleoperated or automated transport between the ports of Zeebrugge and Antwerp over a trajectory of c. 100km including a stretch of highway of 30-40km.[28] For this trajectory, it is perfectly feasible to refuel or recharge close to the remote control centres, either in Antwerp or Zeebrugge.

However, in the long term, the situation may be more challenging as highway trajectories could span multiple countries and located several 100 kilometres away from the home station. In particular two potential issues arise. First, teleoperators will no longer be able of taking on the task as fuelling or charging will take place on the road. Second, the fuelling or charging infrastructure on the road will not be under the control of the teleoperation fleet manager.

As such, specialised fuelling or charging infrastructure will need to emerge along major highway corridors, owned and operated by third parties. This infrastructure will either need to deploy dedicated staff (similar to how fuelling stations used to operate in Europe 20+ years ago), or equip the stations with automated fuelling or charging equipment. This creates a potential chicken-egg situation as teleoperation will not be rolled out over longer distances in the absence of specialised infrastructure, and such infrastructure will not emerge if there is no demonstrated demand for its services.

In order to facilitate and expediate the emergence of specialised infrastructure, coordinated action is advised. Potential providers of these services should become part of the teleoperation (or automated driving) ecosystem from an early stage. Likely candidates are major operators of existing fuel stations along highway corridors or landowners with conveniently located properties. Discussions should take place on the organisational, financial and regulatory aspects of delegated fuelling. Absent such coordinated action, long-distance Highway or Cross-border deployments of teleoperated transport may not materialize or at least not to the full geographic extent (e.g. limited to one particular corridor).

In conclusion, while the need to refuel or recharge on the road is not a showstopper per se, it does constitute an impediment to extent that the geographic scope of a teleoperation roll-out on highways will be smaller than absent this impediment.

Water-based scenarios

In the water-based scenario, fuelling (or *bunkering*) is a complex process which either requires a bunkering barge to be moved alongside the vessel with the assistance of tugboats, or pipeline infrastructure which allow fuelling from the pier. It is the on-board crew which takes care of the bunkering (with the help of onshore crew or with the help of the bunker barge). In the absence of an on-board crew, a shore crew should come on-board to do the fuelling, under the supervision of the remote skipper. **In contrast to the land-based scenarios that also require specialized crew to fuel, this poses less of a challenge as current processes already require the involvement of a specialized crew**.

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[27] The new Regulation for the deployment of alternative fuels infrastructure (AFIR) may boost development of shared charging infrastructure in so-called zero-emission hubs in strategic areas (e.g. portal environments).

[28] These two ports are operated by Port of Antwerp Bruges since the merger in April 2022.

4.2 Liability

Liability is the (legal) responsibility of an entity to compensate for adverse outcomes caused to another entity due to the former entity's actions, negligence, or failure to act with reasonable care. In today's (non-teleoperated) logistical chains, these liabilities are tightly managed. Hundreds of years of logistical operations have resulted in mature systems which can provide proper compensation for adverse outcomes (harm, damage or loss) by the parties responsible for those outcomes while limiting moral hazard (i.e. not taking proper precautions to limit risk because one is shielded from the adverse consequences related to the risk).

With teleoperated and automated driving systems comes increased complexity. Teleoperated transport requires the interaction between different innovative components with the chain between operator action and operation result including both software and connectivity processes. For example, if a truck does not give right of way, the question becomes whether the operator did not give the instruction to the vehicle to stop (which would indicate operator error) or whether he actually did but connectivity, software or hardware issues prevented the instruction from bringing the vehicle to a stop (which would indicate a fault with the teleoperation system). This complexity is further amplified by the lack of data to assess the risks involved. Teleoperated has not been rolled out commercially at sufficient scale and data collection has thus far not been coordinated to have resulted in a large dataset, from which robust conclusions related to the risks of teleoperation can be drawn.

This poses a number of challenges to the way liability has been dealt with in the past.[29]

1. Attribution of fault: How can insurance companies properly appraise the risks involved with teleoperation and determine liability when things go wrong?
2. Driver liability in the context of reliance on (automated) software systems: Can the operator of a teleoperated or automated vehicle be held liable for adverse outcomes resulting from the use of teleoperated vehicles?
3. Product liability: Who is liable for adverse outcomes resulting from deficiencies in the teleoperated vehicle or teleoperation system?

Each of these points will be tackled in turn.

4.2.1 Addressing insurance uncertainty through a Vehicle Data Recorder

Insurers may be reluctant to provide insurance for teleoperated vehicles, in particular at the outset. Lack of historical data on teleoperated transport (of any kind) means that insurance companies cannot make a proper risk assessment, resulting in an insurance market that does not clear: insurance premiums account for this uncertainty and are higher than what should be considered appropriate for the actual risks incurred and also than what a prospective teleoperation service provider may be willing to pay. This may be specifically the case for the teleoperation scenarios that take place on public roads, where the risk and impact of adverse outcomes on third parties is highest.

The importance of properly priced insurance schemes cannot be overstated. If no insurer is willing to insure a teleoperation service provider at a reasonable price, then roll-out of teleoperation (on public roads) could be halted.

In order to tackle this hurdle, coordinated action will be required.

First, it is advised that insurance companies are directly involved from the early stages of deployment of teleoperated transport. This is evidenced by two recent teleoperation pilots in other

[29] A fourth topic is who should be held liable for adverse outcomes resulting from degraded connectivity. As this topic is closely linked to the discussion on 5G-related roadblocks, it will be tackled in Section 6.

fields:

- Colruyt is running a pilot with indirect control teleoperation in a Belgian city, using small unmanned vehicles to deliver groceries to customers. Colruyt faced considerable difficulties in finding an insurer for the pilot, eventually receiving only one offer from AG who saw this pilot as an opportunity to "*follow new evolutions closely, gain experience with them and collect data that [can be used] in the evaluation of risks*", rather than as a standard commercial case.[30]
- Elmo launched a teleoperation pilot in the Netherlands bringing shared cars to its customers. The pilot is a collaboration with among others the Dutch insurer Aon, who "*will support [Elmo] from the risk assessment and insurance side*".[31]

Second, to accommodate insurers' increasing reliance on data to assess risk and determine fault, OEMs should be required to store and share the data when requested "*to create hybrid insurance policies and ensure that liability can be fairly and appropriately defined while protecting vehicle owners' personal information*"[32]. In particular, there is a need for **a data recording system**, not unlike those that have been successfully applied in aviation for decades.[33] Such a 'Vehicle Data Recorder' would keep a log in real-time of all items that are relevant to teleoperation of a vehicle, such as (i) vehicle-side data (metrics on the state of the vehicle, including crash data), (ii) remote control centre data (metrics on the commands given at the remote control centre), (iii) connectivity data (metrics on the state of the connectivity faced by the vehicle), and (iv) environmental data (metrics on the state of the surrounding environment, such as congestion, obstacles, etc.).

The importance of collecting, retaining and sharing of data, in particular following a collision to determine what went wrong and who was responsible (i.e. accident cause analysis) notably is also emphasized by the UK Law Commission advice on Remote Driving. They advocated for standards for data retention, enforced as a condition for obtaining a teleoperation license (see section 5.4), with a data retention period of at least 3 years. In addition, the Commission advocated for a duty to share data with an insurer where necessary to decide claims fairly and accurately (UK Law Commission 2023a).

Two recent initiatives at UN and EU level aim for putting in place (mandatory) systems collecting and storing a determined range of vehicle data. First, in the context of the General Safety Regulation (EU Regulation 2019/2144 – see Section 5.2.2), the EU mandated the inclusion of an **Event Data Recorder** (EDR) in all new vehicles starting July 2024.[34] This EDR should record and store "*critical crash-related parameters and information shortly before, during and immediately after a collision*" (EU Regulation 2019/2144). The concept of the EDR is distinctly research-focused: "*the data […] can be made available to national authorities […] only for the purpose of accident research and analysis, including for the purposes of type approval of systems and components*" (EU Regulation 2019/2144). There is an explicit prohibition to record any identifiers such as the Vehicle Identification Number (VIN) and time and place of the crash. Second, within the relevant UN working group, work is underway on a **Data Storage System for Automated Driving (DSSAD)**. It is aimed specifically at automated vehicles and at recording the

[30] See here.

[31] See here.

[32] See here.

[33] The parallel between Flight Data Recorders (also known as 'black boxes') can be drawn. Born out of the need to understand aircraft accidents, these have proven to be a crucial element towards improving aviation safety (up to the very high standards we observe today). It took 40+ years to go from its early developments until wide acceptance and standardisation. Teleoperated transport (and automated driving) have the benefit of hindsight, where important learnings on technology, procedures and regulation from Flight Data Recorders can be used.

[34] For coverage on this regulation see for example here.

status of the automated driving system versus the driver being in control. Where the EDR will store during a quite short time a large amount of anonymized data on a trigger basis (e.g. when the airbag is deployed), the DSSAD should store a limited amount of relevant data (e.g. who is driving) on a continuous basis and must be able to deliver these when requested by an authorized entity.

It is the consortium's opinion that a Vehicle Data Recorder for teleoperated vehicles should rather build on the concept of the DSSAD, than on the concept of the EDR. The concerns for privacy are valid when implementing an EDR in all new vehicles; for teleoperated vehicles however a balance needs to be found between addressing these concerns and making sure that authorities and insurers have access to the type of data that would allow them to overcome the uncertainty they are facing. In this, teleoperated transport and automated driving systems share the same challenge, and the former should piggyback on the ongoing initiatives of the latter.

In conclusion, advocacy work should be undertaken to put teleoperated transport on the agenda of the entities that oversee (mandatory) data storage systems for automated driving.

4.2.2 The (tele)operator or its employer remain liable for adverse outcomes from teleoperation

At first sight, operational liability in a teleoperation context is not different from liability in a standard, non-teleoperated, context.[35] Typically, under *vicarious liability* an employer (in this case the teleoperation service provider) can be held liable for adverse outcomes resulting from the actions of an employee (in this case the teleoperator).[36] In reality, the insurer will be responsible for compensating third parties, also in a teleoperation context: "W*here an accident is caused by a [teleoperated vehicle] and a person suffers damage as a result, the insurer is [considered automatically] liable for that damage*" (UK Law Commission 2023a). That does not mean, however, that the insurer or the teleoperation service provider cannot in its turn claim damages from the manufacturer of the vehicle or developer of the software subject to indications that the error was due to faulty vehicles or software (see Section 4.2.3). Similarly, the normal rules of "*contributory negligence*" should apply: "*when a collision is to any extent the fault of the injured party, compensation is reduced to the extent that the court thinks is just and equitable*" (UK Law Commission 2023a). Finally, vicarious liability does not apply to criminal liability (i.e. resulting in criminal charges related to errors resulting from teleoperation; as opposed to civil liability). Generally, individuals are only held criminally liable for their own wrongful acts and the law currently only foresees criminal liability for operators of vehicles with which criminal conduct was made. The legality principle[37] therefore precludes any entity other than the (tele)operator from being held criminally liable.

However, given the heavy reliance on software (including automated driving systems in the case of hybrid and direct control teleoperation), **the standard approach on criminal liability may be disproportionally unfair to teleoperators**. Though the debate among legal scholars has not been fully settled, the current viewpoint seems to be that the (tele)operator should be held liable for damage resulting from erroneous behaviour of the automated driving system software: "*Whoever enjoys the benefits of automobility should, when the related risks materialize, also bear the ensuing costs: 'motoring should pay its way'. Whoever chooses to participate to motorized traffic should simply […] be held responsible for the correct functioning of his vehicle and the*

[35] See also De Bruyne (2021) for an excellent discussion (in Dutch) on liability in an automated driving context for Belgium.

[36] For example, in Belgium, Article 1384, paragraph 3 of the Belgian Civil Code states that employers are liable for the damage caused by their employees in the function in which they employed them.

[37] Behaviour should only be considered criminal if it has been clearly defined and prohibited by law prior to the behaviour.

intelligent systems that are part of the vehicle" (Van Wees 2015). However, as argued in the Advice on Remote Driving prepared by the UK Law Commission, "*a [teleoperator] might have little control over problems caused by failures […] Yet, they may still face criminal prosecution if things go wrong*". The Advice posits that "*the responsibility for maintaining safety in areas beyond the driver's knowledge or control should lie with the organisation [i.e. the teleoperation service provider], not the individual*" (UK Law Commission 2023a).

Two developments are therefore proposed to provide legal certainty to teleoperators:

- The UK Advice on Remote Driving proposes the **introduction of a statutory defence** where "*a [teleoperator] should not be found guilty of a driving offence if a competent and careful driver in the [teleoperator's] circumstances (i) would not have been aware of the circumstances giving rise to the liability; and (ii) would not have avoided commission of the offence*". Where the defence applies "*the regulator should explore the issues with the [teleoperation service provider] to find out what went wrong and consider regulatory sanctions*" (UK Law Commission 2023a).
- **The traffic law should be amended** or detailed to make it explicit who, and from which level of automation, will be held criminally liable for violations with or by the (partially) automated vehicle.

4.2.3 Product liability is managed via vehicle-by-vehicle homologation

As operators may hand over operational control to the vehicle, or may increasingly rely on novel technologies and software to be able to exert operational control (as is the case for teleoperation), the liability for damages caused by deficiencies in the hard- or software of the vehicle becomes more important. Whereas with traditional vehicles the vast majority of incidents are due to driver error, [38] this may no longer be the case in a future with teleoperated and automated vehicles (De Bruyne (2021)). Automated driving indeed faces the challenge of a focus shift from operational liability to product liability. "*As drivers become less responsible for road safety, more liability risk will [be] assumed by manufacturers, component suppliers, and technology companies involved in building automated [or teleoperated] vehicles and the software that controls them*"[39].

Deficiencies could be pre-existing (i.e. originating from the design or manufacturing process) or arise in the course of the vehicle lifetime. In the former case the OEM is liable for adverse outcomes (damages) to third parties – product liability; in the latter case the custodian of the vehicle, typically the owner, is liable – object liability.[40] In both cases liability applies, even if the OEM or custodian is not at fault, that is, their behaviour was not negligent, was not careless and did not violate any laws. The OEM or custodian can however reclaim damages from third parties that were proven to have committed an error. For example, if the deficiency originated from bad maintenance under the supervision of a subcontractor, the custodian could reclaim damages from that party.

In a standard automotive context, product liability risks are managed through three processes:

- **Homologation of a vehicle type:** This process, applicable to a very large majority of

[38] A 2007 study by the European Commission and the International Road Transport Union studied 642 accidents on European roads which involved at least one truck. For only 5% of those accidents the cause could be traced back to technical failure of the vehicle (see here). A more recent study from the US National Highway Traffic Safety Administration shows that the critical reason (i.e. the last event in the crash causal chain) was assigned to a vehicle component's failure or degradation in only 2 percent of the crashes – with 94% of the crashes due to operator error (see here).

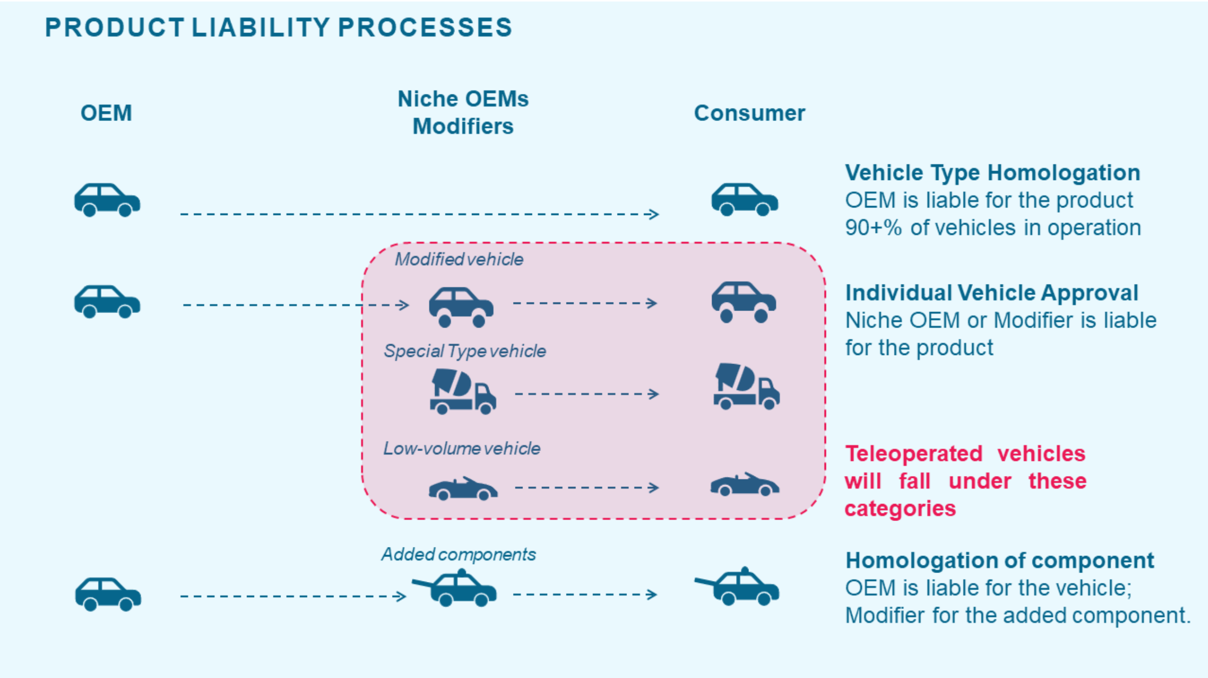
[39] See here.

[40] Typically, the owner of the good (and not the operator) will be presumed to be custodian.

vehicles operational on public roads, certifies that a vehicle (type) complies with the regulations, standards and technical requirements set forth by the relevant regulatory authorities and governing bodies.[41] Through the homologation process, the OEM can ensure that the vehicles it puts on the market comply with requirements thus safeguarding itself against product liability claims. OEMs will not assume liability for vehicles on public roads that are not properly homologated (under its supervision).

