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D3.1: Business cases and initial value network

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Abstract

This document is aimed to describe and analyze the deployment of teleoperated in transport and logistics from a supply chain perspective. The document presents the results of Task 3.1 and provides a basis for the development of 5G business cases and models for teleoperated transport in cross-border operations. The document presents an overview of identified operational and organizational changes required in the supply chain to adopt teleoperation in a supply chain setting (including the roles of logistics facilities and other supporting services), an analysis of the teleoperator to vehicle ratio which is the main driver for the business case of logistics service providers and the business case calculation dashboard that allows researchers and transport companies to assess the benefits of teleoperation for a specific operation. As teleoperation in logistics has received little attention in research this research is explorative and for a better understanding additional studies are required.

Keywords:

Teleoperated driving, business model, value network, driver activities

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

EXECUTIVE SUMMARY

Connected and automated vehicles are expected to provide various benefits for transportation and logistics operations. However, there are still many challenges that need to be resolved before large-scale deployment of connected and fully automated vehicles is possible. Teleoperated transport can be an important enabler for the introduction of connected and automated transport. Teleoperation makes the move to driver-less vehicles possible, but still offers the possibility to drive and support vehicles in complex situations in which autonomous systems are not yet able to drive a vehicle safely through traffic or in traffic situations in which there is no social support. Teleoperation can also aid in resolving the truck driver shortage issue that many logistics companies face. Recent advancements in automation and telecommunication technologies offer promising solutions for technical challenges involved with deployment of teleoperated transport. Yet, there are many non-technical challenges such as operational, economical, legal and societal challenges related to teleoperated transport that remain unresolved. This study provides an overview of the requirements of teleoperated transport in logistics operations, and offers an in-dept assessment of business cases of teleoperated transport in logistics operations.

The main goal of this work package is to define and evaluate 5G-enabled CAM business cases from both a qualitative and quantitative perspective, and to provide recommendations based on business and governance models for optimal deployment. This task will propose, analyze and validate different business model configurations. Since the literature on deployment of teleoperated vehicles in logistics or large fleet operations is scares, this study adopts an explorative approach with the aim of describing the relevant economic, technological and organizational issues that need to be considered in the design, development and operation of teleoperated transport in logistics. The explorative methodology applied in this research consists of the following five steps.

1. Explorative interviews were held with experts and professionals in the field in order to identify which challenges and organizational issues are most crucial for deployment of teleoperated transport systems in logistics operations.
2. To get a better understanding of how the introduction of teleoperated driving will impact current logistics operations and to identify the impacts on business models and the business case of logistics companies, three topics were selected for more detailed analysis, namely, impacts of teleoperated driving on current driver tasks and responsibilities, allocation of these tasks and responsibilities to other stakeholders, and planning of teleoperated driving with respect to the vehicle and teleoperator allocation.
3. The insights provided by the study of the aforementioned topics lead to the development of three distinct tools; the first tool is a business case model that allows transport operators to compare the operational costs of traditional logistics company with that of a company using teleoperated vehicles; the second tool is an organizational model; and the third tool is an initial value network model.
4. The findings of the first three research steps regarding teleoperated road transport for goods were generalized for barge and passenger transport. The purpose of this step was to distinguish which findings and issues are relevant for barge and transport as well and which ones are specific to each field.
5. Conclusions were drawn based on the results of the first four steps. A summary of the conclusions is provided below.

Teleoperations in logistics are primarily interesting for the logistics industry because it allows logistics services providers to increase the productivity of drivers and trucks. Teleoperated drivers can be allocated to other trucks while trucks have come to standstill whilst they are waiting or (un)loading. Trucks can be exploited more effectively and efficiently because their deployment is not limited to the allowed driving hours of drivers that have to rest before they can continue their journey. The gain in productivity is significant in logistics operations with long waiting times, with long loading/unloading times and/or in long haul international transports.

The main benefit of teleoperation is the opportunity to deploy a driver onto another vehicle once a vehicle goes to a standstill. A group of operators can support a fleet of vehicles that is larger than the number of operators. The teleoperator-to-vehicle ratio (TO/V-ratio) gives insight into which percentage of the required traditional drivers would be sufficient to operate the fleet with teleoperators. The TO/V ratio depends heavily on the characteristics on the logistics operations (e.g., percentage of the time vehicles come to a standstill) and the service levels that have been agreed with supply chain partner.

Furthermore, the simulation of a synthetic case study with 450 vehicles showed that the TO/V ratio decreases if the number of vehicles increases. Teleoperation for companies managing larger fleets will be more cost-effective than companies operating smaller fleet. This implies that the traditional owner-operator or other SMEs operating a small number of trucks contracted by larger logistics service provides could be vulnerable if large companies start exploiting these economies of scale with new business models that focus on teleoperated driving.

Not all activities currently performed by drivers can be executed by a teleoperator. While some activities can be automated in the near future (opening and closing of doors, connecting trailers) or digitized (e.g. waybills), in other cases local presence is required to perform physical activities or physical checks on the cargo or vehicle. The contractual arrangements required for the transfer of responsibilities for safe loading and lashing of the cargo need further investigation.

Drivers are responsible for finding their ways at a logistics facility presenting their documents, receiving instructions for loading or unloading, and collecting and checking the documents for the next transport. Following the example of Waymo for organizing the control room for autonomous taxi service, the consortium suggests shifting all the non-driving tasks from the teleoperated driver to a trucking support operator who is in close contact with the various logistics facilities and support stations (for refueling and safe parking). The trucking support operator can organize the documentation and procedures at a warehouse.

Regarding barge transportation, the technology for teleoperation is already commercially available in Belgium and the Netherlands. Currently, the main barrier for deployment of commercial services is that it is not permitted by law to sail without a captain or shipper physically present on the ship. The costs and benefits of teleoperated barging is different compared to road transport because waiting and (un)loading times are different compared to road transport and also fitting the teleoperation kit to a vessel takes more effort, partly because of the diversity in ship designs and age. As there is also other crew on the ship, there is no need for transfer of tasks and responsibilities related to physical activities to other supply chain or third parties.

Teleoperation in passenger transport can be introduced for taxi and bus services. The business case for taxi services is promising since waiting for a new ride has a significant share in the taxi driver's daily activities. However, teleoperation in bus transportation in public transport does not seem to have significant benefits. Waiting times and times needed for entry and exit of passenger are generally much shorter than for road transport and taxi services.

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ABBREVIATIONS

AI	Artificial Intelligence
CACC	Cooperative Adaptive Cruise Control
CAD	Connected and Automated Driving
CAM	Connected and Automated Mobility
CAPEX	Capital Expenditure
CMR	Way bill - contract for the international carriage of goods by road
CO2	CO2 Carbon Dioxide emission
C-V2X	Cellular to vehicle to everything
DC	Distribution Center
ERP	Enterprise Resource Planning system
ETA	Estimated Time of Arrival
FIFO	First In First Out
FTL	Full Truck Load
GNSS	Global Navigation Satellite System
HD	High Definition
HMI	Human Machine Interface
INCOTERMS	International Commercial Terms
KPI	Key Performance Indicator
LSP	Logistics Service Provider
LTE	Long Term Evolution
LTL	Less than Truck Load
M(V)NO	Mobile (Virtual) Network Operator
MaaS	Mobility as a Service
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure
NSP	Network Solutions and Equipment Provider
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PRO	Private Road Operator
RA	Road Authority (incl. traffic agency)
RAN	Radio access networks
SLA	Service Level Agreement
SSP	Security Services Provider
SW/OBU	Software/On Board Unit
TMS	Transport Management System
TO	Teleoperation
TO/V	Teleoperator-to-vehicle ratio
TOC	Teleoperation control center
TOD	Teleoperated Driving
WP	Work package

1. INTRODUCTION

1.1 Teleoperated transport

Connected and automated driving is expected to revolutionize transportation and logistics by providing benefits such as safety, traffic efficiency, comfort, and reducing emissions as well as enabling novel concepts such as robo-taxis, car-sharing and truck platooning (Milakis et al., 2017). Recent advancements in vehicle and communication technologies have enabled connected and automated driving in certain controlled environments (e.g., driving on motorways under normal weather conditions). However, some challenges for enabling connected and automated driving in all driving domains and under all conditions remain unresolved.

According to (SAE International, 2018), there are six levels of vehicle automation. Driving automation systems at level-0, level-1 and level-2 provide the driver with longitudinal and lateral support (i.e. emerging braking, adaptive cruise control and lane keeping). Such technologies are available on some vehicles currently sold on the market and are rapidly becoming more commonplace. They can be classified as " hand- and/ or feet off driving". At level-3, automated driving systems monitor the environment and execute driving tasks on certain operating design domains (e.g., driving in motorways), allowing the drivers to avert their attention from driving tasks while being ready to take back control in case of a failure in the automated driving system. This level is also referred to as "eyes-off driving". Level-4 automated driving systems, also referred to as "mind-off driving", are expected to handle the fail-safe situation autonomously; however, within a limited operating design domain. Therefore, level-3 and level-4 automated driving systems can only be activiated on specific road segments and specific conditions. Finally, level 5 refers to fully autonomous vehicles with unlimited operating design domains. This last level of automation signals a major evolution in the prospect of mobility, but it is not expected in the near future (Shladover, 2016).