- **Individual Vehicle Approval**: This process is foreseen in the EU when a vehicle is not subject to type approval because it is not part of a mass-produced series. This typically applies to vehicles that are (i) modified to such an extent that safety and/or emissions are affected; (ii) of a special type (e.g. construction or agricultural vehicles); or (iii) produced in such small volumes that it is not worth the cost of full type approval. In these cases, vehicles are approved on a vehicle-by-vehicle basis and the manufacturer of the vehicle takes on the product liability.[42]
- **Component Homologation:** It is also possible to have individual components certified or homologated that are added to the vehicle after production by the OEM (e.g. the case of tuned vehicles). In such a case, the manufacturer of the component is liable for adverse outcomes resulting from deficiencies in the component, such that it needs to be subject to an anticipatory certification process.

Figure 6: Product liability processes in an automotive context



Teleoperated vehicles will likely fall under the category of vehicles that require individual vehicle approval – at least in a first period. As we will see in Section 5.3, it will take a long time before type-approved (mass-produced) series of teleoperated vehicles are commercially available. Toyota and V-TRON estimate that homologation of novel systems in a vehicle takes upwards of five years (including testing, validation and homologation phase). Considering work to regulate type approval and homologation of teleoperated vehicles has yet to start, a further delay of 10+ years may be unavoidable. In the short, medium and even long term it is therefore

[41] For more details, see Section 5.

[42] A fourth category that is less relevant here are vehicles that have been manufactured outside the EU and are not type-approved for EU standards (e.g. imported US-made large pick-up trucks).

safe to assume that teleoperated vehicles will be considered ‘modified vehicles’, with the teleoperation system being installed *on top* of an existing vehicle; ‘special type vehicles’ used for niche applications; or vehicles produced in ‘small series’ - or as a combination of the three. It is unlikely that the teleoperation system will be considered just a ‘component’ given its significant impact on how the vehicle operates and hence on (traffic) safety.

The entity installing the teleoperation system will therefore be liable for adverse outcomes resulting from deficiencies in the vehicle. OEMs providing the base vehicle (in the case of modified vehicles) have limited control over how the teleoperation systems will interact with the rest of the vehicle, and they will decline responsibility for the good functioning of the entire vehicle.[43]

The assessment of deficiencies will require jurisprudence to set out what is considered a reasonable expectation with respect to the safety of a teleoperation vehicle. A user’s expectations on safety when using a particular good are key for both product and object liability. In the case of product liability, a product is considered deficient if it does not meet the safety standards that could be reasonably expected from the product. This is ultimately a discretionary assessment by a judge based on a user’s typical expectations with respect to safety. Similarly, in the case of object liability, a judge will have to make a comparison of the good against a ‘model’ good of the same type. The criteria of what constitutes a model good will in turn also be based on societal expectations of the safety aspects of the good. For innovative products (such as teleoperation or automated driving), the safety expectations may be unrealistic as users do not have a proper benchmark against which to judge these products and may set unreasonably high expectations (e.g. of 100% safe operations). The assessment of product liability against the expectations from the users of the product can therefore be problematic. For example, a teleoperator may have unrealistically high expectations about a teleoperation system’s ability to avoid collisions with other vehicles - therefore inviting the operator to take more risks than needed. Therefore, a policy change is needed which clearly sets out a reasonable expectation on vehicle safety. This could be based on the ‘risk/utility’ principle which considers a product as deficient if the risk of damage resulting from a particular design or production choice is larger than the cost of implementing an alternative design in which that risk is mitigated. Similarly, with respect to the model good, one may put as an expectation that overall safety performance of a teleoperated vehicle is at least as good as that of a non-teleoperated vehicle (De Bruyne 2021).

[43] Some OEMs are very reluctant to allow teleoperation modified versions of their vehicles for use on public roads. There are however some examples where OEMs have given clearance: In Estonia and Finland, Elmo uses modified Nissans for its deployed teleoperated car sharing service.

5 LEGAL

This section discusses the required efforts by regulatory bodies to have the existing legal framework adapted for addressing key challenges posed by teleoperated transport. Currently, this legal framework does not allow teleoperated transport on public roads (except when exempted for pilots or tests). We explore the required adjustments and highlight the key considerations in shaping a comprehensive and future-proof legal framework for teleoperated transport.

KEY FINDINGS

- In the short term, the system of exemptions enables (small-scale) commercial deployments of teleoperation scenarios on public roads, though standardization and harmonization of the procedures could make the approach more efficient.
- In the longer term, the need to work out type approval for teleoperated vehicles constitutes a major roadblock for larger scale deployments. Getting teleoperation on the agenda of the relevant regulatory bodies should therefore be a key priority.
- In addition, work should be made of a licensing system for teleoperation service providers to make them accountable for the safety of their operations.

Table 6: Legal roadblocks to deployment of teleoperation

Legal Roadblocks to Deployment of Teleoperation	L1 TO @ Terminal	L2 Shuttle Run	L3 Highway	L4 Cross-border	W2 Shuttle Barge	W3/4 A to B Barge	Solution	First steps	Timeline of resolution
Exemption process is tedious, untransparent and costly	☺	😐	😐	😐	😐	😐	Standardization and Harmonization of Exemption process.	(TO Service Providers) Push exemption granting bodies to harmonize and standardize procedures	0-5 years
Creation of **type approval process** for teleoperated vehicles has not started yet in the EU [only for large-scale deployments]	☺	☹	☹	☹	☺	☺	Regulatory change to enable type approval of teleoperated vehicles	(TO Vehicle Providers) Push to put direct control teleoperated vehicles on the UNECE agenda	10+ years
Lack of accountability by service providers could have detrimental effects on safety of teleoperation	☺	😐	😐	😐	😐	😐	Introduction of licensing system for teleoperation, harmonized at EU level	(Regulatory Agencies) Create a roadmap towards a teleoperated transport licensing framework	5-10 years

LEGEND

☺	No issues related to the topic and the scenario
😐	Either issues are minor or easy to solve
☹	Issue is both major and hard to solve

For a discussion on the regulatory landscape, only the teleoperation scenarios that take place on public roads (L2, L3 and L4) are relevant. The deployment of teleoperated vehicles (whether for testing or in the context of a commercial rollout) is not an issue from a regulatory perspective.[44] Private roads are managed by private operators who can freely set the parameters and boundaries for deployment on their roads without any need for regulatory involvement.

As regards scenarios which take place on public roads, small-scale deployments of

[44] Though civil and criminal liability issues may still arise – see the relevant section for a discussion on that.

teleoperated transport on public roads are possible today through the system of exemptions, whereby a national authority grants an authorization to operate under specific conditions. Exemptions are granted on a case-by-case basis and will be limited to a specific (fleet of) vehicle(s), area and time period. The exemption holds even if the existing regulatory framework does not fully accommodate or address the unique aspects of teleoperation. Exemptions are mostly used for experimentation purposes, though could also be used as a short-term solution while waiting for further adjustments to the regulatory landscape for teleoperated transport.

The exemption request procedure is perceived as tedious and costly and varies per country. This constitutes a minor roadblock for the roll-out of small-scale teleoperated transport, as it hampers the rate of innovation and slows down the evolution towards commercially viable teleoperation deployments.

The following steps should be undertaken to overcome this minor roadblock, borrowing from the experiences and learnings of automated driving:

- Harmonization of exemption rules at the EU level, with a unique set of rules across countries, and the potential to request exemptions across different EU countries in a single go;
- Standardization of the exemption approval process, with a central single point of contact at national level or an EU government agency, a transparent process flow and the possibility to appeal a decision.

The system of exemptions, even if standardized and harmonized, does not scale well as exemptions are granted on a case-by-case basis. In the longer term, the system of exemptions therefore inevitably will hit its limits and more robust changes to the regulatory landscape will be needed.

The regulatory landscape for road traffic in the EU is built on two pillars[45]: regulations on traffic rules and regulations on safety requirements for (motorized) vehicles.

As regards regulations on traffic rules, there does not appear to be a major roadblock for the deployment of teleoperated transport on public roads. Regulation on traffic rules is governed by the Geneva (1949) and Vienna (1968) Conventions on Road Traffic which are ratified by most EU countries. The Vienna Convention has recently been updated to allow for the introduction of advanced automated driving systems (beyond SAE Level 3), relaxing the requirement that the on-board driver should always be in control of the vehicle. While debate on this is still ongoing within the relevant bodies, it seems to be the case that remote driving is compatible with this updated version of the Vienna Convention, or at least with future versions without the need for additional concerted action to that effect.

As regards vehicle safety regulations, these pose a major roadblock for the large-scale deployment of teleoperation on public roads. There is a series of EU Directives and Regulations on vehicle type approval which have set out what safety requirements (motorized) vehicles should meet before being allowed on public roads. Recent updates to existing regulations have taken place to account for type approval of vehicles equipped with SAE Level 4 automated driving systems, as long as it concerns a production in small series. However, the resulting legal framework for type approval does not address the technical and functional requirements posed by teleoperation in the envisioned scenarios.[46] Even more concerning is the fact that teleoperation and remote driving is currently not being discussed in the context of future versions of the EU type approval framework, contrary to both driver assistance systems and automated driving

[45] At least the part relevant for teleoperation.

[46] Remote driving is only addressed in a sideways and restrictive manner as a supporting functionality for automated driving systems.

functionalities.

We therefore face the following situation:

- The introduction of teleoperated vehicles at scale will require regulatory adjustments to the type approval process beyond those already initiated for automated driving systems;
- As teleoperated driving is currently virtually absent from the regulatory agenda, the process of making these necessary adjustments is still in the very early stages;
- Teleoperation for large-scale deployments will therefore have to run through the full regulatory cycle which to our best estimates will take more than a decade.

Getting teleoperated driving on the regulatory agenda on vehicle safety should therefore be a priority after conclusion of this project. Parties who believe in the future of large-scale teleoperated transport should organise and start building a case for inclusion of teleoperated systems in the type approval process at the relevant regulatory bodies. This could involve a follow-up project which focuses on more extensive experimentation in different countries and could help advance the work on defining the safety requirements for teleoperated vehicles (similar to the Hi-Drive and L3Pilot projects for automated vehicles).

In addition, work should be undertaken to introduce a licensing system for teleoperation service providers.[47] Such a system is necessitated by the fact that safe teleoperation not only requires safe vehicles, but also proper connectivity, proper remote infrastructure and properly trained personnel. The system would therefore go beyond the safety requirements of the vehicles but would also keep the service provider accountable for the way its operations are run. It would give national or EU authorities the tools to police teleoperation service providers. In the short to medium term, a licensing system could supplement the exemption procedure: teleoperation service providers could obtain a license to roll-out a series of teleoperation deployments covered by the scope of the license without the need to request exemptions for each deployment separately. In order to make cross-border teleoperated transport viable, it is recommended that such a licensing system is organized, or at least harmonized, at EU level.

In what follows we first discuss the system of exemptions, its shortcomings and a solution to these shortcomings. We then discuss the current regulatory landscape and its shortcomings vis-à-vis teleoperated transport. Next, we provide insights into a possible solution for the shortcomings to the regulatory landscape. Finally, we shed some light on the idea of a licensing system.

5.1 Exemptions as short-term solution for experimentation and small-scale commercial rollout

Teleoperated vehicles are ‘experimental’ vehicles in that they are not conform the safety requirements set out by the EU regulation that deals with type approval. They critically rely on connectivity, are operated from outside the vehicle and equipped with various sensors, cameras and other technologies whose integration in the vehicle has not been officially homologated. As such, they are not allowed on public roads within the EU.

This creates a Catch-22 situation: teleoperated vehicles are not allowed on public roads because they are not proven safe, but to demonstrate their safety, field operational tests (or FOTs) on public roads are required. Public road testing of teleoperated transport is vital for: validating its safety within the existing mobility system and transportation infrastructure; assessing its co-existence with actual logistic frameworks and related dependencies and its response to real-world challenges that cannot be anticipated in a lab environment; refining human-vehicle

[47] A licensing systems for teleoperated driving was first proposed by the UK Law Commission in its Advice paper on Remote Driving.

interaction and operator decision-making; building public trust by demonstrating the benefits and safety features of teleoperated transport; and finally providing an evidence-based foundation for the development of regulatory frameworks by gathering valuable data and insights. Testing thus ensures that teleoperated transport systems are ready for widespread roll-out, while prioritizing the safety of all road users.

To overcome this Catch-22, in most EU countries a system of exemptions exists. A national authority grants a specific authorization to allow experimental vehicles (such as teleoperated vehicles) on public roads, exempting the vehicle from the type approval requirements that apply to standard vehicles. These exemptions are temporary, issued on a case-by-case basis and limited to a particular vehicle, area and time period. Exemptions have been used by various partners in the project such as V-Tron (in the Netherlands) and Seafar (in Belgium for barges).[48]

To apply for an exemption, the exemption requesting party is to present a safety case demonstrating that the teleoperated vehicle and its intended operation is safe for the public roads on which the operation will take place. This safety case includes a discussion of the differences to the vehicle relative to a standard vehicle; risk mitigation strategies; incident protocols; the adequacy of the communication network; the remote control centre; staff training; etc.

Exemptions therefore ensure that innovation progress does not grind to a halt. Yet, the system is not without flaws.

First, the exemption request procedure as it exists today in various EU countries is tedious and ad-hoc, and therefore costly. Anecdotal evidence from Seafar suggests that the procedure on the granting body's side is not standardized, with the involvement of different agencies and different contact persons for every new request and different approaches to granting the request – even when evidence is provided on a safe (granted) operation elsewhere. Similarly, for V-Tron in the Netherlands, while the granting body (RDW) takes the lead, it asks for advice to other entities such as SWOV (for road users), CROW (traffic control), police, etc. The efforts spent by these entities are difficult to predict and related costs need to be borne by the exemption requester. For the Netherlands, V-Tron estimates that the procedure of obtaining an exemption costs around 150.000 EUR, which is a significant amount considering the (small) scale at which experiments on public roads are run.

Second, while guidelines exist at the EU level on exemption procedures, these are uniquely geared towards experimentation of automated driving systems. For example, in April 2019, the European Commission with the support of the Technical Committee on Motor Vehicles, issued a set of Guidelines on the exemption procedure for the EU approval of automated vehicles, which could help national ad-hoc assessments of these vehicle types.[49] For teleoperated driving, clear guidelines are not yet available with definitions and assessment requirements lacking. All this makes the risk assessment more complex, putting the burden of showing that the systems are safe fully on the exemption requester.

The project partners, however, do not consider these two challenges to be a major roadblock. While they admit that the process is tedious, they do not face any significant time delays to receive approval for the teleoperation experiments within the current legal framework. Nevertheless, a couple of recommended actions could help make the process more efficient.

Harmonisation of exemption approval rules. Today, exemption rules are quite diverse and not harmonized between the different authorities, within and across countries. As a result, the exemption rules can include a wide range of ad hoc conditions and assessments. Also, the costs to fulfil the exemption can vary widely between different authorities. This leads to the perverse

[48] The possibility to ask for exemptions is also mentioned in the EU General Safety Regulation for (motorized) vehicles – see Art. 39 of Regulation (EU) 2018/858.

[49] See here.

effect where a teleoperation service provider that wants to roll out teleoperation will pick the jurisdiction with the lowest barriers (“cherry picking”). In addition, a teleoperation service provider that wants to test across multiple jurisdictions will experience large costs and miss out on economics of scale. A harmonisation of rules would streamline the exemption processes across Europe, while preventing the cherry-picking contest for experiments.

Harmonisation of exemptions related to automated driving systems is already underway. The aforementioned Guidelines serve as an important step towards harmonisation, even though the principles of these guidelines are as of yet not binding. Harmonisation efforts are also being undertaken in two EU innovation projects: First, in L3Pilot a large consortium of partners in the EU automotive ecosystem aimed to pave the way for large-scale field tests of series cars on public roads. The consortium noted the myriad of exemption procedures across different national authorities and strongly “*advocates further work towards an internationally harmonized legal framework for [testing] automated driving*” (L3Pilot 2019). Further, “*all vehicle manufacturers in L3Pilot have implemented internal processes regarding how to conduct experiments on public roads”* (L3Pilot 2019). Second, in L3Pilot’s successor Hi-Drive, a harmonized admission procedure is being developed for experimental operation of vehicles with connected and automated driving functions on public roads. It is the project’s intention to develop this procedure in tied cooperation with representatives of responsible national authorities and of the EU Commission to ensure wide acceptance. The proposed procedure would consist of a vehicle approval process (which is aligned with the latest regulation on type approval of vehicles with automated driving systems – see section 5.2) and an application-specific process linked to a specified operating area.

Similar harmonisation steps should be undertaken for teleoperation. A follow-up project to 5G-Blueprint should aim to conduct large-scale field tests on public roads in different countries and specifically focus on standardising and harmonising exemption procedures for these tests.

Standardisation of the exemption approval process. The exemption approval process should be standardised, with a central single point of contact at government or (EU) agency level, a transparent process flow supported by concerted assessment and the possibility to appeal a decision. The single point of contact could coordinate the internal processes at an agency and communicate the requested actions to the party requesting the exemption. Such standardisation will make the timeline and costs more transparent, as well as simplify interpretation of requested conditions during the preparatory phase.

The system of exemptions, even if standardized and harmonized at the EU level, does not scale well, both for the requesting party and for the granting party. On the requesting side, any change to the scope of the proposed deployment will require a request for a new exemption. As exemptions are granted on a case-by-case basis, any change to the vehicle used, to the technology installed on the vehicle, to the application or to the geographic scope of the deployment will void the existing exemption. On the granting side, as highlighted in an advice on remote driving by the UK Law Commission, exemptions “*provide too few powers to inspect [operations] or to sanction those who breach conditions*” (UK Law Commission 2023b).[50] So granting authorities risk becoming overwhelmed by exemption requests, while not having the levers to enforce exemption restrictions.