The analyses of automated driving system disengagements occurring during the automated vehicle tests in the United States indicate that the existing vehicles are not capable of performing all dynamic driving tasks reliably and flawlessly in all conditions, particularly in complex urban environments (Boggs et al., 2020; Dixit et al., 2016; Favarò et al., 2018; Lv et al., 2018). Some studies have proposed solutions to remedy this issue via adjusting the infrastructure and whitelisting to utilize automated driving on selected roads (Farah et al., 2018; Madadi et al., 2020), or via dedicated lanes for automated vehicles (Chen et al., 2016). However, these solutions can be costly.

Teleoperated driving (TOD) or remote-controlled driving could be complementary to automated driving (e.g., a teleoperator taking control in particularly complex driving situations) as well as a transition technology to fully automated driving (Boban et al., 2018; Neumeier et al., 2018). Modern teleoperation has been in use since the 1940's and has been applied in various fields, such as space exploration, military operations, mining, surgery and port operations (Chi et al., 2012; Lichiardopol, 2007).

In general, teleoperation (TO) refers to a system where a human being controls a robot from a distance. Any teleoperated system is defined by three main elements; the robot, the operator interface, and the communications link (Winfield, 2000). The robot, which is the vehicle in case of TOD, integrates mechanical and electronic components. Its design varies over operating environments and application domains. In TOD, the vehicle is equipped with cameras and sensors (e.g., radar and lidar) to monitor its environment, and possibly on-board processors and software to analyze and perceive the environment. The operator interface generally consists of displays to show the information gathered by the robot's sensors and input devices in order for the operator to enter commands and execute control over the robot. The communication link provides the means for a two-way communication to allow the flow of information between the robot and the operator (i.e., information gathered by the robot's sensors and the command entries by the operator). For TOD, general definitions as well as TOD system design and architecture are provided by Gnatzig et al. (2013) and Neumeier et al. (2018). Moreover, several simulation tools for teleoperated driving are developed so far (Hofbauer et al., 2020; Neumeier et al., 2019a). Yet in order to have a fully operational TOD system, there are technical challenges with respect to each of the three aforementioned teleoperation elements that need to be addressed.

With regard to the vehicle, the main technical challenge is acquiring precise information about the environment via sensors along with software to analyze this information and actuators to execute control commands. It is shown in (Neumeier and Facchi, 2019) that these requirements can be met using current state-of-the-art technologies. Moreover, most of these elements are used in automated driving systems as well (Zhu et al., 2017). In theory, the vehicles being teleoperated can be of any automation level, with the condition that that a vehicle needs to be designed as drive-by-wire vehicle. Level-0 to level-2 automated vehicles require constant monitoring and control by the teleoperator while level-3 and level-4 vehicles may operate independently on certain operating design domains and request assistance from the teleoperator outside their operating design domain (Goodall, 2020). The focus of this project is on teleoperation of level-0 to level-2 vehicles, which require constant monitoring and control by the teleoperator while driving.

The operator interface presents challenges such as video quality, immersion and situation awareness for the operator (Neumeier et al., 2020). Several solutions based on virtual and augmented reality have been suggested to mitigate these issues (Chucholowski, 2016; Georg et al., 2018; Hosseini and Lienkamp, 2016). However, these solutions are not mature and operational yet.

The communication link is perhaps the most challenging of all TOD system components. Cellular networks appear to be the most promising alternatives so far, yet the level of bandwidth and latency that the existing 4G LTE and LTE+ networks offer along with issues such as reliability and packet loss associated with them make it difficult to consider them viable communication links in teleoperated driving (Davis et al., 2010; Neumeier et al., 2019b, 2019c). Mid-band and high-band 5G networks are expected to overcome these difficulties when they become broadly available, yet the coverage, particularly for high-band 5G networks might remain an issue in the near future (Sauter, 2017). Latency and reliability challenges can already be addressed with low band 5G.

Other solutions such as whitelisting via a "free corridor" and path planning have been suggested in the literature to enable teleoperated driving within restricted domains (Hosseini et al., 2014; Neumeier et al., 2019b; Tang et al., 2014). These approaches are in line with the whitelisting approach suggested in (Madadi et al., 2020), which presents automated driving subnetworks as a safe operating domain for automated vehicles. Such subnetworks can be deployed for teleoperated driving as well. However, these are transitional options to enable the technologies on limited domains before they reach full maturity. More permanent solutions are required to enable flawless and reliable teleoperated mobility.

Safety and security of TOD systems are implicitly mentioned above; however, some factors should be explicitly mentioned. Continuous and reliable connectivity between the vehicle and the teleoperator is of paramount importance for obvious safety reasons. Moreover, the teleoperator must be trained properly to avoid making errors while driving. Yet according to the experts, in exceptional cases, a temporary loss of connectivity or teleoperator errors might occur. Therefore, collision avoidance systems and standard minimum risk maneuvers are necessary in order for the vehicle to be able to resolve these situations. Cyber security of the connection is another indispensable requirement for safe operation of TOD systems, which needs to be guaranteed.

Teleoperated driving is expected to have major implications for logistics and fleet operations as well. It is suggested in (D'Orey et al., 2016) that teleoperated taxi fleets could revolutionize urban mobility by offering a cost-effective and safe door-to-door transportation service. The authors use an empirical evaluation to conclude that the implementation of the service can reduce the number of drivers by up to 27%. The operational performance of fleets of teleoperated vehicles is explored by Goodall (2020). The authors assumed that a team of teleoperators would be responsible for monitoring a large fleet of automated vehicles and would take control of the vehicle upon request by the vehicles' automated driving system. Such concepts are relevant when the teleoperated vehicles are level-4 automated vehicles. Hjelt (2021) studied the total cost of ownership of autonomously operated buses at autonomy level 4 and 5 supported by remote operators. Teleoperation could also tackle the critical first and last mile in passenger car and truck platooning, hence would significantly enhance chances for bringing this to reality (Bhoopalam et al., 2018; Boban et al., 2018), which can significantly reduce logistics or fleet operations costs and environmental impacts.

The adoption of teleoperated driving could also help in tackling growing operator shortages in the logistics industry. When it comes to truck drivers, demand in the Netherlands and Belgium is growing steadily while the supply is lagging due to poor labor conditions, long working hours and long periods away from home. This has led to persistent shortages of truck drivers (International Transport Forum, 2017; STL, 2019; VDAB, 2019). Teleoperation has the potential to solve these problems by transforming truck drivers to teleoperators, thereby eliminating the need for difficult working conditions and working away from home.

1.2 Goal of 5G Blueprint

The overall objective of the 5G-Blueprint project is to design and validate a technical architecture, business and governance models for uninterrupted cross-border teleoperated transport based on 5G connectivity. The project's outcome should be usable as the blueprint for subsequent operational pan-European deployment of teleoperated transport solutions in the logistics sector and beyond.

To achieve this, the 5G-Blueprint will explore and define:

- The economics of 5G tools in cross border transport & logistics as well as passenger transport: bringing CAPEX (capital expenditure) and OPEX (operational expenditure) into view, both on the supply (telecom) side and the demand (transport & logistics) side for the transformation of current business practices as well as new value propositions
- The Governance issues and solutions pertaining to responsibilities and accountability within the value chain dependent on cross border connectivity and seamless services relating to the Dutch & Belgian regulatory framework (telecommunications, traffic and CAM

(Connected and Automated Mobility) experimentation laws, contracts, value chain management)
- Tactical and operational (pre-) conditions that need to be in place to get the full value of 5G tooled transport & logistics. This includes implementing use cases that increase cooperative awareness to guarantee safe and responsible teleoperated transport

1.3 Focus of task WP3.1: Business cases and initial value network

The goal of work package 3 is to define and evaluate 5G-enabled CAM business cases from both a qualitative and quantitative perspective, and to provide recommendations based on business and governance models for optimal deployment. This task will propose, analyze and validate different business model configurations. Business models should answer questions related to the control and distribution of the assets and the rents within the ecosystem, the interoperability of different vendor solutions, the distribution of computing power and data, the value proposition offered to prospective customers, and the revenue models associated with each model. The business model analysis should also address specific challenges involved in the studied settings: for instance, cross-border CAM services along the Flemish-Dutch corridor will require the involvement of multiple mobile network operators, raising the issue of seamless cross-border roaming obligations and agreements.

Task 3.1 focuses on the exploration of business cases and organizational changes from the end user perspective: logistics, or more generally, fleet operators. Therefore, the aim of this task is to define the general requirements of teleoperation in logistics, and to translate them to specifications for business cases. The identification of organizational requirements and challenges will focus on the required changes to the way logistics operators currently operate and identify solutions to accommodate and reallocate tasks that cannot be performed by teleoperators. Furthermore, this task will define an initial value network, based on the logistics use case, and investigate the main cross-border coordination challenges and requirements envisioned. In Task 3.1 we focus on teleoperation with autonomy levels 0 to 2, which mean that a teleoperator operators as a driver and is always operating a single vehicle.

1.4 Structure of the document

This report is structured as follows. Chapter 2 presents the general methodology used in this study; Chapter 3 defines requirements for teleoperation in logistics; Chapter 4 discusses organizational changes and requirements; Chapter 5 elaborates on teleoperated transport planning; Chapter 6 includes the business case analysis for teleoperated road transport; Chapter 7 presents a value network analysis; Chapter 8 is dedicated to discussion and generalization of the results; and finally, Chapter 9 concludes the report.

2. METHODOLOGY

2.1 Approach

The literature on deployment of teleoperated vehicles in logistics or large fleet operations is scarce. Therefore, we adopt an explorative approach in this project with the aim to describe the relevant economic, technological and organizational issues that need to be considered in the design, development and operation of teleoperated transport in logistics.