In the long term, more robust changes to the regulatory landscape will be needed along with the introduction of a licensing system. To these elements we turn next.

[50] The Advice was referring to the system of Vehicle Special Orders which is the equivalent of exemptions in the UK.

5.2 The current regulatory landscape on type approvals is not adapted to teleoperated transport

The legal framework for road traffic with motorized vehicles in the EU is built on two pillars: (i) a set of standardized traffic rules to be respected when entering the public road network, essentially governing expected safe driving behaviour; and (ii) regulations on the safety requirements motorized vehicles are to meet before they are allowed on EU public roads. We discuss these two pillars in turn.

5.2.1 Traffic rules

The Geneva and Vienna Conventions on Road Traffic (signed in 1949 and 1968 respectively) are international treaties aimed at facilitating international road traffic and increasing road safety by establishing a set of standard traffic rules. Most EU countries have ratified both Conventions, with the exception of Ireland, Malta and Cyprus which have only ratified the Geneva Convention. Article 8 of the Vienna Convention stipulates that "*every moving vehicle or combination of vehicles shall have a driver*", and that "*every driver shall at all times be able to control his vehicle*". The Convention therefore puts the concept of the driver, i.e. "*any person who drives a […] vehicle*", firmly in focus. **While it is not expressly stated, the general presumption behind Article 8 is that the driver is present in the vehicle**.[51] Both fully automated driving systems and teleoperated transport would therefore be at odds with the 1968 version of the Vienna Convention.

In 2016, UNECE, the UN body in charge of setting out and integrating international regulations on land transport within different European and national laws, made some amendments to the Vienna Convention thus "*paving the way for automated driving*"[52]. In particular, the amendment to Article 8 states that "*vehicle systems which influence the way vehicles are driven shall be deemed to be in conformity with [Article 8]*" (UNECE 2014), "*provided that these technologies are in conformity with the United Nations vehicle regulations or can be overridden or switched off by the driver*".[53] The amendment thus allowed for "*automated driving technologies transferring driving tasks to the vehicle*" on public roads.[54][55]

While formulated specifically with advanced driver assistance or automated driving systems in mind, the 2016 UNECE amendment has three implications for teleoperated transport.

First, the amendment opens the door for another person or 'system' to be in control other than an on-board driver. While it is not expressly stated, the wording of the amendment can also be interpreted as including the possibility of teleoperation, considering teleoperation is also a "*vehicle system which influence[s] the way vehicles are driven*" (UNECE 2014). This is at least the view of UK participants to the UNECE forum for Road Traffic Safety which, in a 2019 draft resolution stated that "*a combination of the remote driver and vehicle that is able to safely exercise*

[51] The Convention puts the vehicle and the driver consistently in the same location: for example, Article 11 states that "*before overtaking, every driver shall […] make sure that no driver who is following him has begun to overtake him*". This wording is inconsistent with a remote driver.

[52] See here.

[53] See here.

[54] See here.

[55] Note however that there is still some debate on the extent to which higher levels of automated driving (SAE Levels 4 and 5) are compatible with the amended version of the Vienna Convention. See for example the "Report of the Global Forum for Road Traffic Safety on its seventy-seventh session" in which delegates from France declared that "*vehicles with SAE levels 4 and 5 on the French territory would not be in conformity with the country's obligations under the 1968 Convention on Road Traffic*" (para. 15). Further amendments are being discussed and proposed.

dynamic control as well as, or better than, a driver inside the vehicle, would be compatible with the road safety principles of the [Vienna Convention]".[56] In a follow-up in 2021 and 2023, UK, Germany and Finland participants effectively prepared an informal paper which included safety principles for remote driving that are designed to fulfil the requirements from the Vienna Convention.[57] At the time of drafting this Deliverable, the topic was still under discussion at UNECE.

Second, **the (in)compatibility of teleoperated transport with (future versions of) the Vienna Convention should not be considered a major roadblock**. The amendment and ensuing work within the UNECE forum for Road Traffic Safety in our opinion suggest that (i) future amendments will take on board the possibility of teleoperated transport; and that (ii) the notion of teleoperated transport, i.e. a situation where the driver operates a vehicle from outside the vehicle, is not considered more problematic than higher levels of automated driving.

Third, set amendment emphasises the importance of (and need for) conformity with UN vehicle regulations in the case of teleoperated transport (and higher levels of automation). The amendment indeed allows for innovative and advanced systems provided they are either conform with vehicle regulations, or can be overridden or switched off by an on-board driver. The latter however is not fulfilled in the envisioned teleoperated transport scenarios as these per definition exclude any operator on-board.[58]

As such, while teleoperated transport may not be at odds with the latest (or next) version of the Vienna convention, compatibility will require conformity with vehicle regulations. To this topic we turn next.

5.2.2 Vehicle regulations

Regulations are in place which specify the safety requirements of a vehicle before it is allowed on the public road. These regulations consist of the "*type approval (of vehicle systems, parts and equipment), the conformity of production (i.e. the means to prove the ability, for manufacturers, to produce a series of products that exactly match the type approval specifications) and the mutual recognition of the type approvals*".[59] [60]

These regulations go back to 1958 when, under the umbrella of the UNECE, the UN Vehicle Regulations were established. This is a set of international technical standards and requirements for vehicles with a clear description of functions, testing procedures and validation processes. The Regulations aimed to ensure safety, environmental protection, and fair competition in the automotive industry on a global scale. In 1998, a structured and standardized type approval process was added to the UN Regulations. This regulation identifies 163 vehicle subsystems for which every detail is specified, including how to test and homologate it.[61] Further work on refining the regulation and adjusting it to changing circumstances is ongoing within the World Forum for the harmonization of vehicle regulations (WP.29).

In parallel, and driven by the UNECE's work on UN Vehicle Regulations, similar regulations were implemented in the EU. The latest iteration is the revised General Safety Regulation from 2018 (Regulation 2018/858) which foresees in a harmonized type approval and market surveillance procedure across all EU member states for motor vehicles and their trailers and of systems,

[56] Proposed Draft resolution on Remote Driving, 17-20 September 2019, paragraph 11.

[57] See "Informal paper on Remote Driving", 20-24 September 2019, and 13-17 March 2023.

[58] And neither is it an envisioned option for the higher levels of automation (SAE Level 4 and SAE Level 5).

[59] See https://unece.org/wp29-introduction

[60] In what follows, we denote the combination of these processes simply by "type approval".

[61] Situation on 01/03/2022.

components and separate technical units intended for such vehicles.[62]

In July 2022 an amendment of the General Safety Regulation (Regulation 2019/2144) entered into force, constituting a first step towards a type approval process for (fully) automated and driverless vehicles in the EU. This regulation "*introduced a range of mandatory advanced driver assistant systems to improve road safety and established the legal framework for the approval of automated and fully driverless vehicles in the EU*".[63] [64]

The revised Regulation 2019/2144 amending regulation 2018/858 kickstarted a series of EU and national initiatives to work out type approval requirements and procedures for automated driving systems. Regulation 2022/1426, still to be completed with implementation details, laid down the rules for the application of the revised Regulation 2019/2144 "*as regards uniform procedures and technical specifications for the type-approval of the automated driving system […] of fully automated vehicles*".[65] The initiative however pertained to specific use cases and operational design domains (fully automated vehicles in a specific area, hub-to-hub and automated valet parking) and for small series of a particular motor vehicle type (passenger vehicles with less than 8 seats; and goods vehicles of less than 3.5 tonnes).[66] In Europe at least Germany passed the AFGBV ordinance,[67] which allowed the KBA, the German type approval body, to issue national type approvals for motor vehicles with a fully automated driving function in defined operating areas (SAE Level 4).

While these initiatives are an important step towards future deployment of automated driving systems, they do not really move the needle for teleoperation.

Regulation 2022/1426 only discusses teleoperation in the context of a 'remote intervention operator', which implies a very restricted form of teleoperation: remote manual driving (i.e. the dynamic driving task) is only intended "*to evacuate the fully automated vehicle to a nearby preferable location*",[68] at a maximum speed of 6km/h and a maximum distance over which control is possible of less than 10 metres - basically a 'non-time critical' intervention.

In addition, the technical and functional requirements of direct control teleoperation are very different from those of automated driving systems. Teleoperation heavily relies on connectivity and the remote control environment as safety-critical elements – elements that are less relevant for automated driving systems. The stipulations of Regulation 2022/1426 do not easily translate to teleoperation and therefore cannot be seen as a realistic step towards type approval of teleoperated vehicles.

Finally, Regulation 2022/1426 only deals with (small-series) type approval of passenger vehicles (up to 8 passengers, for vehicles of less than 3.5 tonnes) and does not cover freight-related

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[62]See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018R0858 . Regulation 2018/858 succeeded Directive 2007/46 which first introduced an EU-wide type approval system where type approval no longer had to be obtained for each member state separately. Prior to the 2007 Directive, while type approval procedures were harmonized, they were still implemented at the national level (and so type approvals needed to be obtained for each member state) – as per the Directive 70/156 from 1970. These EU regulations typically take over the body of UN regulations in force at the time of drafting the regulation, with some minor adjustments in some places.

[63] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4312

[64] As to the former, the Regulation stipulates that by July 2024 all new vehicles should be equipped with a set of standard safety-related driver assistant systems. For trucks this includes technologies for better recognizing possible blind spots, warnings to prevent collisions with pedestrians or cyclists and tire pressure monitoring systems.

[65] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R1426

[66] This regulation is still to be complemented with implementing details which can be expected in the fall of 2023.

[67] "Verordnung zur Genehmigung und zum Betrieb von Kraftfahrzeugen mit autonomer Fahrfunktion in festgelegten Betriebsbereichen" or "Ordinance on the approval and operation of motor vehicles with automated driving function in defined operating areas"

[68] Regulation (EU) 2019/2144, Article 2, paragraph 24(d).

operations and in particular the use cases and scenarios envisioned in the 5G-Blueprint project.

In addition to this, to date, there has been little effort to put type approval of teleoperated vehicles on the regulatory roadmap of the EU or the UNECE. We did not spot any initiative on the current UNECE working programme on Vehicle Regulations, which lists all items of interest to start working on, linked to teleoperation. Similarly, there is no indication that the safety requirements related to teleoperated vehicles are effectively on the agenda of the relevant regulatory bodies at the EU level.

In conclusion, specific regulation for the type approval of teleoperated vehicles is crucial for large-scale deployment of teleoperated transport while such work seems not yet started. As such, the absence of appropriate legislation regarding type approval of teleoperated vehicles poses a major roadblock for a larger-scale deployment of teleoperation on public roads.

In the next section, we dive deeper into the timeline for such type approval regulation and concrete next steps.

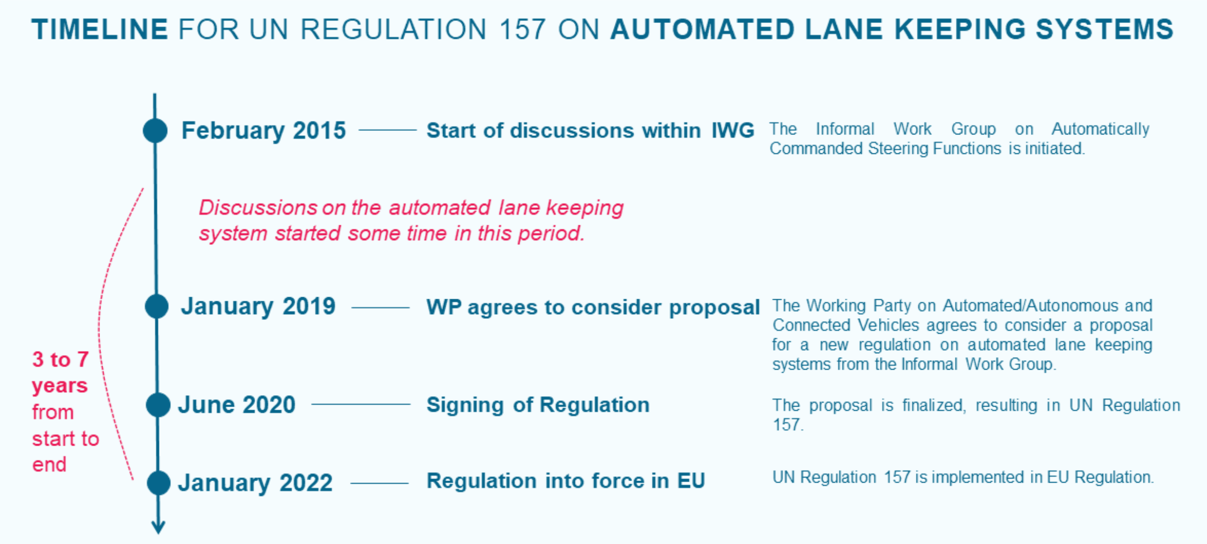
5.3 Regulation on type approval for teleoperated vehicles will likely take more than a decade

The introduction of a new vehicle subsystem to the EU type approval regulation involves a long and complex regulatory process. It requires extensive work within the relevant UNECE Working Party and subsequent ratification at the EU level. The process can be broken down into the following steps:

- **Preparation in Informal Working Group(s):** An Informal Working Group is set up which defines the scope, functionality and test procedures. After discussion and agreement, the work of the group is presented to the relevant UNECE Working Party (for example the one on Automated/Autonomous and Connected Vehicles) who then has to decide whether or not to consider the proposal.
- **Finalizing the proposal in a Working Party**: Within the UNECE Working Party, the proposal is then further discussed and refined (with rounds of feedback from relevant parties) until a final proposal can be agreed.
- **Implementation at EU level:** The outcome is then implemented at EU level. Typically, as specific expertise and capacity is limited at level of the EU institutions, the text is transposed into EU legislation without modifications.

The timing of these steps is not fixed, though partners indicate that the process is likely to take upwards of 5 years. The following example for UN Regulation 157 on Automated Lane Keeping Systems sheds some light on what the typical lead times are from the start of the preparation in the Informal Working Group to entry into force at the EU level.

Figure 7: Timeline for UN Regulation 157



The actual time required until the large-scale deployment of type-approved teleoperated vehicles will likely be considerably higher than the 5 or so years needed for just the UNECE process and probably upwards of 10 year, because (i) additional regulation may be needed at EU level on top of what is agreed at UNECE level before the homologation process can start; (ii) the homologation process itself takes about 5 years and (iii) the topic of teleoperated driving first needs to be brought to the attention of the UNECE and the EU before work on it can start.

First, it is likely that the EU will implement additional regulation to shape the type approval process for teleoperated vehicles. These vehicles differ substantially from standard vehicles in the way they are driven and the technology used, as is the case for fully automated vehicles. For the latter type of vehicles, the EU supplemented the UN Regulations on the systems related to automated driving with more comprehensive regulation such as Regulation 2019/2144 and Regulation 2022/1426 mentioned earlier. This shows that, when it comes to radically different ways of operating a vehicle, the EU will be very deliberate in designing a comprehensive type approval system which guarantees the safety of the vehicle. It also shows that the EU will go for a step-wise approach where it allows type approval procedures for a select number of applications for small series first (e.g. via Regulation 2022/1426).

Second, only after the type approval regulation is in force can homologation of teleoperated vehicle systems start in earnest. As already indicated in Section 4.2.3, Toyota and V-TRON estimate that homologation of novel systems in a vehicle takes more than five years (including testing, validation and homologation phase).

Third, before work at the UNECE and EU on type approval of teleoperated vehicles can start, it first needs to be put on the roadmaps of the relevant bodies within these organisations. The initiative to do so typically comes from an industry (via a federation), from a group of companies across industries (via an association) or from a country (for example because they are dealing with a growing number of exemption requests) or the EU. These organisations will petition the UNECE to look into the need for an additional functionality or technology in the type approval process. This phase will typically take several years as studies and advocacy papers need to be prepared on how the functionality or technology could meaningfully contribute to the safety of motorized traffic and on how the type approval should be implemented.

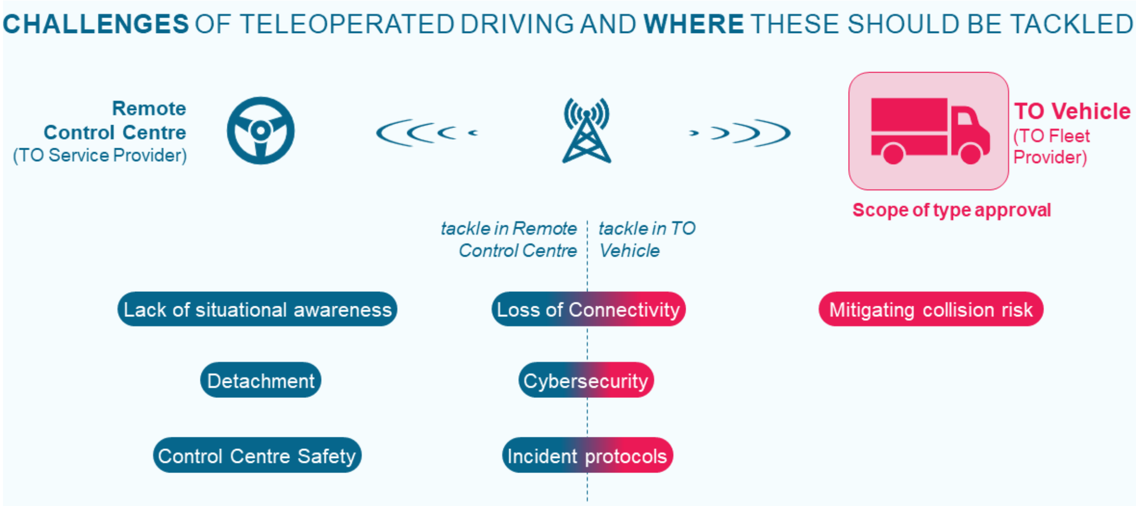
Considering the lengthy process, getting type approval of teleoperated vehicles on the UNECE agenda should therefore be a key priority for those parties who believe in the future of large-scale teleoperated transport. This would entail setting up an association for teleoperated transport with dedicated staff who build a case for the inclusion of teleoperated systems in the type approval process and actively advocate for legislation on teleoperated transport. Such an approach will however require strong shoulders with a profound knowledge of the regulatory process and with a long breath and deep pockets.

These regulatory efforts could be complemented by a follow-up project to 5G-Blueprint which focuses on more extensive experimentation with teleoperated transport on public roads in different countries. The set-up would be similar to the L3Pilot and its successor Hi-Drive which aim to "*create, harmonise and manage a Europe-wide testing and demonstration environment for high automation*".[69] The learnings from such follow-up project could advance the work on defining the safety requirements for teleoperated vehicles, and at the same time elevate the profile of teleoperated transport at the relevant regulatory bodies.

5.4 A licensing system is needed to ensure overall safety of teleoperation

Safe teleoperated transport is not only about having vehicles which satisfy a series of safety requirements. The safety challenges posed by teleoperated transport are not limited to the teleoperation system installed in the vehicle, but are also affected by among others connectivity, remote control infrastructure and personnel. In the Advice on Remote Driving prepared by the UK Law Commission, a number of safety challenges associated with teleoperated driving were identified. These included loss of connectivity, mitigating the risk of collision if remote driving fails, lack of situational awareness by the operator, risk of detachment by the operator from the reality of the task, cybersecurity, the safety of the control centre and dealing with potential incidents.[70] Some of these challenges could indeed be tackled in the scope of the type approval regulation – such as how to deal with connectivity loss inside the vehicle, cybersecurity issues or fallback scenarios in the case of failure. However, other challenges are out of scope of type approval and remain to be tackled at the level of the TO service provider, in a Remote Control Centre. This includes having to deal with lack of situational awareness, the risk of detachment and ensuring safety of the control centre itself (see also Section 4.1.1) as illustrated in the diagram below:

Figure 8: Challenges for teleoperated transport



If new regulation (only) focuses on the vehicle through the type approval process, other challenges affecting the safety of teleoperation still need to be addressed. There is a need to not only hold the vehicle manufacturer accountable (through type approval) but also the TO Service Provider for the safety-critical aspects of the teleoperation service provided.

In line with the UK Law Commission's advice on Remote Driving, we therefore suggest

[69] See www.hi-drive.eu.

[70] "Remote Driving: Advice to Government SUMMARY", prepared by the UK Law Commission, page 3 and 4.

teleoperated transport to be overseen by a licensing organisation. This organisation is to hand out licenses (or ‘permits’) to teleoperation service providers that they consider, after thorough assessment, meeting the standards required for safe teleoperation. The licensing organisation would also have the power to inspect operations and sanction those providers who breach conditions – similar to an ISO certification process.

To obtain such license, teleoperation service providers would have to show that they are financially healthy and professionally competent to run the service. They would also be required to submit a safety case analysis “*showing how [the] operation is sufficiently safe for roads and other public places*”.[71] This safety case is similar to the case submitted when requesting an exemption and should include:[72]

- The scope of the operation: Vehicles used, time period, routes, etc.
- The adequacy of the communication network: For the geographic area of operation, connectivity maps should be provided. If there are gaps in coverage, the provider would have to explain how it will deal with those gaps in safe manner. See also Section 6.2.3.
- The risk mitigation system if communication fails: This should contain a discussion of technologies and protocols in place, both at the vehicle side and at the control centre side.
- Cybersecurity
- Workstation design and functionality
- Security of the remote operations centre
- Staff: This should contain a discussion on how staff is trained; on how staff health is monitored; and on staff attention and rest periods.
- Roadworthiness checks: This should detail how the provider ensures that the fleet and operating equipment in the control centre remains up to date and in good condition.
- Incident protocols: This should detail how the provider plans to communicate with external parties involved in the incident, and how the incident is handled more generally.

Ideally, the introduction of the licensing system should precede the regulatory changes discussed in Section 5.3, as it could already be useful in the short to medium term. A licensing system could supplement the exemption procedure: teleoperation service providers could obtain a license to roll-out a series of teleoperation deployments covered by the scope of the license without the need to request exemptions for each deployment separately.

The UK Law Commission advice on Remote Driving highlights a practical issue with ensuring accountability in a context of cross-border transport. *“[Teleoperated transport] brings the possibility that vehicles may be driven on British roads from another jurisdiction. […] British authorities would likely lack investigative powers and would need assistance from authorities in the foreign jurisdiction. […] Even if the driver is identified and evidence for a prosecution obtained, the need to extradite the driver would lead to further delays and expense. And extradition cannot be guaranteed.*” They conclude that “*these factors combine to bring a real risk of injustice for victims of [teleoperated transport] on British roads when the [transport] is performed by companies and individuals located abroad*” (UK Law Commission 2023b). On the basis of that analysis, they conclude that **teleoperated transport on British roads should not be allowed when the teleoperator is based abroad**.

A prohibition of teleoperation from abroad would constitute a serious challenge for the deployment of scenarios L4 – Cross-border and W3/4 – A to B Barge. It will not be possible

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[71] Ibid., paragraph A.35.

[72] This list is for the most part based on the Advice paper on Remote Driving, paragraph A.35.

for a teleoperation service provider to operate a cross-border transport from one remote control centre. Instead, the teleoperation service provider would need to operate multiple remote control centres (at least one in each country), or the transport would need to be handed over to another teleoperation service provider. Neither of these solutions is perfect, undermining the viability of cross-border teleoperated transport.

Instead of a flat-out prohibition, we therefor recommend that the introduction of the licensing system is taken up at the EU level, or that at least harmonisation of the licensing framework takes place.

6 5G

This section discusses the challenges related to ensuring a stable 5G connection for teleoperated transport and the required efforts to overcome these challenges. Teleoperation puts considerable requirements on the 5G network, in terms of bandwidth needs per user, number of expected users and geographic coverage. In addition, cross-border teleoperation requires a governance framework for seamless handover and roaming between MNO's. Finally, demands from teleoperation service providers should not go at the expense of the quality of service provided to other users of the 5G network.

KEY FINDINGS

- Only minor 5G-related challenges for L1, L2 and W2 deployments: the combination of automated fallbacks and dynamic adjustments to supply and demand (essentially controlled degradation of service levels) suffice to deal with network saturation issues.
- For scenarios L3, L4 and W3/4, network saturation episodes and coverage gaps are likely to be significant, unpredictable and dangerous and a controlled degradation of service level through dynamic adjustments may not be a satisfactory solution.
- To unlock large-scale teleoperation deployments, further developments are needed: the expansion of network infrastructure; further development of proactive, dynamic and predictive network awareness; the creation of a governance framework which oversees feasible teleoperation deployments within a connectivity context; and the introduction of service level agreements with customers that have specific and material requirements (e.g. for scenarios L3 and L4 – teleoperation over an extended geographic area).
- For scenarios L4 and W4, seamless roaming and handover at border crossings pose particular challenges for large-scale deployment of direct control teleoperation. Further maturation of the innovations from the 5G-Blueprint project (inter-PLMN handover, dual-SIM) are needed.

Table 7: 5G roadblocks to deployment of teleoperation

5G Roadblocks to Deployment of Teleoperation	L1	L2	L3	L4	W2	W3/4	Solution	First steps	Timeline of resolution
	TO @ Terminal	Shuttle Run	Highway	Cross-border	Shuttle Barge	A to B Barge			
Network saturation and **coverage** issues may hamper potential of Teleoperation	😐	😐	☹	☹	😐	☹	Expand network infrastructure; develop network awareness; create governance framework; introduce novel business models	(Telecom Regulators) Investigate how transparency on 5G coverage should be adjusted to the needs of teleoperation	5-10 years
The MNO has limited control over quality of service provided by **roaming** MNOs	☺	☺	☺	☹	☺	☹	Optimized Steering of Roaming; Automated Driving fallback; Coverage on Demand; Agreements between Roaming partners	(MNOs) Investigate: Optimized Steering of Roaming, scalability of Inter-PLMN handover, Dual SIM, Service Level Agreements between MNOs	5-10 years
The solutions enabling seamless **handover** need to mature before large-scale deployment can take place	☺	☺	☺	☹	☺	☹	Hybrid control teleoperation at border crossings Maturation of inter-PLMN handover.	(TO Service providers) Use dual-sim for first cross-border deployments at limited scale and investigate the need for seamless handover at scale.	5-10 years

LEGEND

☺	No issues related to the topic and the scenario
😐	Either issues are minor or easy to solve
☹	Issue is both major and hard to solve

The main 5G-related challenge for teleoperation is that the demand for uplink bandwidth will put considerable stress on the available capacity, in particular in the early stages of deployment of the 5G network. Network saturation episodes may occur in which demand for network resources exceeds the supply thereof. These episodes may also be caused by gaps in coverage (i.e. areas where there is no supply of resources). If uncontrolled, these episodes may have serious consequences for teleoperation. Fallback systems should be in place to mitigate the adverse (and potentially lethal) effects of a loss in connectivity. Prevention of a breakdown in connectivity is almost as, if not more, important. In first instance, prevention aims to resolve network saturation through dynamic network optimization, by either reactively or preferably proactively reducing the level of service. As a result of this, teleoperation service provider will be faced with gradual degradation in service quality to which they can respond by also gradually reducing their demand for network resources (e.g. by reducing quality of video streams).

For deployments of teleoperation services on public networks and in particular deployments with an extensive geographic scope (such as scenarios L3, L4 and W3/4), these uplink capacity issues pose a real roadblock. In those instances, network saturation episodes are likely to be significant (in terms of frequency, depth and duration), unpredictable and dangerous. The current state of the art in terms of dynamic network adjustments to demand and supply of uplink bandwidth may no longer suffice. Average service levels could be seriously impacted to the extent that the business case, safety and ultimately viability of teleoperated transport is undermined.

In order to tackle this roadblock, **four developments** need to take place in the coming years:

- **Network infrastructure needs to be expanded** to accommodate for large-scale deployments of teleoperated transport along relevant transport axes. The decision to do so is essentially a business decision, where network providers will only invest if the demand for the expanded infrastructure leads to sufficient additional revenues to justify the investment.
- **Network awareness and dynamic re-configuration needs to be further developed.** This refers to a fully automated system that gives a 5G network the ability to measure, predict and interpret the state of the network and dynamically and independently adapt the network when needed. Network awareness has the potential to increase the capacity utilization of a network, though the timeline for deployment is highly uncertain. The development of predictive, dynamic, cooperative and proactive Network Awareness could take upwards of a decade, though intermediate forms, such as predictive network awareness, could already happen in several years' time. Recent evolutions in AI and machine learning algorithms may speed up development.
- **A governance framework is needed** which determines for every set of connectivity conditions (good/mediocre/bad) the admissible scope for teleoperation (e.g. teleoperation speeds); maps this admissible scope to the real world situation such that it is clear where and when teleoperation is feasible; and oversees that teleoperation (within the right scope) is authorized only within the appropriate spatiotemporal context.
- **Service Level Agreements need to be introduced.** For advanced deployments, teleoperation service providers will need some guarantees from MNOs about the level of connectivity that they can expect. Service Level Agreements establish clear expectations on the quality of connectivity and allow teleoperation service providers to configure their deployment based on the SLA. The operational and legal certainties linked to these SLAs thus overcome the business risks faced by teleoperation service providers.

In order to expediate these four developments, work needs to be started on charting 5G connectivity levels in relevant geographic areas (e.g. in portal areas or highway corridors) and on linking it to the feasibility of safe teleoperation. This should result in a detailed view (a "map") of teleoperation-readiness.

Scenarios L4 and W4 face the distinct challenge that on parts of the trajectory, connectivity needs to be handed over to and provided by foreign MNOs. The 5G-Blueprint has made significant advances on “inter-PLMN handover” solutions enabling seamless handover. However, this technology is at present not (yet) scalable. This challenge shapes what cross-border teleoperated transport may end up looking like: A hybrid form of teleoperation will emerge with support from automated driving functionalities to bypass situations where inter-PLMN handover is not feasible or available and where quality of service levels cannot ensure safe direct teleoperation (e.g. at intra-EU border crossings).[73] In the long term cross-border teleoperation of such a form will be further facilitated by a number of technical innovations. In the short term, the inter-PLMN handover solution could be further supplemented by a dual SIM solution (in particular in edge cases),in combination with the governance framework mentioned above.

Finally, net neutrality likely does not pose a challenge for the deployment of teleoperation over public networks. Connectivity reserved for teleoperation should be considered a special type of connectivity service which may not need to adhere to the net neutrality rules that apply for general internet access services. Connectivity providers will however need to ensure that the special connectivity services provided to teleoperation service providers does not harm the general services. A proper dimensioning of the 5G network based on information provided by the client is therefore important.

6.1 Resolving network saturation comes at the cost of degraded levels of service

Network saturation occurs when demand for 5G network resources at a specific place and time approaches or exceeds the supply of 5G network resources at that place and time.[74] A special case, also considered here, are gaps in coverage, areas without proper 5G network resources. When the network becomes saturated or in areas with weak coverage, users may experience slower uplink or downlink speeds, increased latency or other performance issues. If unforeseen, network saturation episodes may have serious consequences for teleoperation as teleoperators may suddenly be faced with degraded streaming quality or worse, a loss of connection with the teleoperated vehicle. It is therefore important to put systems in place which allow the teleoperation service provider to deal with network saturation episodes in a safe and efficient manner.

Among the various components of 5G connectivity, uplink capacity is the element that is most prone to saturation. Indeed, 5GAA, the 5G Automotive Association, consider that “*the data rate between the vehicle and the [teleoperator] is usually uplink intensive, especially for human [teleoperators] who rely on video signals from vehicles to perceive the environment*” (5GAA 2021). Further, in 5GCroCo it was concluded that, “*among the three 5GCroCo use cases studied, the only [*use case*] imposing strict spectrum demands in the uplink (UL) is the [teleoperation] use case. In the downlink (DL), all of them are heavy data rate consumers. In most of the scenarios considered, however, [*downlink requirements*] are not enough to saturate the available bandwidth*” (5GCroCo 2022). As we will see below, this is also confirmed by the research undertaken within the 5G-Blueprint project.

In what follows we will assess the extent to which available uplink capacity can match uplink requirements; the current state of the art to address network saturation; as well as potential

[73] Borders between EU and non-EU countries are not in scope of this analysis. These pose particular challenges (such as border controls) to the proposed hybrid form of teleoperation that will not be tackled in this deliverable.

[74] Connectivity via 5G offers significantly more resources than LTE connectivity, in terms of bandwidth, latency and stability. As per 5GAA: “*5G networks are needed for deploying [teleoperation] services, not only to benefit from the significantly reduced latency below 10 ms, but also to meet the increasing system capacity demand in a broad [teleoperation] deployment*” (5GAA 2021). This does not mean however that 5G networks cannot become oversaturated.

disadvantages of the state of the art.

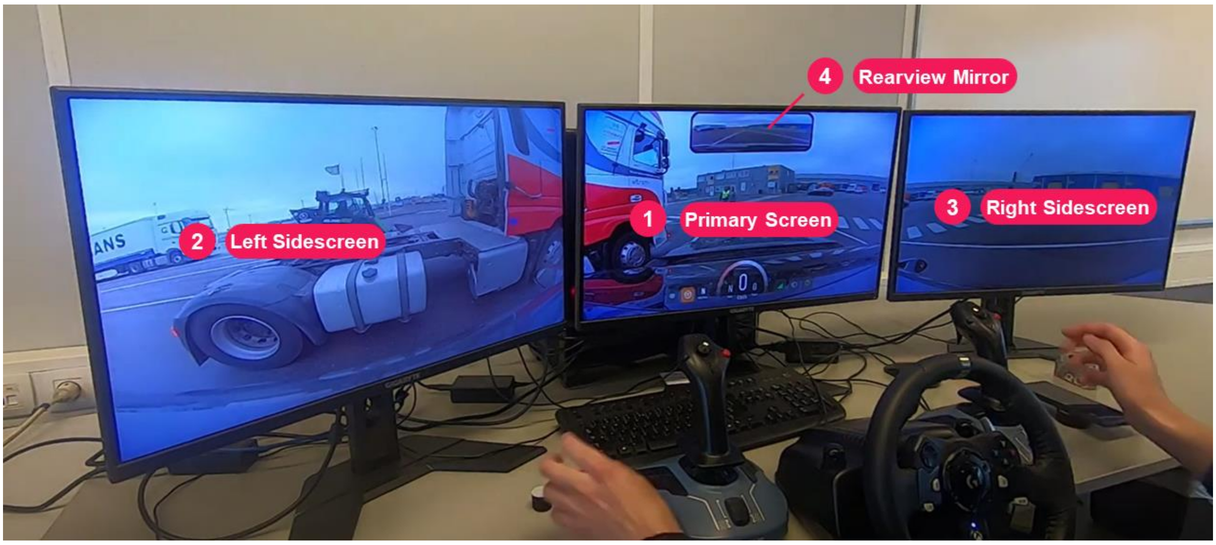
6.1.1 Uplink capacity may not match uplink requirements

To the extent that uplink requirements exceed available uplink capacity, the quality of connectivity may be degraded or connectivity may break down all together.

Demand for uplink capacity

Teleoperators need to rely on high-quality video images from multiple angles which are streamed from the teleoperated vehicle. In order to approximate (or exceed) the spatial awareness of an on-board driver, the teleoperator needs at least four camera angles and preferable more: a primary angle showing images from the front window; two side angles (stitched to each side of the primary angle) showing images from the side mirrors, side windows and far right corner of the front window; and a rear-view angle mimicking the view one gets from the rear-view mirror – see the image below. Ideally, these video images are streamed in high-definition (at least 720p) and preferably in ultra-high-definition (4K).

Figure 9: Screenshot from 5G-Blueprint Teleoperation Showcase showing camera angles used[75]



These video stream requirements imply that a considerable amount of data will need to be sent from the vehicle to a network base station (i.e. a cell).