The explorative methodology applied in this research consists of 5 steps:

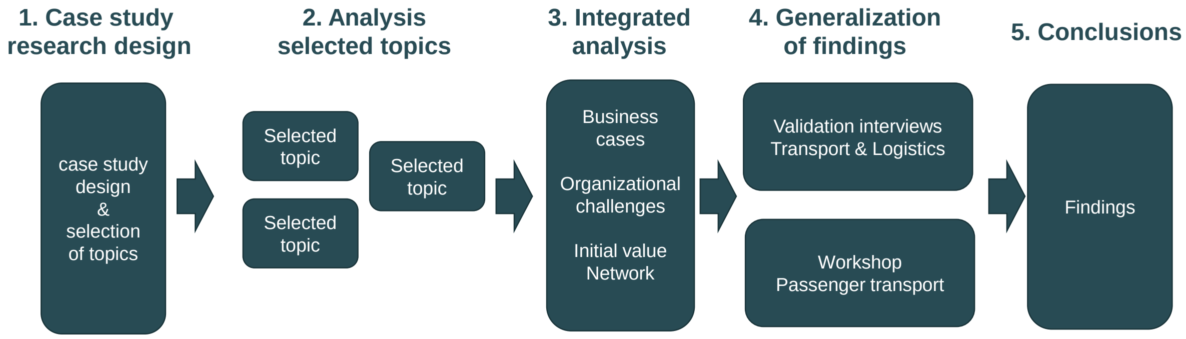

Figure 1 Methodology of task 3.1

1. **Case study research design & selection of topics**
   To identify which economic, technological and organizational issues need to be considered and which of these topics are most crucial for the development of business cases and organizational requirements in the 5G Blueprint project, explorative interviews were held with all the use case owners of WP4 Teleoperated transport and the leaders of WP6 Enabling functions. A total of 9 interviews were conducted. The reports of the interviews were validated by the respondents. The overview of the requirements for teleoperated transport is presented in Chapter 3. Based on this overview, three topics were selected for further analysis (see step 2).

2. **Analysis of selected topics**
   To get a better understanding of how the introduction of teleoperated driving will impact current logistics operations and to identify the impact on business models and the business case of logistics companies, three topics were selected for more detailed analysis:
   a. Impact of TOD on current driver tasks & responsibilities. Teleoperated transport can take care of the driving activities, but there are still other tasks and responsibilities of the driver that need to be executed. To explore what tasks and responsibilities drivers have, interviews were conducted with three transport operators.
   b. Allocation of tasks & responsibilities to the teleoperation center and other stakeholders. In this topic three issues are explored: (1) Which tasks and responsibilities still need human support in the near future and which can be automated? (2) If a task requires human support, which tasks can be performed by the teleoperated center and which require local presence? And finally: (3) If tasks are allocated to the teleoperation center, how can tasks be best fulfilled? Answering these questions provides a first insight into the value network that is required to deploy a complete teleoperated driving scenario.

c. Planning of TOD with respect to the vehicles. An important factor in the business case of teleoperated driving is the extent in which the teleoperation center is capable of reallocating drivers from vehicles that are waiting, loading or unloading to vehicles that are waiting to be driven. The number of drivers required for a given fleet of vehicles depends heavily on the characteristics of the operation: occurrence of waiting times, duration of loading and unloading, etc. To explore the impact of the characteristics of logistics operation we studied the logistics operations of three transport companies in containers, bulk and tank transportation.

3. **Integrated analysis**
   The insights from the three selected topics are combined into two tools.
   a. Business case model that allows transport operators to compare the logistics costs (CAPEX and OPEX) of a traditional transport operation with the teleoperated operation.
   b. Initial value network model. The initial value network is based on the discussion in the 5G Blueprint consortium and existing literature.

4. **Generalization of findings**
   The main focus of the analysis performed was on road transport. In the generalization of the findings, we consulted experts form the barge transport and passenger transport to identify which findings could apply to these fleet operations as well and which issues would be typical for these respective operations and are still missing in the findings based on the analysis of road transport.

5. **Conclusions**
   Finally, conclusions are drawn from the empirical data collected and analyzed in this project.

2.2 Scope

The task 3.1 provides insight into a number of business cases underpinning required investments and the development of 5G infrastructure and services for teleoperated transport. This means we do not provide the answers to all questions related to teleoperation of fleets of vehicles or barges. The scope of the research is as follows

- The primary focus of the research is on logistics operations in road transport. In terms of the number of vehicles that is operated and requires adequate 5G-connectity, this market is larger than other fleet operations (barges and public transport, taxi and coach services) in a cross-border region. An initial view on the impacts and benefits for barge and passenger transport is provided by a generalization of the findings of the road transport sector.