Estimates of the uplink requirements of teleoperation range from 25 Mbps to 64 Mbps. These estimates are based on the assumption that camera images are being streamed at the ideal resolution (e.g. in HD or ultra-HD), without any degradation in resolution. The lower-bound estimate is based on a back-of-the-envelope calculation which assumes a teleoperated vehicle with four 4K camera's, a required uplink bandwidth of 5Mbps per camera stream and additional uplink needed for the vehicle control interface and telemetry sources.[76] In its White Paper, 5GAA provides an estimate of 32Mbps, while 5GCroco puts the required uplink bandwidth at 64Mpbs per user (5GAA 2021, 5GCroCo 2022).

These estimates reflect requirements to achieve ideal operational conditions (in terms of safety and speed). As we will see below, they do not reflect what is minimally required for teleoperation at reduced operational conditions.

Supply of uplink capacity

[75] See https://www.youtube.com/watch?v=7x8Q0akxWZM.

[76] See 5G-Blueprint (2023a), page 16 and following (in particular Table 1).

The MNO partners in the 5G-Blueprint project estimate that, under good coverage conditions, the theoretically available uplink capacity per user from a 3.5Ghz 5G Standalone macro cell in the envisioned setup is 25 to 40 Mbps. The actual capacity at a specific time will depend on contextual factors such as the distance from the cell, obstacles in the way or interference from other users. For example, in Sas van Gent, KPN noticed that the uplink capacity fluctuates because of its position next to a waterway as the metal of the passing vessels have a limiting effect on uplink capacity. It will also depend on the specific configuration of the network.[77] The figures presented here reflect a theoretical range based on particular choices made by the MNO partners in the 5G-Blueprint project.

The total available uplink capacity can be 3 to 16 times higher than the uplink capacity per user through *beamforming*. "*Rather than sending a signal from a broadcast antenna to be spread in all directions,[…] beamforming uses multiple antennas [('beams')] to send out and direct the same signal toward a single receiving device*".[78] Thus, and as explained in D3.3, "*the same [uplink] capacity can be provided simultaneously in the form of several beams if users are sufficiently spaced*" (5G-Blueprint, 2022c). On small cells, it is possible to install 3 beams; on large cells ('macrocells') there are typically 4, 8 or 16 beams installed. This implies that one macrocell could provide 25-40 Mpbs uplink capacity to up to 16 different users (i.e. vehicles) – giving a total uplink capacity of up to 640 Mbps.

Demand vs Supply

It is likely that teleoperation will put considerable stress on the available uplink capacity, with a risk of network saturation. The supply of uplink per user under the envisioned 5G network setup (25-40Mbps) may not be able to meet the demand for uplink under ideal operational conditions (25-64 Mbps). In addition, the number of users that will be able to connect is also limited, putting constraints on the extent to which large-scale deployments are possible. Uplink capacity hence poses serious challenges for the scalability of the network to accommodate massive deployments of teleoperated transport.

6.1.2 Current solutions to oversaturation focus on reducing levels of service

In the worst case, saturated networks may lead to a loss of connectivity between teleoperator and teleoperated vehicle which may have serious consequences. The table below provides an overview of the potential impact of a breakdown in the connection between the vehicle and the remote control centre on the basis of ASIL.[79,80,81] It is clear from the table that, for most scenarios, an uncontrolled breakdown in connectivity should be avoided at all costs.

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[77] Configuration elements include the channel bandwidth, the multi-user setup ('MIMO'), the time-division duplex ('TDD') configuration, the frequency modulation and the coding schemes. For more technical details, we refer to the deliverables from Work Package 5.

[78] See here.

[79] ASIL (Automotive Safety Integrity Levels) looks at the potential impact of a failure of a specific component of a vehicle (in this case connectivity between the vehicle and the remote control centre) on the safety of occupants and other road users. The ASIL methodology analyses the extent of potential harm of the failure (severity), the probability of harm (exposure) and the extent of mitigating measures in case of failure (controllability) and assigns a risk rating from A (minor injuries) to D (potentially multiple fatalities).

[80] See Annex A for a detailed description of the analysis.

[81] The 5GAA study on functional safety also ran an ASIL analysis for a generic teleoperation use case on public roads and concluded that "*for the 'direct control' use cases, the system needs to be designed generally according to ASIL D level [i.e. assuming that failure could have severe consequences including the possibility of multiple fatalities]. The 'indirect control' use case might need lower ASIL levels, however this depends on the capability of the vehicle to perform 'plausibility checks' of the given indirect control commands with independent ego-sensors in the vehicle*". Our analysis provides a more nuanced view as it looks at different scenarios.

Table 8: Potential impact of a breakdown in connectivity for a teleoperated transport

	L1 Terminal Operations	L2 Local Shuttle	L3+L4 Highway + Cross-border	W2+W3/4 Barge
Potential impact of breakdown	Low *Minor or no injuries*	Medium *Serious injuries, low risk of death*	High *(Multiple) fatalities or life-threatening injuries*	Low *Minor or no injuries*
Reason	Operation in controlled* environment, at low speeds	Operation in semi-controlled environment, at low speeds	Operation in uncontrolled environment, at higher speeds	Operation at low speeds, good fallback and limited interaction with vulnerable road user

** An environment is controlled when (i) connectivity is robust across the whole relevant area and breakdowns are easy to foresee; (ii) other road users are aware of the operation and the risks it entails; and (iii) safety protocols are in place and enforced.*

Teleoperation service providers and connectivity providers have therefore set up a number of ways to deal with saturated network traffic in a safe and efficient manner. Such solutions could either be focused on mitigating the impact of a breakdown in connectivity, or on preventing the breakdown all together by reducing the load on the network:

Mitigation. The necessary offline fallback systems and protocols should be in place to mitigate the adverse impact of a loss in connectivity. Automated driving systems should ensure that the teleoperated vehicle can be put in a 'minimal risk condition', which could involve slowing down the vehicle, activating hazard lights, moving to a safe area and possibly stopping the vehicle. Mitigating measures using automated driving systems will likely be an integral part of the type approval requirements imposed by the regulator for teleoperated vehicles – see Section 5.

Prevention. The current focus is also on preventing a breakdown in connectivity via dynamic adjustments to supply and demand**.** These adjustments would involve the temporary reduction of demand for uplink capacity by a user and/or the shift of uplink resources to where the demand is.

Adjusting supply

As explained in Deliverable 5.4 (5G-Blueprint 2023c), network service providers can do three things to prevent a breakdown of connectivity due to uplink capacity issues – reducing the level of service across all users, shifting resources or increasing bandwidth reserved for uplink.

Reduce level of service. The standard response to network saturation is to reduce the level of service for all users. In standard connectivity systems, this reduction is shared equally. With network slicing, priority could be given to some users – protecting their uplink from significant degradation. However, this comes with the potential issue of net neutrality – see below.

Shift resources. Uplink resources can be dynamically shifted from one user to another. Based on the specific requirements of a teleoperation user at a specific point in time, a network allocation algorithm may decide to shift resources away from another (e.g. non-teleoperation) user with less requirements at that point in time. Dynamic resource allocation is one of the main advantages of network slicing where the Domain Manager allocates resources to slices based on their demands and priorities.

Adjust uplink ratio. Network service providers can adjust the share of bandwidth capacity dedicated to uplink. The capacity will be used for both downlink and uplink and depending on requirements an allocation of capacity can be made. The setup proposed within 5G-Blueprint has an uplink-to-downlink ratio of 1:3, so 25% of the available capacity is allocated to uplink.[82][83] For

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[82] See 5G Blueprint (2023a), page 33.

[83] This is typical for commercial 5G deployments, where an uplink-to-downlink ratio of 1:2 or 1:3 is common. See for example the ZTE Uplink Enhancement Technology White Paper, which states that many of the popular 5G Frequency bands reserve approximately 30% of bandwidth for uplink (so a 1:2 ratio of uplink to downlink). Ofcom has mandated a 1:3 ratio. And this paper mentions typical ratios of 3:7 and 1:4, also indicating that "*the available uplink [capacity is] relatively small*".

uplink intensive applications such as teleoperation, the uplink-to-downlink ratio could be set higher (e.g. 1:1 or even 2:1). Crucially, the proposed 5G setup uses 'Time-Division Duplex' (TDD) schemes (which most commercial 3.5Ghz 5G networks do). In theory these schemes enable dynamic adjustment of the uplink-to-downlink ration in real-time. However, in practice TDD schemes are shared by MNOs across different countries;[84] adjustments to the scheme therefore should be coordinated at a supranational level. As long as demand for bandwidth remains for the most part on the downlink side, it is unlikely that such adjustments will materialize.

Adjusting demand

Network service providers insist that customers should have a plan in place to adjust demand downwards when faced with a saturated network. Despite the dynamic adjustment tools at their disposal, network service providers will not always be able to safeguard one channel of data against a degradation in the level of service.

For teleoperation, such plan would consist of dynamically adjusting demand for uplink resources based on the real-time or predicted network conditions. Safe teleoperation does not always require the full set of ultra-high-definition video streams. Depending on the operational requirements, less stringent set-ups would be possible, thus reducing the uplink demands from the network. Demand for uplink bandwidth should therefore be seen on a spectrum: in the ideal scenario it is 25Mbps, but teleoperation is also possible with less uplink bandwidth, albeit within a reduced operational domain.

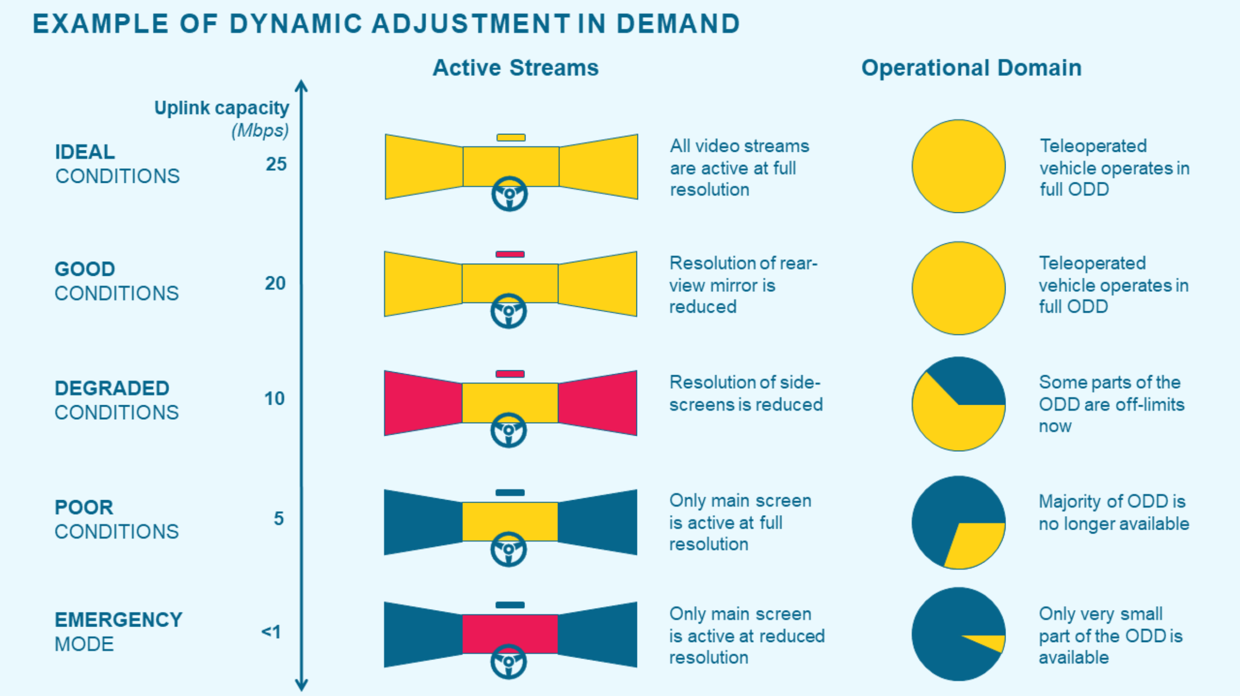
Dynamic adjustment is achieved by reducing the requested resolution of one or several of the streams, or shutting down one or more streams. In the below diagram, we present an example of what such adjustment could look like.[85] Under ideal conditions, all streams are active at full resolution. As the available uplink capacity decreases, the resolution of less important streams (such as rear-view mirror or sidescreens) is gradually reduced and eventually shut down. If uplink capacity decreases even further, the resolution of the main screen is reduced.

Crucially, as capacity demand is adjusted downwards, the operational domain of the teleoperated vehicles, i.e. the situations that can be safely handled through teleoperation, **becomes more restricted**. For minor adjustments – such as reducing the resolution of sidescreens – teleoperation at higher speeds may no longer be feasible. As adjustments get major, the operational domain is further restricted. If available uplink capacity becomes so low so as to only enable streaming of the main screen at reduced resolution, the teleoperated vehicle goes into emergency mode in which the vehicle comes to a safe stop.

[84] For example, MNOs in the Netherlands, Belgium and Germany share the same TDD scheme.

[85] This is a simplified version of V-TRON's adjustment protocol.

Figure 10: Example of dynamic adjustment in demand



In essence, while there is some scope to increase the overall supply, the main solution to deal with saturated networks is to reduce the resources allocated to each user, i.e. a degradation of the level of service provided.

6.1.3 These solutions may undermine the potential of the envisioned Teleoperation scenarios

Real-time dynamic adjustments as they exist today constitute a safe and efficient solution, provided network saturation episodes are:

- **limited**, in terms of frequency, magnitude and duration: In this case, the user can easily adjust uplink demand for a short period of time without having to sacrifice too much of the safety and the quality of its provided service.
- **predictable**: The network provider and/or the user can anticipate the network saturation episodes by taking necessary precautions and adjusting demand proactively.
- **not risky**: Even if dynamic adjustment fails and connectivity does break down, the impact on operations will be limited.

This is likely the case for local deployments at small scale (e.g. scenarios L1, L2 and W1). These scenarios will run on a private network in a controlled (portal) environment. The provider of the network will be able to set up the network so as to fit the requirements of the teleoperation application (potentially taking into account other use-cases as well); the network idiosyncrasies of the site (such as obstacles) will be well mapped and predictable; and the impact of a loss in connectivity will be relatively limited given the low speeds and the controlled environment.

Dynamic adjustment may not suffice as a solution for deployments beyond the private network (such as scenarios L3 and L4). The variation in the number of users and its unpredictability makes it more likely that unforeseen bottlenecks occur; the large geographic scale and the presence of many different types of users makes network traffic and capacity difficult to predict; and the impact of a loss in connectivity is considerable as serious injuries or fatalities could occur.

In conclusion:

- Uplink capacity issues are not a roadblock for initial small-scale deployments on private networks. These issues are likely to be limited, predictable and with limited risk, and can be resolved through smart dynamic adjustments to demand and supply of uplink bandwidth.
- However, for deployments on public networks or more complex large deployments, uplink capacity issues do pose a roadblock. Network saturation episodes will lead to frequent, intensive and unpredictable degradations in the level of service with significant risk of severe accidents.
- To the extent that teleoperation service providers will require a minimal level of service to operate a viable business, this could in time undermine the sustainability of teleoperated transport. For example, if connectivity conditions are so bad that the teleoperated transport needs to drive at reduced speeds for a significant amount of time, the expected time and cost savings may not materialize.

6.2 In the long term, further developments are needed

The strain of uplink demand on capacity poses a roadblock for deployments in Scenarios L3 and L4 and also for large-scale deployments in Scenarios L1, L2 and W2, W3/4. In order to facilitate such deployments, developments in four domains are required – infrastructure, network awareness and re-configuration, governance and business.

6.2.1 Infrastructure investments: A business decision

Investments in 5G infrastructure can considerably increase the (uplink) capacity available to a single user as well as overall. There are two ways to increase 5G capacity in a specific area.

First, the frequency bands deployed on a single macro cell can be expanded. Frequency bands below 6Ghz allow for the creation of wider channel bandwidths, which enable the uplink of more data at once. For example, in the current setup Telenet and KPN has foreseen a channel bandwidth of 40-50 MHz, which could be increased up to 100 MHz for the envisioned frequency band type (n78).[86] As such, they could double the uplink capacity if demand justifies it. The expansion of frequency bands at the cell level is in principle a straightforward procedure, though it ultimately depends on the availability of spectrum.[87] Bandwidth (and hence uplink capacity) can be further increased through "carrier aggregation" – i.e. using multiple bands of frequency spectrum simultaneously. This however requires the user equipment to be capable to transmit across multiple antennas.

Second, the existing radio network could be densified by adding (small) cells. Adding more cells could help to: reduce user load per cell, as users can be spread out over more cells; improve signal quality, as users will on average by closer to a cell; reduce interference, as small cells over short distance have a smaller interference range; improve spatial use of the frequency bands, and; deal with high-traffic areas or areas where obstacles result in poor coverage. Network densification is a complex and expensive process though, in particular on highways. It requires finding new sites to put a cell on and then building expensive radio infrastructure on that site.[88]

The increase of capacity through investments in infrastructure will essentially be a

[86] See here.

[87] By way of illustration: In 5G-Blueprint, 3.5GHz 5G networks are used which can be expanded to 100MHz bands. Telenet already has 3.5GHz in production in Belgium so could technically already expand the frequency band; On the other hand, 3.5GHz is not yet auctioned in the Netherlands (with the national auction being delayed). So, before KPN could consider expanding its frequency bands, it would first need to acquire the relevant spectrum which constitutes a significant investment.

[88] For more info on the costs involved, we refer to Deliverable 3.3.

business decision. Network providers will only be willing to provide the necessary investments if demand for the expanded infrastructure translates into sufficient additional revenues to justify the investment. So, if for example the current infrastructure is not sufficient only for a small part of the existing user base, and if these users only represent a small part of the provider's revenues, it may not be worthwhile to expand infrastructure to accommodate these users. Such an investment can likely only be justified if a large part of the (potential) user base demands improved levels of service and is willing to pay for it. Deliverables 3.3, 3.4 and Section 7 provide further insights on this.