- The logistics sector is characterized by the wide variety of logistics flows and, subsequently, a wide range of specific logistics services to transport these goods. While teleoperated driving in the road itself does not make a real difference when comparing logistics flows and operations, the operation at loading and unloading locations will have influence on the complexity and business case of teleoperation. In this project, we focus on Full Truck Load (FTL) operations between logistics centers as a first operational environment for teleoperation. In general, there is sufficient space at logistics centers to park and maneuver vehicles, there are few vulnerable road users to consider in case of maneuvering and parking, there are facilities for loading and unloading (personnel and equipment), and the complexity of loading, unloading and the correct partial loads is not an issue. Examples of FTL transport are container transport, bulk and (liquid) tank transport.

- The focus of Task 3.1 is to provide an overview of and insight into the operational environment for teleoperated transport. This means that it provides insight into a number of important issues that need to be considered to deploy teleoperated transport in logistics (see selected topics). The research does not provide specific solutions for the various issues that need to be resolved. The contribution of Task 3.1 consists of identifying the issues to be integrated in the 5G Blueprint roadmap.

3. REQUIREMENTS OF TELEOPERATION IN LOGISTICS

Teleoperation is the ability to operate any vehicle from any place in the world based on data picked up by a sensor kit placed on those vehicles. Apart from camera images, board computer, radar and lidar, sensors will allow real-time access to all relevant dynamic features required for the Operator to truly see and judge the actual driving environment presented on the TO dashboard, enabling precise steering of the vehicle from a teleoperation center. 5G connection is deemed necessary for transmitting such large amounts of data in real-time. Under the 5G Blueprint project, an initial assessment of the prerequisites for teleoperation provided a clear insight regarding the upcoming challenges.

3.1 Safety requirements

Although a 5G connection is expected to provide the stability and coverage that 4G cannot, a basic of level of safety will have to be guaranteed. Overall understanding is that this will require a certain amount of autonomy of the teleoperated vehicle by enabling it to brake, stop and/or pull over safely in case of emergency such as immediate risk of collision or loss of connection to the teleoperator. There is some contradiction to this requirement as we should assume that 5G will be stable enough to support a real-time connection at all times and that a teleoperator will always be monitoring when the vehicle is moving and therefore the vehicle should not be required to have to brake or pull-over autonomously. In the next subparagraphs we preset a few reasons why this could be reconsidered.

3.1.1 Public mindset

Bringing driverless vehicles onto the road will demand a significant change of public mindset. Regular drivers will no longer be able to make eye contact and assess if they were spotted by the teleoperator. A zero tolerance for accidents will need to be adopted to ensure that the public will feel safe to share the road with a teleoperated vehicle. This means that a vehicle will always need to guarantee to be able to stop in case of collision risk with other road users, be it with or without control of a teleoperator.

3.1.2 (Human) errors

Errors can always occur. A teleoperator could miss an alert or object provided on the dashboard, misread the movements of another vehicle, push the wrong button or pedal or respond too late. Technical issues could always occur, sensors could malfunction, cameras could break leaving the teleoperator without a full view of the situation.

3.1.3 Minimum Risk Manoeuvres

By implementing teleoperation additional layers are added to the human – machine interaction. Imagine a cyclist coming up around the corner and crossing the street: normally the driver will see the cyclist, process the information and take appropriate action by braking. Now in case of teleoperation, the vehicle will detect the cyclist by use of its sensors and transmit the data to the teleoperator. The teleoperator needs to process the alert and take appropriate action by pushing the brake. The command is sent back to the vehicle which then brakes. Obviously, due to a semi-real time connection, the communication delay will be a few extra milliseconds on top of the human response time (200ms), but this could still make the difference. The opportunity here is to take the human action out of the equation and thereby introducing a new process. The cyclist would be spotted by the vehicle's sensors and the will immediately adapt its speed, hereby decreasing the braking distance with a few potentially lifesaving meters. In the end, this would mean that teleoperation would not be a risk to road safety but rather enable a safety level increase.

3.2 Technical requirements

The technical requirements are quite straightforward. As teleoperation will be fully supported by data communication, one needs to ensure that on the one hand the necessary data is captured and on the other hand, it can move back and forth between the vehicle and the teleoperator. The incoming data to the teleoperator includes images and precise location data and the outgoing data includes the control commands (e.g., steering and acceleration). Taking a closer look at the first factor, data will be collected by the vehicle's lidar and radar sensors, cameras and board computer. Only by use of this data, will a teleoperator be able to get enough information and images to be able to drive the vehicle from a distance. If the equipment fails, it is no longer safe to keep the vehicle on the road and it should stop or pull over, either by control of the teleoperator or autonomously depending on the situation. The question remains what should happen if neither the vehicle itself nor the teleoperator are able to conduct a safe stop due to breakdown of key equipment. Can a failsafe protocol be developed that covers all possible scenarios?