Deployment of additional infrastructure in an area will therefore only take place when demands for higher levels of service are widespread among the potential user base.

6.2.2 Network awareness and re-configuration: Bringing dynamic adjustments to the next level

The aforementioned dynamic adjustments to supply of and demand for uplink capacity require a detailed view of the current and future network conditions. Monitoring, diagnostic and functional systems should be put in place at the side of the network provider to ensure that an appropriate adjustment can be made. Absent such systems, dynamic adjustments will always be reactive which could negatively affect the safety of teleoperation: as acknowledged by 5GAA, a purely reaction-based approach, "*i.e. reacting when or after a [change in connectivity] has happened […] may be unsuitable for automotive use cases as the adaptation of an application may involve mechanical actions, e.g. slowing down a vehicle from 100 km/h to 70 km/h, which require a certain amount of time to be completed*" (5GAA 2021b).

Currently, network providers have automated rule-based systems in place which intervene based on a set of criteria ('*if metric X has value Y, then do Z*'). These rules have been derived from offline pattern recognition analyses which ranges in sophistication from simple spreadsheet analysis to more advanced machine learning modelling. The MNO partners in the 5G-Blueprint project have indicated that their current focus is on improving the pattern recognition for the real-time state of the network. They see AI as a potential gamechanger in this to help recognize and anticipate crucial patterns in network traffic evolution.

These rule-based systems are already somewhat proactive. They allow network providers to anticipate saturation in the network by proactively reducing service levels. Compared to a pure reactive approach, the reduction in service levels will be more gradual thus giving users the chance to properly prepare for the reduction.

The MNO partners in the project indicate that current systems – with potentially some further sophistication on the pattern recognition analysis – suffice for the current commercial deployments. The commercially deployed systems are perfectly capable of anticipating structural trends over a period of months or days in a specific and well-defined area. For example, if a confluence of operations from different users leads to a specific uptick in uplink demand every Monday morning, then this will show up in the pattern recognition and the network provider can adjust its resourcing accordingly. Idiosyncratic events (e.g. the arrival of an unusually large vessel which causes interference with the 5G network and reduces uplink capacity) can however not be picked up by this analysis. The fallback there would be either a pure reactive approach or timely communication between the site owner and the network provider (assuming the event can be foreseen).

The automated rules-based systems fall short in two ways:

- **Not proactive enough**. While they help to reduce the impact of network saturation on a user's operations, they are not able to prevent network saturation itself.
- **Not dynamic**. Rules need to be updated at regular intervals (through human intervention) as the system itself is not able to learn as the environment changes.

These shortfalls imply that for more advance deployments (such as scenarios L3 and L4),

an automated rules-based system will reach its limits. Patterns in network performance will be more difficult to pick up on public roads as there are more confounding factors that can influence network performance. Further, the environment is also more prone to unforeseen changes such that rules identified at a specific date may no longer be relevant two months later. For these deployments, more sophisticated monitoring and diagnostics tools may be needed.

An evolution towards Network Awareness and re-configurability may therefore be required. Network awareness refers to a fully automated system that gives a 5G network the ability (i) to measure and predict the state of the network (both from supply- and demand-side); (ii) to interpret the measurements and predictions; and (iii) to dynamically and independently adapt and re-configure the network when needed. Network awareness fulfils two major roles. First, it can be used to dynamically optimize the network to deliver the best performance given the conditions and the needs of the various applications. Second, it can also pass on the information on network conditions to connected devices. For example, the information could be sent to the teleoperation service provider in real-time who could use the info to make more informed decisions on network usage and network resource management.

Network awareness, in its intended form, is predictive, dynamic, cooperative and proactive.

- **Predictive**. Network awareness would include Predictive Quality of Service (Predictive QoS). Where the rules-based system can 'predict' the future state of the network through pattern recognition[89], Predictive QoS can go a step further by correlating quality of service at time T to network metrics prior to time T[90]. By adding prediction, mobile networks can "*provide in advance notifications about anticipated QoS changes to the vehicle and [the teleoperator]*" (5GAA 2021a). This opens up the possibility "*to inform a [teleoperated transport] application about an expected change of achievable QoS, giving the application time to react to the expected change before the change takes effect*" (5GAA 2021b). As such, "*predictive QoS will be an effective tool for [teleoperated transport] applications to adapt behaviours*" (5GAA 2021b). Also, in 5GCroco, "*QoS prediction has been identified as one key solution*" (5GCroco 2021). Though, "*applying predictive QoS to [teleoperated transport] services in deployment still requires further research and standardization work*" (5GAA 2021b).
- **Dynamic**. In Network Awareness, adjustments to a changing environment would be baked into the system through adaptive and continuous learning.
- **Cooperative**. Network Awareness will actively take on board input from other sources, in particular customers, to get a sense of the future state of the network. The network will not only be able to know current demand for its resources, but also future demand and take actions accordingly.
- **Proactive**. Through proper forecasting, modelling and network optimization, Network Awareness would allow the 5G network to prevent saturation events by proactively and selectively reducing service levels. On the whole, this could lead to more gradual degradations in service levels which are likely to be more limited.

The timeline for deployment of Network Awareness is highly uncertain. The development of predictive, dynamic, cooperative and proactive Network Awareness could take upwards of a decade, though intermediate forms, such as predictive network awareness, could already happen in several years' time. Recent evolutions in AI, machine learning algorithms and the development

[89] E.g. "The network is typically saturated at that spot on Tuesdays from 10:00 till 10:15, so it is likely that it will be saturated there next Tuesday as well."

[90] E.g. "Metric X and Y have values A and B at Tuesday 09:00, so it is likely that the network will be saturated at Tuesday 10:00."

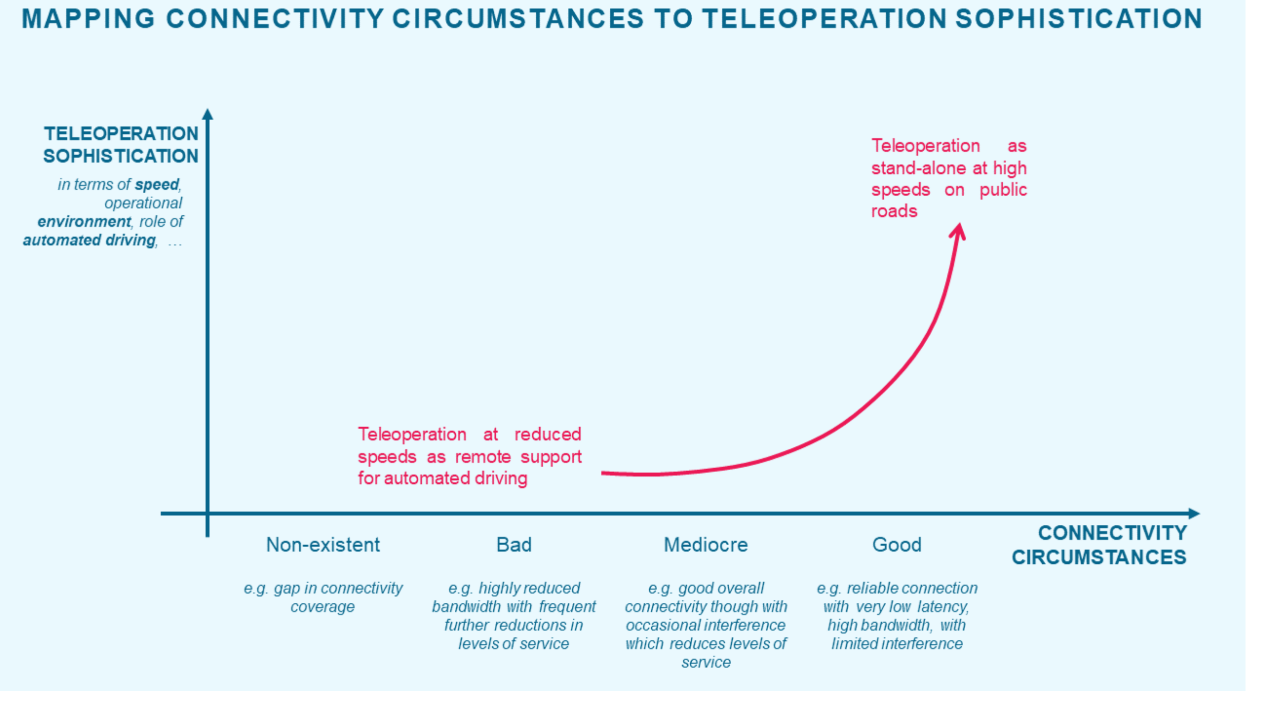
of digital twins may speed up development.

6.2.3 Governance should lay the groundwork for deployment

Oversight from a regulatory body will be needed, considering the risks involved with unmanned transport for third parties on public roads and the reliance on connectivity of teleoperation. This regulatory body should: set out connectivity conditions under which teleoperation on public roads can be deemed safe; determine the spatiotemporal road network that fall under these conditions, and; oversee that only operations within this road network are authorized.

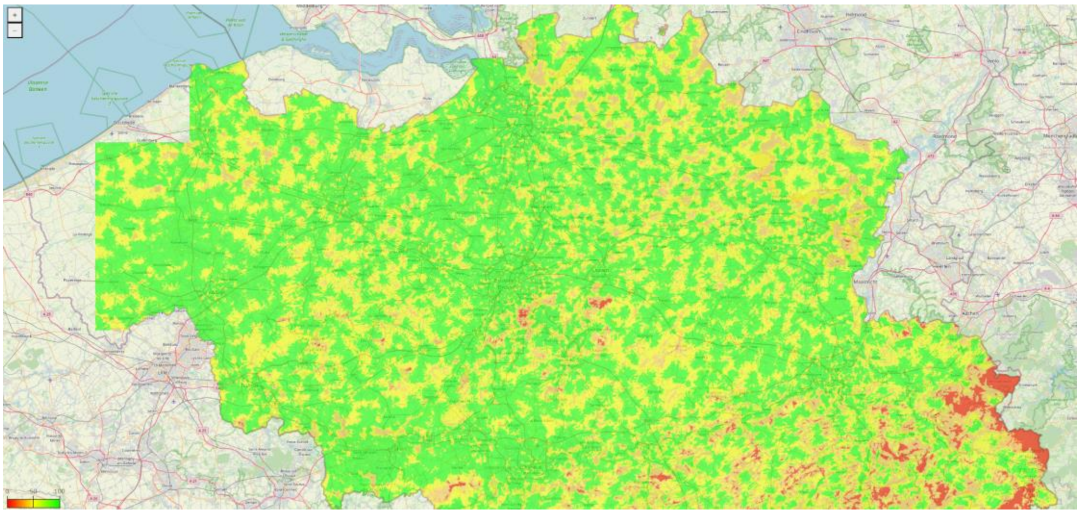
Set out connectivity conditions. Work should be undertaken to map the connectivity circumstances to the teleoperation domain, the level of sophistication that is admissible under these circumstances – see the diagram below. A classification of connectivity circumstances should be made based on a number of parameters such as reliability, capacity (per user and by number of users), latency, interference from other sources, etc. For each class of connectivity circumstance, the level of teleoperation sophistication should be determined. This level of sophistication is specified in terms of admissible speed, the operational environment (private roads, semi-public roads, public roads, highways, etc.) and the role of automated driving (in support of teleoperation or vice versa). The mapping should be done on the basis of the risks involved with each connectivity circumstance and level of sophistication, taking into account the existence and maturity levels of mitigating fall-back systems and preventive measures such as dynamic network optimization and network awareness.

Figure 11: Mapping connectivity circumstances to teleoperation sophistication



Determine the appropriate spatiotemporal road network. The (theoretical) mapping of circumstances to teleoperation sophistication should then be applied to the real-world spatiotemporal context. On the basis of historic connectivity data provided by network providers and users, a connectivity heatmap should be constructed which provides insights into where and when which connectivity circumstances apply. By using the mapping from the previous step, one then obtains a view on which type of teleoperation is admissible where and when within a relevant geography. These *heatmaps* are similar to the connectivity heatmaps already published on the website of the Belgian telecom regulator BIPT today – see below. Where the typical heatmaps are quite general in nature, the heatmaps proposed here are uniquely geared towards setting out the spatiotemporal context within which teleoperation is feasible.

Figure 12: Telenet 4G connectivity heatmap from BIPT



This step will require considerable transparency from network providers and its main users, as they will have to share detailed historic data on connectivity.

Authorize operations within the appropriate road network. In the context of the aforementioned licensing system (see Section 5.4), teleoperation service providers will have to present a connectivity case to the authorizing body. This connectivity case will have to (i) set out the sophistication of the intended operation, including mitigating fallback systems and preventive measures in place; (ii) indicate where and when operation is intended to take place; and (iii) demonstrate that the intended operation is admissible within the intended spatiotemporal context.

The first step towards building a governance framework of the type described above is to chart the as-is situation. We need to obtain a view on the level of 5G connectivity provided in relevant geographical areas (e.g. portal areas or highway corridors), in terms of what it means for teleoperation potential. Concretely, this means that uplink capacity levels (on average or within 5%-95%-bounds) need to be mapped, which teleoperation service providers can then use to determine the feasibility of a safe and viable operation and assess whether preventive actions on their side (such as the ones discussed in Section 6.1.2) are manageable.

6.2.4 Service Level Agreements as a way to manage elevated needs of customers

Today, connectivity providers mostly work on a best effort basis – they will do their best to provide connectivity close to 100% of the time but indicate they cannot be held liable if connectivity breaks down. The question now is whether, in the context of teleoperated transport, best effort connectivity will be sufficient for a safe and economically viable teleoperation ecosystem.

At the outset it should be noted that a system whereby an MNO fully guarantees connectivity is not an option. Connectivity may break down for a number of reasons (location, terrain, weather conditions, network congestion, device compatibility, …) which are not all under the control of the MNO. Ensuring 100% connectivity for a single MNO would be prohibitively expensive rendering any 5G business model unviable. In addition, insurance of this type of agreements for MNOs would be very complex and expensive.

This leaves the aforementioned 'best-effort' connectivity and Service Level Agreement ('SLA') connectivity as potential options. In the latter, the MNO and the customer enter into an SLA in which the MNO agrees to provide connectivity with a specified level of reliability. The connectivity customer (the teleoperation service provider in this case) is then expected to take this reliability level into account when designing and deploying a safe operation; unless explicitly stated in the SLA the connectivity customer remains liable for any damage caused by a breakdown in connectivity. However, the MNO would be susceptible to damage claims if it cannot meet the reliability levels specified in the SLA. The use of SLAs by MNO is relatively new and uptake has been slow so far.

The choice between best effort and SLA connectivity will depend on the criticality of ensuring a specific reliability level for a safe operation, and on the reliability level required.[91]

For Scenarios Terminal Operation (L1), Shuttle Run (L2) and Shuttle Run barge (W2), connectivity on a best-effort basis suffices. As we discussed in Section 6.1.3, real-time dynamic adjustments as they exist today in a best-effort context constitute a safe and efficient solution for these scenarios. The episodes of unreliable connectivity will be limited, predictable and not risky, such that ensuring close-to-100% reliability is not critical.

For more complex Scenarios such as Highway (L3), Cross-border (L4) and A to B barge (W3/4), SLA connectivity may be needed. A best-effort model may undermine the viability of the teleoperation business case for these scenarios as mere real-time dynamic adjustments will reach their limits, considering that episodes of unreliable connectivity will have a large (adverse) impact. Before deciding to deploy an advanced version of teleoperation, teleoperation service providers will need some guarantees from MNOs about the level of connectivity that they can expect. SLAs establish clear expectations on the quality of connectivity and allow teleoperation service providers to configure their deployment based on the SLA. The operational and legal certainties linked to these SLAs thus overcome the business risks faced by teleoperation service providers.

For MNOs, SLAs entail a departure from their usual best-effort business model vis-à-vis public network services. Nevertheless, SLAs may also be beneficial for MNOs:

- Price differentiation: SLAs allow MNOs to extract more value from customers who are willing to pay extra for a higher and consistent level of service. In a best-effort setting, this extra source of revenue may remain untapped.
- Resource allocation: SLAs also provide detailed insight into the requirements of the customer, allowing MNOs to efficiently (and dynamically) allocate resources. In a best-effort setting, the customer requirements are a black box, complicating the task of dynamic network optimization. With SLAs, the customer is invited to specify what he needs, when and where which facilitates the task of the MNO to optimize the network. SLAs also open the door for more advanced coordination where the customer shares with the MNO its real-time and forecasted needs.

6.3 Roaming and cross-border handover as particular challenges for cross-border scenarios

The provision of low-latency, high-bandwidth and ultrareliable quality of service becomes even more complex when the teleoperated transport crosses a border, for example in Scenarios L4 (Cross-border) and W3/4 (A to B Barge).[92],[93] The connection needs to be handed over to a foreign MNO on whose network the teleoperation service provider will roam. The home MNO there faces the challenge of dealing with "*technical, operational and regulatory complexities to ensure that [its] customers can use mobile services wherever they go. […] This must be done while maintaining quality standards and complying with all applicable regulations in the countries where the service is offered*" (5G-Blueprint 2023b).

In practice, home MNOs face two challenges to accommodate its subscribers when roaming away from the home network.

[91] Along with the need for good monitoring systems in place to check if the SLA is being adhered to or not.

[92] This section is a synthesis of Deliverable D5.3 (5G-Blueprint 2023b) which provides more details on the matter.

[93] We only discuss international roaming here. National roaming also exists, for example to share coverage in scarcely populated areas within the same country. The challenges faced with national roaming are similar though less complex. Hence the focus on international roaming.

First, it is difficult for a home MNO to ensure the quality of service on roaming networks. As explained in Deliverable 5.3, "*within an MNO's home country, an MNO can choose to add radio sites for improved coverage or capacity (in the defined and agreed service area). It can add/increase redundancy or backup power to a site for improved availability. However, when it comes to roaming, the MNO does not have the autonomy to make this decision independently. When roaming, these network improvements are subject to the cooperation with a foreign MNO and the need to comply to agreements and technical capabilities of both the home and visited networks*" (5G-Blueprint 2023b). This poses an issue for the teleoperated transport use-case as end-users require a specific minimum quality of service, which the home MNO needs to provide abroad using networks it has no or limited control over.

Second, the commercial large-scale implementation of seamless handover from one network to another is technically complex and challenging in terms of scalability. Seamless handover can be established through inter-PLMN handover[94], which configures the handover in such a way that it is as if the user is still connected to the home network. Trials of inter-PLMN handover in 5G-Blueprint have shown promise in a controlled environment, since it was convincingly demonstrated that handover can be done seamlessly with no noticeable interruption and a latency of less than 100ms.[95] However, challenges remain for this solution:

- Implementation beyond predefined locations is challenging. To make handover work "*interfaces [between different networks] need to be introduced to ensure that individual radio cells [operated by the home MNO] recognize their neighbouring cells [operated by the foreign MNO]*" (5G-Blueprint 2023b), in much the same way that individual radio cells operated by the same MNO recognize each other. This implies that handover needs to be configured at cell-level at a specific (border) location.
- Seamless inter-PLMN handover does not allow home MNOs to steer the user towards a foreign network that is suitable for the user's specific needs: "*the current standards do not support a selection mechanism based on the preferences of the [home MNO], […] ignoring user-specific subscriptions or roaming agreements*". The challenge is amplified when handover needs to take place between two visiting networks: when crossing from the home country of an MNO to the network of a neighbouring country, the home MNO can still preselect the chosen network to a certain level; when handing over between two visiting networks, the two foreign MNOs configure and determine the handover, beyond the control of the home MNO.

These challenges can be (partially) overcome through a combination of governance and technical solutions. From the governance side, we see three solutions. In particular:

- **Automated driving fallback at handover points**. Direct teleoperation at border locations requires seamless handover which as indicated above is challenging at scale. Instead, hybrid teleoperation should be applied where the automated driving system takes over at handover points. This requires that these points are located on stretches of road in which fully automated driving is feasible (e.g. on highways).
- **EU-wide governance framework on 5G corridors**. As explained in Section 6.2.3, teleoperated transport should only be allowed along corridors where it has been demonstrated that the provided connectivity meets the requirements posed by teleoperation (e.g. with inter-PLMN handover in place). This implies that teleoperation will not take place anytime anywhere, but only on international transport corridors with sufficient coverage to allow for (hybrid forms of) teleoperation.
- **Service Level Agreements**. Roaming partners (i.e. MNOs) will need to agree on the

[94] PLMN stands for Public Land Mobile Network.

[95] See Deliverable D5.4 (5G-Blueprint)

delivery of Quality of Service levels, essentially requiring SLAs. There have been recent initiatives within the GSMA[96] to develop and incorporate SLAs between roaming partners.

From a technical side, Deliverable 5.3 proposes three concepts and/or solutions for further investigation:

- **Optimized Steering of Roaming**. This technical concept focuses on optimizing the network selection for subscribers when roaming between different mobile networks. Steering of Roaming helps to ensure that subscribers connect to the most suitable network for their needs. Deliverable 5.3 notes that "*while [Steering of Roaming] plays a crucial role in providing a smooth and efficient transition between networks, its primary purpose is not specifically designed to support teleoperation services*" (5G-Blueprint 2023b). The Deliverable further notes however that "*the concept of Optimized Steering of Roaming is currently unavailable*" and that no specifications or implementation guidelines are included in the latest 3GPP release. [97] Vendors of Steering of Roaming services therefore are invited to develop solutions that guarantee the seamless continuity of the service for TO applications. The potential impact of an optimized Steering of Roaming solution on the implementation of cross-border teleoperation services should be evaluated and technical specifications need to be developed which demonstrate real benefits for the cross-border scenarios in upcoming 3GPP releases.
- **Dual SIM**. A second potential solution to seamless handover that was implemented and validated in the 5G-Blueprint project is simultaneous usage of multiple SIM-cards. "*When crossing a border, SIM 1 would remain connected to the existing network, while simultaneously, SIM 2 would initiate a connection with the appearing network as soon as the signal strength permits. Once a stable connection is established via SIM 2, the first SIM can disconnect from the old network and initiate a connection with the new network as well or even with a different network in the visited country*" (5G-Blueprint 2023b).[98] It has the advantage that it can already be deployed today, while awaiting the further maturation of Inter-PLMN handover which might make it obsolete. However, the solution poses a challenge for teleoperation service providers: it requires the teleoperation service provider to arrange different SIM cards for the different networks it wants to use in the different countries that it wants to serve; and it needs to manage somehow which of these SIMs should be active in the user equipment at a specific time. Apart from Seafar's experimentation with the solution, the solution remains untested in a commercial cross-border setting.
- **Coverage on Demand**. Instead of aiming to provide roaming connectivity across a whole trajectory, MNOs could opt to only provide coverage on demand, at specific locations. For example, in the context of Scenario L4, a vehicle could drive autonomously on the highway and may request assistance from a teleoperator when leaving the highway (or when facing other complex traffic situations). In that case, the teleoperation service provider may request connectivity from the MNO. Coverage on Demand may decrease the complexity substantially: ensuring a connectivity service for a specified quality level during a few minutes is easier than reserving uplink capacity over an unknown route with an unknown time frame.

In conclusion, the aforementioned challenges imply that direct teleoperation at border crossings is unlikely to take place at a large scale. Rather, a hybrid form of teleoperation will emerge with

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[96] Global Systems for Mobile communication Association, a global organization unifying the mobile ecosystem to discover, develop and deliver innovation.

[97] 3GPP is a partnership that develops protocols for mobile telecommunications, such as 5G.

[98] Testing this dual SIM solution for seamless cross-border teleoperation is the subject of 5G-Blueprint Deliverable D5.5.

support from automated driving systems to bypass situations where inter-PLMN handover is not yet in place and where quality of service levels cannot ensure safe direct teleoperation (e.g. at border crossings). In the long-term cross-border teleoperation of such a form will be further facilitated by technical innovations on Optimized Steering of Roaming and Coverage on Demand. In the short term, the inter-PLMN handover solution could be further supplemented by a dual SIM solution (in particular in edge cases), in combination with the governance framework described in Section 6.2.3.

6.4 Net neutrality

Network slicing gives MNO's the opportunity to offer separate virtual 5G mobile networks on top of a single physical network infrastructure. These slices are configurated to suit the specific needs of the customer, with varying performance characteristics (in terms of bandwidth, latency, reliability, etc.) across slices in comparison to the standard 'public internet access slice' (henceforth 'PIA').

Network slicing as a concept is not at odds with the EU Regulation on Net Neutrality and its general rule that Internet Service Providers (ISPs) must treat all traffic equally. A distinction should be made between the PIA slice and dedicated purpose-built network slices: "*net neutrality rules shall naturally apply to the [*former] *while for the [*latter]*, special rules apply based on commercial agreements"* (5GAA 2020b)*.* Specifically for network slices linked to the provision of CAM services (including automated and teleoperated driving), the 5G Mobix-project concluded that these slices do not fall under the strict rules of net neutrality (5G Mobix 2023). In their view, applications around CAM services should be viewed as *Specialized Services* ('SpS') through which MNOs can offer a connectivity service that is differentiated from the standard *Internet Access Services* ('IAS').[99]

That being said, however, the regulation on Net Neutrality also poses some restrictions on network slicing, and SpS in general. More specifically it states that "*the offering of SpS should not be at the cost of the quality of IAS: 'Providers … may offer or facilitate such services only if the network capacity is sufficient to provide them in addition to any internet access services provided. Such services … shall not be to the detriment of the availability or general quality of internet access services for end-users.' For mobile networks, a specific note has to be made: a temporal negative impact of SpSs on the quality of IASs is acceptable, as the number of users in a (radio) cell may be difficult to anticipate. The impact should be unavoidable, minimal and of short duration though*" (5G Mobix 2023). By adding CAM SpS to the overall connectivity picture, the overall availability of resources for the IAS may change. As indicated by 5G Mobix the precise impact depends on "*the provision of additional resources in the network [as a result of the SpS]*" and "*the distribution of available resources between the IAS and the SpS*" (5G Mobix 2023).

The aforementioned 5G Mobix-analysis makes a number of recommendations for operational situations: (i) we should **check whether sufficient resources have been added** from measurements or from the changes in network dimensioning, which may be complex in practice; (ii) the **use of resources by the SpS should be managed**. "*For example, a Session Admission Control (SAC) mechanism for CAM sessions could be used to limit the number of parallel CAM sessions and their combined resource usage, to ensure that sufficient resources remain available for IAS. As another example, in radio resource portioning, a different technical approach, each slice is provided with its own radio resources which would thus intrinsically protect the IAS*

[99] D6.8 of the 5G Mobix-project considers that all three requirements to be considered an SpS hold for CAM services: (i) the service offered is different from IAS, as it does not provide connectivity to the internet; (ii) the service is optimized for specific content, applications or services; and (iii) the optimization is objectively necessary in order to meet required levels of quality. As regards the latter it is concluded that "*given the very strict requirements of the [teleoperated] driving service, in particular the uplink data rate, delay and reliability, it is unlikely that the service can be realistically provided with the required quality via a regular IAS today*" (5G Mobix 2023).

performance from the CAM SpS. A SAC mechanism would in that case still be useful to ensure that CAM sessions cannot crowd out one another" (5G Mobix 2023).

The MNO partners in the 5G-Blueprint-project acknowledge the need for proper dimensioning based on information provided by the client. Rather than a real-time check, they see this as a due diligence step in the on-boarding process of a new SpS customer. In that step, the required capacity should be estimated, and proper provisions should be made to ensure that the prospective customer's request does not impact IAS users. The required capacity will also be subject to negotiation. If more capacity is needed than the network can handle, the network may then choose to transfer part of the income into additional investments.

The need for an SAC is less clear for the MNO partners. If the on-boarding step is carried out properly, conflicts between CAM SpS and IAs will be limited, such that sufficient resources will remain available most of the time.

In conclusion, net neutrality is unlikely to pose a material challenge for the deployment of teleoperation over public networks. As the teleoperation and other uses for 5G connectivity develops, special care will however need to be taken that infrastructure can handle both these specialized services and the more general internet access services.

7 BUSINESS

This section discusses the business-related aspects to deployment of teleoperated transport, building on the work in previous Work Package 3 Deliverables – D3.2 (Business Models), D3.3 (Techno-economic Analysis), and D3.4 (Validation of Business Models). We limit ourselves in this section to highlighting the key findings from these deliverables with respect to the business case.

KEY FINDINGS

- For the more advanced scenarios there may not yet be a positive business case. The timing at which the operational, legal and technical challenges are resolved determines when specific scenarios have a positive business case.
- Coordination between stakeholders will be needed to kick-start teleoperation.
- Teleoperation deployment will follow investments in 5G, rather than the other way around.

7.1 The teleoperation business case may need some time to mature

For each of the teleoperation scenarios considered, at least one viable business model has been identified. This became evident after the in-depth analysis presented in earlier Deliverables D3.2, D3.3 and D3.4. A positive business case is the cornerstone of the commercial viability of any innovation. It requires that the (expected) benefits accruing to the parties that run the entrepreneurial risks outweigh the (expected) costs that these parties incur. In teleoperation, these benefits come in the form of operational efficiency gains by reducing idle times, enhancing comfort and safety for workers and, potentially, addressing labour shortages. The cost of teleoperation – besides the financial investment required to develop, build and scale a teleoperation service – lies in the various operational, legal and technical challenges which were the focus of previous sections.

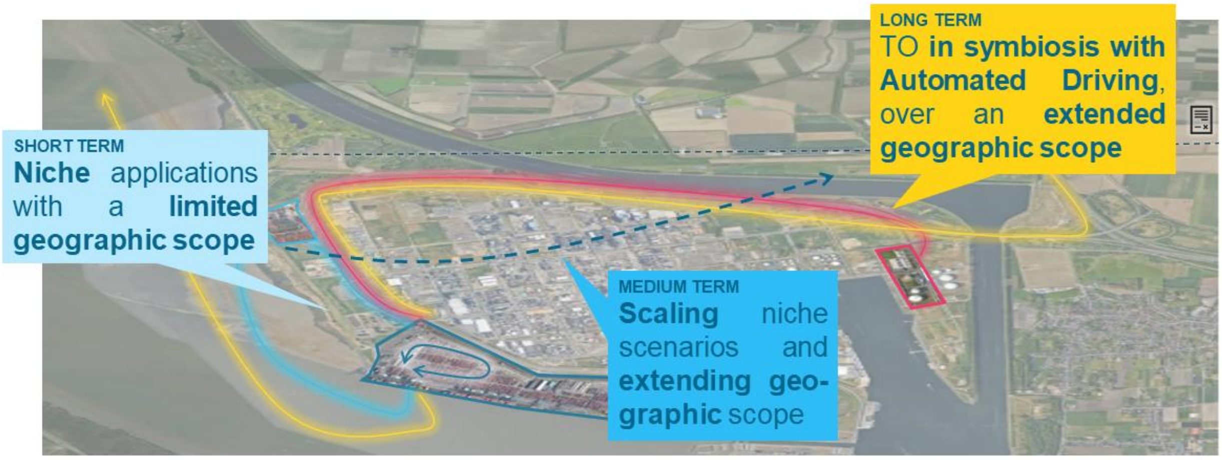
The business case for some scenarios seems not yet there today. Time will be needed to reduce the cost impact of the aforementioned operational, legal and technical challenges. For example, the reluctance of insurance companies to provide insurance for teleoperation services could make the insurance cost of rolling out such services prohibitively high. In addition, operational efficiency gains may only be unlocked after certain challenges are resolved. For example, if a robust 5G network is still lacking on a large stretch of an envisioned teleoperation trajectory, then an on-board driver may still be needed for part of the transport, thus reducing the potential efficiency gains from using a teleoperator.

The timing at which the operational, legal and technical challenges are resolved determines when specific scenarios have a positive business case. This timing has been described in detail in Section 3 of Deliverable 3.4 and can be summarized as follows:

- **Short term – Niche scenarios with limited geographic scope**: The business case for teleoperation is already clear today for simple deployments in controlled environments (e.g. port terminals). This includes Scenarios L1a (RTG Crane) and W2 (Shuttle Run Barge), which already have deployments today, and eventually also L1b (Terminal Tractor), and some very simple deployments of L2 (Shuttle Run) and W3/4 (A to B barge).
- **Medium term – Scaling of niche scenarios and extending geographic scope**: As teleoperation services gain maturity and as the operational, legal and technical challenges are gradually resolved, the initial deployments at the aforementioned niche scenarios can be scaled up (e.g. more ports follow the example of the first movers) or geographically extended (e.g. towards public roads). Two crucial aspects that will drive this evolution are the roll-out of 5G networks and the commercialization of automated driving systems, enabling teleoperation to become realistic and feasible also over longer distances in particular where automated driving covers for the gaps in coverage.

- **Long term – Teleoperation in support of automated driving systems and vice versa**: In the long term, automated driving systems will help to unlock the business case for teleoperation and vice versa. Teleoperation will become largely hybrid with direct control teleoperation limited to specific areas (e.g. up to or on highway ramps) where fully automated driving is not (yet) possible; at the same time will teleoperation functionalities become an integral part of automated driving systems to provide for fallback in case the automated driving system fails. In the even longer term, teleoperation will eventually evolve to a pure indirect role where oversight is provided by the teleoperator who gives tactical and strategic instructions to an otherwise fully automated vehicle. This transition is expected first in waterways scenarios and in scenario L1, because of the lower domain complexity of these scenarios and the readiness of automation capabilities for cranes, yard vehicles and barges.

Figure 13: Overview of timing of various business cases



7.2 In order to realize the business case, coordination will be needed

Teleoperated transport will not just 'happen' but will require a concerted kick-start. While the business case may already be clear for some scenarios, the materialization of the business case will require cooperation and coordinated action among different stakeholders. Likewise, in order to arrive at a positive business case for other, more advanced, scenarios, coordinated action will be required for resolving the challenges discussed in previous Sections. In any case will the introduction of teleoperated transport go hand in hand with new technology, services and operations within the existing logistics ecosystem.

The question then arises which party is a natural candidate to take the initiative on the coordination of a successful commercial deployment. Deliverable 3.4 has carried out an extensive assessment on the stakeholders who are most likely to orchestrate a deployment, depending on the scenario considered.

- **L1 (TO@Terminal)** – It can be expected that the terminal or site operator will take the lead, as the business case for this stakeholder will be the main driver to launch teleoperation in this scenario. The deployment of an L1a (RTG Crane) application at the Lineage terminal (formerly Kloosterboer) at Vlissingen is a good example of this.
- **L2 (Shuttle Run) and W2/3/4 (water-based)** – Here there are two options. Option 1 is an independent teleoperation service provider who contacts potential customers and takes actions to resolve potential hurdles. This option would require an entrepreneurial start-up company who is willing to take risks. Seafar is a good example of that. Alternatively, Option 2 is a logistics company (or joint venture of local logistics companies) who have a clear business case for teleoperation and are willing to take the risk.

- **L3/L4 (Highway / Cross-border)** – Before these scenarios can be successfully deployed, considerable coordinated action should be taken. The initiative for these actions will likely come from multiple sides. First, OEMs may see teleoperation as a cornerstone for safe automated transport. In that respect, they will already take concrete actions to resolve the challenges described in this deliverable, in particular those related to the vehicle itself. Second, large transport companies could become teleoperation service providers (as they can gain a competitive advantage and would like to keep control over the entire transportation journey). In the longer term, large digital platforms (e.g. hosted by such a logistics company, or an OEM) could emerge, which provide matchmaking between cargo owners, vehicle owners and teleoperation service providers.