The second factor connects to the coverage and ultra-low latency bandwith that need to be ensured. Development of teleoperation technology is moving forth based on the assumption that 5G will offer increased network stability, sufficient network coverage even in remote areas, low latency with semi-real time connection and high bandwidth to transmit a vast amount of high-quality data simultaneously, even in cross border situations. It is still to be validated if this is a feasible expectation. Already doubts have been expressed regarding the possibilities for upscaling, will the connection remain strong enough even if thousands of teleoperated trucks, vessels and other vehicles are relying on 5G? Will it be possible to guarantee network coverage at remote locations and cross border? If mid band or high band 5G is required for TOD, densification of the network (i.e. a large number of smaller antennas) is required to uphold connection, which leads to a whole new list of questions regarding investment, location, maintenance, liability and last but not least the service fee for end-users.

3.3 Operational requirements

When it comes to daily operations of a teleoperated logistic company there are various processes that will require a significant change. We will highlight the most important ones. They can be split in three categories: shift of driver responsibilities, teleoperated transport planning and supply chain restructuring.

3.3.1 Re-allocation of driver responsibilities

Teleoperated vehicles will change the way of working not only for drivers, but for everyone who in one way or another is interacting with the vehicle and/or it's driver. To understand the operational and organizational requirements, a basic understanding of the role of a driver is needed. In logistics, a driver is not only responsible for driving the truck from a to b, but there are additional activities that fall under their remit. First, they are responsible for their truck and trailer, checking if all wires and hydraulic lines are connected, if the tires are safe, if the lights are working, they couple and decouple trailers and make sure both are connected properly.

They need to ensure that the cargo is secure, undamaged and in line with documentation, some drivers even handle their own loading and unloading, depending on the product or location. While doing so, they interact with several operators at the loading site. Starting at check-in where identification and transport documentation is checked and where they are guided to the proper loading dock or bridge. Then, depending on the load and location, with the operators on site that are assisting with loading/unloading before heading back to check-out for a CMR and potential other documentation depending on the cargo destination. On route, a driver fuels the truck when needed, ensures the truck is locked and cargo sealed before moving on.

For all these activities a solution will need to be found, preferably by digitization and robotization, which could work for the document flow and identification at check-in and check-out and for loading and unloading containers, but for some activities a solution will need to be found in the hands of other humans. A warehouse operator could load a truck and perform all aforementioned checks, but this would imply a shift in liability and cost from the carrier to the warehouse. Fueling stations could hire extra people for fueling, but this would require a different way of payment and will lead to increase of fuel prices. It goes without saying that agreement with all involved parties needs to be established before teleoperation can become a new mode of transport.

3.3.2 Teleoperated transport setup

As a first phase in teleoperation, a teleoperator will be controlling the vehicle at all times once control is taken. When the vehicle is at a stand-still, for example when waiting for or during loading, the teleoperator can move on to the next vehicle in need of control. From this perspective, we assume that a teleoperator will only take over control while standing still. However, it should also be possible to hand-over from one teleoperator to another whilst driving for example during a teleoperator break or shift change, or in case of platooning, when leaving the platoon.

Proper service level agreements will have to be established with regards to take-over by the teleoperator. Warehouses would not appreciate that a vehicle keeps occupying a loading dock unnecessarily while waiting for a teleoperator to log-on. For long trajectories, a 24-hour service would be required to keep the vehicle in motion even at nighttime. This would not be a prerequisite as such, as the vehicle could be parked at a nearby truck parking waiting until the morning teleoperator shift logs-on again, but advisable as this would mean that both load and truck would be left unmonitored and capital use would be decreased.

To comply to these requirements, a centralized teleoperation control center would be the recommended business model. Having a large pool of teleoperators that can carry out different shifts and that can support each other during breaks or in case of emergency, will provide the best service level possible.

3.3.3 Possibilities for supply chain restructuring

On the shipping and receiving side of teleoperated transport, teleoperation will provide a vast opportunity to save time, money and resources by a supply chain restructuring. We already touched upon the topic of communication under point A. but that is only the beginning. Firstly, due to 24-hour transportation, inbound and outbound flows can be spread over the day, decreasing peak hours at the beginning and the end of the day. The entire cycle from shipper to customer will be shortened as driver resting hours are no longer required. Advanced digitization of transport will allow shippers and receivers to prepare for the incoming vehicle, hereby moving away from the firefighting mode and gaining more control. Crossdocking could become the norm herewith decreasing the need for storage space. Production flows can be adjusted to the time the goods are expected and preparation for the outbound flow can already be started in advance by calling upon a teleoperated vehicle to be ready for loading at the end of the production line. In short, teleoperation is considered to be the next step on the path to industry 4.0

3.4 Economic requirements

One of the goals of the 5G Blueprint consortium is to validate the cost benefit structure behind the concept of teleoperation. In that regard, the following elements were identified.