7.3 Teleoperation deployment will follow investments in 5G

The viability of the business case for teleoperated transport inevitably depends on 5G coverage, in particular on the scale at which 5G networks will be rolled out and whether these networks are properly dimensioned to meet the needs of teleoperated transport. This holds specifically for deployments with an extensive geographic scope. If large parts of the envisioned geographic scope for teleoperation remain without 5G coverage, the operational efficiencies linked to teleoperated transport cannot be realized. For example, in Scenario L3 (Highway) deployment can only be profitable if sufficient highway entry and exit points are covered by 5G.

At the same time, it is unlikely that teleoperation use-cases on their own are sufficient to spur the required investments in 5G infrastructure. Again, this holds in particular for more advanced scenarios with a more extended geographic scope (e.g. Scenarios L3 (Highway)). The study carried out in Deliverable D3.3 found that significant investments would be needed in 5G, relative to the expected returns from teleoperation. It recommended to focus 5G investments on areas where many teleoperation use-case could be deployed in a geographically limited area; and to reduce use-case requirements for the uplink capacity in order to save the costs related to 5G connectivity (see also Section 6). On that basis, Deliverable D3.4 concluded that for an MNO to invest in 5G infrastructure, demand needs to come from more use-cases than just teleoperation. Teleoperation can be used as a launching service for 5G, but more use-cases are necessary to make it a profitable business. As a result, we consider it highly unlikely that MNOs will make investments in 5G infrastructure in anticipation of a future deployment of teleoperation.

This has two important consequences:

- **Investments in 5G infrastructure are only likely in high-demand areas**: As also explained in Section 6.2.1, MNOs will only consider making costly investments in 5G infrastructure if there is sufficient demand for the increased quality that 5G can offer, not just from teleoperation service providers but also from other (potential) users. Investments in areas with limited economic and residential activity, such as rural stretches of highway, are therefore unlikely.
- **Teleoperation deployments will follow investments in 5G infrastructure**: A contemplated teleoperation deployment should consider the 5G network as given. Roll-out of teleoperation in a specific area will therefore be dependent on the quality of the 5G network provided in that area. In other words, 5G investments will not be made based on teleoperation roll-out plans; rather, teleoperation roll-out plans will be made based on earlier and foreseen investments in 5G. This further underlines the importance of a governance framework (see Section 6.2.3) that provides prospective teleoperation service providers with transparency as to where its service could be deployed and hence whether their business case is positive.

8 CONCLUDING REMARKS

This Deliverable aimed to shed light on the required steps towards a healthy ecosystem for teleoperated transport. While the 5G-Blueprint project demonstrated the technical and business potential of 5G-enabled (and cross-border) teleoperated transport, **coordinated action is required** to make it a commercial reality. This calls for a **gradual process** in which the least complex deployments – in a controlled environment with a limited geographic scope – are rolled out first; in parallel, technical, operational and regulatory steps need to be taken to clear the way for more ambitious deployments. The **involvement of all relevant stakeholders** in this process is crucial: Unmanned transport (and teleoperation in particular) entails a huge logistics paradigm shift with knock-on effects that go beyond the partners directly involved in rolling out unmanned transport. The needs, concerns and opportunities of all stakeholders directly or indirectly involved need to be aligned to ensure that no coordination problems arise further down the road.

The potential of 5G connectivity to unlock the business case for teleoperated transport is clear: the low-latency, high-bandwidth and ultrareliable connectivity that can be provided over 5G are absolute necessities for any ambitious deployment of teleoperated transport. So, while more simple forms of teleoperated transport can be deployed on 4G or wired connectivity, our clear recommendation is for teleoperation service providers to adopt a **5G-focused deployment strategy** – a future-proof strategy that allows these providers to more effectively scale up their services to more ambitious deployments. That being said, it is unlikely that teleoperated transport will set the pace for 5G roll-out. Teleoperation service providers should in that respect **work within the constraints imposed by the communications network**, rather than expecting that the 5G network will be formed based on the needs of teleoperated transport.

Finally, our assessment also revealed the crucial interplay between teleoperation and automated driving. Both technologies are evolving in parallel, and both technologies have their challenges and complexities. Crucially, the two are complementary in that they provide solutions for each other’s shortcomings. Rather than evolving towards an ‘anytime anywhere’ version of direct control teleoperation, the evolution is clearly towards a more **hybrid form of teleoperation** where the teleoperator oversees the automated driving system and directly intervenes when the vehicle ventures beyond the operational domain of the system. As automated driving has a head-start over teleoperation in terms of regulatory and governance initiatives, **teleoperation can only benefit from being included in these initiatives as an integral part of the automated driving solution**.

9 ANNEX – ASIL ANALYSIS

ASIL (Automotive Safety Integrity Levels) looks at the potential impact of a failure of a specific component of a vehicle (in our case the connectivity from the remote control centre to the vehicle and vice versa) on the safety of occupants and other road users. The failure of the component can bring along certain hazard events (e.g. a teleoperated vehicle being stopped on a highway). The ASIL-methodology analyses:

- **Severity**: The extent of potential harm if the hazard event were to materialize;
- **Exposure**: The probability that the hazard event could materialize. This is a function of the probability of a failure occurring (e.g. a breakdown in connectivity) and the probability that the failure leads to a hazard event;
- **Controllability**: The extent that the operator can control the vehicle in case of a failure in the component and avoid or mitigate the hazard event.

Based on this risk analysis, the ASIL-methodology then classifies the safety requirement into 5 categories: **ASIL D**, which is the highest level of risk potentially entailing multiple fatalities and requiring the most stringent safety requirements to prevent a failure of the component to occur; **ASIL C**, a risk level associated with severe injuries (disability or death); **ASIL B**, a risk level associated with moderate injuries (e.g. broken bones); **ASIL A**, a risk level associated with minor injuries; and finally **QM** ("Quality Management"), when there are no automotive hazards and hence no safety requirements to manage.

In 5GAA (2019) the following Hazard Events were identified that are relevant for a breakdown in connectivity in the scenarios considered:

- **Obstacle**. Due to a breakdown in connectivity, the teleoperated vehicle is staying at a dangerous place creating an obstacle or danger for other road users; other road users are not able to react in time to the obstacle and thus collide with the teleoperated vehicle.
- **Manoeuvre**. Due to a breakdown in connectivity, the teleoperated vehicle performs driving manoeuvres that are not as intended by the operator (e.g. driving with the wrong speed or wrong steering angle); as a result, the vehicle can cause an accident to other road users (e.g. hits a pedestrian, or crashes into another vehicle).

For each scenario, and based on these hazard events and an analysis of the severity, exposure and controllability of the event, we can classify the ASIL rating for the connectivity. We use the classification matrix used in the industry.[100] Note that for all scenarios we assume that the consequences of a breakdown in connectivity are uncontrollable by the remote operator: if connectivity is lost, there is no way for the operator to intervene. Any mitigation of the impact should therefore be done on the vehicle-side.

[100] See among others here for an overview.

Severity	Exposure	Controllability		
		C1 (Simple)	C2 (Normal)	C3 (Difficult, Uncontrollable)
S1 LIGHT AND MODERATE INJURIES	E1 (Very low)	QM	QM	QM
	E2 (Low)	QM	QM	QM
	E3 (Medium)	QM	QM	A
	E4 (High)	QM	A	B
S2 SEVERE AND LIFE THREATENING INJURIES – SURVIVAL PROBABLE	E1 (Very low)	QM	QM	QM
	E2 (Low)	QM	QM	A
	E3 (Medium)	QM	A	B
	E4 (High)	A	B	C
S3 LIFE THREATENING INJURIES, FATAL INJURIES	E1 (Very low)	QM	QM	A
	E2 (Low)	QM	A	B
	E3 (Medium)	A	B	C
	E4 (High)	B	C	D

QM (Quality Management)
Development supported by established Quality Management is sufficient.

A – **lowest ASIL** Low risk reduction necessary
B
⋮
C
D – **highest ASIL** High risk reduction necessary

L1a – RTG Crane [ASIL A]. A hazard event in this context is a situation where the crane or the container carried by the crane is in such a position that it poses an immediate danger to persons in the vicinity of the crane. We come to the following conclusions with respect to exposure and severity:

- Low probability of breakdown in connectivity: Cranes are operated via wired connections with connectivity conditions that are easy to monitor and control. It is therefore highly unlikely that connectivity will be lost.
- Low probability of hazard event following breakdown: For the crane operation to lead to a hazard event in the case of a connectivity breakdown, two things need to happen. First, the fallback system which puts the crane in a 'minimal-risk' position and locks the spreader so that the container cannot fall, fails to work; and second, the safety procedures, which specify a perimeter around the crane within which movement is prohibited when the crane is in operation, were not respected. Both conditions are deemed highly unlikely.

So, we consider that connectivity has a 'very low' exposure rating.

- High impact of hazard event: Given the size of the crane and the components of the crane (including the tyres), as well as the height up to which containers are being lifted, the materialization of a hazard event has a potentially big impact. If the fallback system fails and if a person is in the immediate vicinity of the crane, then impact could be lethal.

We therefore consider that connectivity has a 'high' severity rating.

Combined with the fact that the crane is no longer controllable by the teleoperator in case of a breakdown, this implies an ASIL A rating: a breakdown in connectivity is unlikely to result in serious or fatal injuries.

L1b – Terminal Tractor [ASIL A]: A hazard event in this context is either a situation where the tractor comes to a stop at a location where other vehicles are likely to collide with it; or a situation where the tractor collides with another vehicle or person. We come to the following conclusions with respect to exposure and severity:

- Low probability of a breakdown in connectivity: The connectivity in this scenario takes place via a private network operated by a single private network operator. The geographic area will be small and connectivity weaknesses could be identified and addressed in advance. This makes for a highly controlled connectivity environment where it is unlikely that, even in a best-effort setting, a complete breakdown in connectivity will occur.

- Low probability of a hazard event following a breakdown: The terminal tractor in this scenario will be largely automated and equipped with fallback systems which can bring the vehicle to a minimal-risk stop in case of a connectivity breakdown. In addition, the vehicle will drive at slow speeds (likely not surpassing 30kph), especially in those edge cases where direct control by the operator is required. Finally, for a hazard event to materialize it is also required that operators of other vehicles or pedestrians are not displaying the necessary caution (e.g. driving too close to the tractor, or walking where it is not allowed). So even if connectivity breaks down, it is unlikely that a hazard event will materialize.

So, we consider that connectivity has a ‘very low’ or ‘low’ exposure rating.

- Medium impact of hazard event: A collision with another vehicle is, given the low speeds, unlikely to lead to major injuries. A collision with a pedestrian could be more serious, though, given the low speeds, it is unlikely to be fatal.

We therefore consider that connectivity has a ‘medium’ severity rating.

Combined with the fact that the terminal tractor is no longer controllable by the teleoperator in case of a breakdown, this implies an ASIL A rating: a breakdown in connectivity is unlikely to result in serious or fatal injuries.

L2 – Shuttle Run [ASIL B/C]: A hazard event in this context is either a situation where the vehicle comes to a stop at a location where other vehicles are likely to collide with it; or a situation where the vehicle collides with another vehicle or person. We come to the following conclusions with respect to exposure and severity:

- Low probability of a breakdown in connectivity: The connectivity in this scenario takes place via a private network operated by a single private network operator. The geographic area will be small and connectivity weaknesses could be identified. This makes for a controlled connectivity environment where it is unlikely that, even in a best-effort setting, a failure in connectivity will occur. The risk may be somewhat higher than for the L1b scenario as the area is bigger and less easy to control.
- Medium probability of a hazard event following a breakdown: We assume, at least in the short term, that the vehicle will be directly controlled by the teleoperator. This increases the likelihood of a hazard event as no automated systems will be on board which would be able to continue operation or drive the vehicle towards a safe location; instead, if connectivity breaks down the vehicle will simply come to a controlled stop. In addition, the vehicle will (although at low speeds) drive on public roads with a mixed group of road users and less stringent safety procedures (making for example a collision with a pedestrian or cyclist more likely).

So, we consider that connectivity has a ‘low’ to ‘medium’ exposure rating.

- High impact of hazard event: Due to the higher speeds and the less stringent safety procedures, we consider that a collision potentially has a high impact, with possible fatal outcome.

So, we consider that connectivity has a ‘high’ severity rating.

Combined with the fact that the vehicle is no longer controllable by the teleoperator in case of a breakdown, this implies an ASIL B or C rating: a breakdown in connectivity may result in injuries and potentially even fatalities, though the latter is highly unlikely. This is different from the assessment in 5GAA (2019) which assigned a blanket ASIL D rating to all direct control teleoperation use-cases. A lower rating here appears to be warranted however, given the limited probability of the hazard event materializing.

L3+L4 –Highway and Cross-border [**ASIL D**]: A hazard event in this context is either a situation where the vehicle comes to a stop at a location where other vehicles are likely to collide with it; or a situation where the vehicle collides with another vehicle or person. We come to the following conclusions with respect to exposure and severity:

- High probability of a breakdown in connectivity: Connectivity in these scenarios is to be provided along a stretch of highway, potentially by multiple MNOs (and certainly in the case of cross-border transport). This makes that connectivity will be difficult to predict, control and guarantee in a best-effort setting. In addition, transports in these scenarios will cover a lot of ground encountering many diverse situations connectivity-wise. As such, it is likely that at least at some point during the transport the connectivity will break down (considering current set of mitigating measures – see section 6).
- High probability of a hazard event following a breakdown: As in the case of scenario L2, the vehicle will come to a controlled stop. In virtually all situations this will lead to a hazard event as the vehicle will have stopped on the highway (in the worst case scenario not on the emergency lane).

So, we consider that connectivity has a 'high' exposure rating.

- High impact of hazard event: Due to the higher speeds and the less stringent safety procedures, we consider that a collision potentially has a high impact, with possible fatal outcome.

So, we consider that connectivity has a 'high' severity rating.

Combined with the fact that the vehicle is no longer controllable by the teleoperator in case of a breakdown, this implies an ASIL D rating: a breakdown in connectivity may result in the most severe consequences, including multiple fatalities. This is in line with the assessment in 5GAA (2019).

W2 – Shuttle Run Barge [ASIL A]: A hazard event in this context is either a situation where the barge comes to a stop at a location where other vessels are likely to collide with it; or a situation where the vessel collides with another vessel or person on-shore. We come to the following conclusions with respect to exposure and severity:

- Low probability of a breakdown in connectivity: The connectivity in this scenario takes place via a private network operated by a single private network operator. The geographic area will be small and connectivity weaknesses could be identified. This makes for a controlled connectivity environment where it is unlikely that, even in a best-effort setting, a failure in connectivity will occur. The risk may be somewhat higher than for the L1b scenario as the area is bigger and less easy to control.
- Low probability of a hazard event following a breakdown: When connectivity fails, there are two safeguards in place to prevent the barge from encountering a hazard event. First, the vessel has an automatic fallback system that pilots the vessel to a minimal-risk position. Second, the crew on board will be able to take over and pilot the vessel to a safe situation. In addition, it should be noted that the crew is already more vigilant (or in some cases already behind the wheel) in higher risk situations such as port environments.

So, we consider that connectivity has a 'low' exposure rating.

- Medium impact of hazard event: A hazard event will seldom lead to grave physical consequences (though material impact could be significant). It is not excluded though that a fatal outcome could materialize, in particular if the vessel collides with a vulnerable water user (e.g. in smaller vessels, such as canoes).

So, we consider that connectivity has a 'medium' severity rating.

Combined with the fact that the vehicle is no longer controllable by the teleoperator in case of a breakdown, this implies an ASIL A rating: a breakdown in connectivity is unlikely to result in serious or fatal injuries.

W3/4 – A to B Barge [ASIL B]: A hazard event in this context is either a situation where the barge comes to a stop at a location where other vessels are likely to collide with it; or a situation where the vessel collides with another vessel or person on-shore. We come to the following conclusions with respect to exposure and severity:

- High probability of a breakdown in connectivity: Connectivity in these scenarios is to be provided along a stretch of waterway, potentially by multiple MNOs (and certainly in the case of cross-border transport). This makes that connectivity will be difficult to predict, control and guarantee in a best-effort setting. In addition, transports in these scenarios will cover a lot of ground encountering many diverse situations connectivity-wise. As such, it is likely that at least at some point during the transport the connectivity will break down (considering current set of mitigating measures – see section 6).
- Low probability of a hazard event following a breakdown: When connectivity fails, there are two safeguards in place to prevent the barge from encountering a hazard event. First, the vessel has an automatic fallback system that pilots the vessel to a minimal-risk position. Second, the crew on board will be able to take over and pilot the vessel to a safe situation. In addition, it should be noted that the crew is already more vigilant (or in some cases already behind the wheel) in higher risk situations such as port environments.

So, we consider that connectivity has a 'medium' exposure rating.

- Medium impact of hazard event: A hazard event will seldom lead to grave physical consequences (though material impact could be significant). It is not excluded though that a fatal outcome could materialize, in particular if the vessel collides with a vulnerable water user (e.g. in smaller vessels, such as canoes).

So, we consider that connectivity has a 'medium' severity rating.

Combined with the fact that the vehicle is no longer controllable by the teleoperator in case of a breakdown, this implies an ASIL A rating: a breakdown in connectivity is unlikely to result in serious or fatal injuries.

	Exposure	Severity	ASIL
L1a **RTG Crane**	E1 – Very Low	S3 – High	A
L1b **Terminal Tractor**	E1/E2 – (very) low	S2 – Medium	A
L2 **Shuttle Run**	E2/E3 – Low to Medium	S3 – High	B/C
L3+L4 **Highway and Cross-border**	E4 – High	S3 – High	D
W2 **Shuttle Run Barge**	E2 – Low	S2 – Medium	A
W3/4 **A to B Barge**	E3 – Medium	S2 – Medium	B