3.4.1 Teleoperation center

The teleoperator will become a new key role to be implemented in supply chains. The role of the driver will disappear and will basically be replaced by an office job. Considering that the teleoperator will be required to monitor multiple screens and will receive a vast amount of visual, audial and perhaps even sensory information, the role is expected to become quite challenging, thereby requiring a different set of skills and different types of employees. A better understanding of the required education and day to day activities will be necessary, before determining the appropriate teleoperator salary. The question at hand is if the cost for a teleoperator desk job with increased complexity will be lower or higher than that of a driver whose job might be less complex, but who needs to be paid travel expenses, overtime and overnight allowance.

Moreover, if we want to estimate the full cost of human capital, a further understanding of the teleoperation center would be required. The consortium partners agreed that the crucial factor within teleoperation will be the amount of idle time that a chauffeur spends waiting in line at the check-in desk, waiting for and during loading and mandatory resting hours. It would be that idle time that will be used efficiently by a teleoperator by virtually jumping on to the next vehicle. Calculation of the amount of idle time and how it is spread over the day, will allow an estimation on the number of jumps that can be made and hence, how many teleoperators will be required to command a certain fleet.

The final element would be the cost for setting up the teleoperation center. This center could be set-up within the transportation company; hence the transportation company would hire their own teleoperators or to re-educate their drivers to become a teleoperator. Or a company could choose to contract an external centralized teleoperation center to control their fleet (teleoperation as a service). Where drivers were living in the comfort of their cabins, they will now need an office space including a teleoperation control room with all necessary equipment, like computer screens, speakers, a virtual reality headset and chair and an excellent connectivity to 5G network. Another option could be to provide employees with teleoperation set-ups for home offices or decentralized locations.

3.4.2 Third party activities

As described above, some driver activities cannot be carried out by a teleoperator or the vehicle and would need to find a new home within the supply chain. This will lead to a cost shift that should not be neglected and thoroughly discussed with the involved parties.

3.4.3 Vehicle investment

Manufacturing companies will play a big part in the future of teleoperation. It is only with their support that it can become accessible to the logistics sector, either by offering teleoperation kits that are compatible with legacy trucks or by developing new vehicles with built in cameras and sensors, but perhaps without a driver's cabin. The development cost of these products, taking into account the technical, safety and legal requirements will dictate the required investment by potential end-users.

3.4.4 Infrastructure investment

Depending on the set-up for a certain supply chain, it might be required to make adjustments to current physical infrastructure of loading locations, like a camera for container ID registration, a license plate scanner or a dock camera to check the loading process. Depending on the level of digitization, some companies might even need to invest in a new warehouse management system to facilitate electronic documentation and communication. Even on the public roads, investment might be required, not only to maintain a 5G connectivity at all times, but to guarantee public safety by implementing smart roadside units for example. Most partners assume that teleoperation should be developed to fit in the current infrastructure, but seen the difference between companies and countries, it would be wise to take this into consideration.

3.5 Legal requirements

When all aforementioned requirements can be fulfilled, what remains before being able to bring teleoperation to the market, is the creation of a clear legal framework. Firstly, *safety requirements* like the vehicle being able to brake and/or stop of its own accord and an emergency procedure that stipulates how the vehicle should be guided to a safe location by local tow services. Secondly, when the safety requirements are defined, the *technical requirements* of the vehicle and the teleoperation kit of sensors and cameras, including maintenance and authorization conditions can be stipulated. Third, *liability regulations* related to cross border emergencies. For example, if the teleoperator is located in the Netherlands, but the vehicle is driving to Spain for a German company and has to pull an emergency stop due to 5G connectivity loss in Austria. Which parties will carry which responsibility in this case? How are insurance companies to handle these situations and what basic coverage should they provide? Next, the *job requirements* of a teleoperator should be defined. Teleoperator - driver lessons and exams should be developed as well as a license. What will be the requirements? Should a driver have a certain level of experience on the road, or could they start straight from school? What will be the working conditions, what is an appropriate salary, how much rest will be required and how long will a teleoperator be able to work safely behind a screen. Lastly, the *operational requirements* will have to be redefined, for example responsibility for loading/unloading, coupling/decoupling, digitization of data and travel documents, identification, and so on and so forth.

3.6 Impact for logistics industry

The purpose of this report to develop the business case for teleoperated driving. For that reason, we will not consider all factors discussed in this chapter but rather zoom in on the operational aspects that will determine the business case for the logistics industry: the re-allocation of driver responsibilities and teleoperated transport planning.

4. ORGANIZATIONAL CHANGES AND REQUIREMENTS

4.1 Responsibilities of the traditional truck driver

Depending on the cargo type the truck driver has several other responsibilities apart from driving From interviews with logistics parties, both internal as well as external to the 5G Blueprint consortium, these have been identified and are visualized in the figure below.

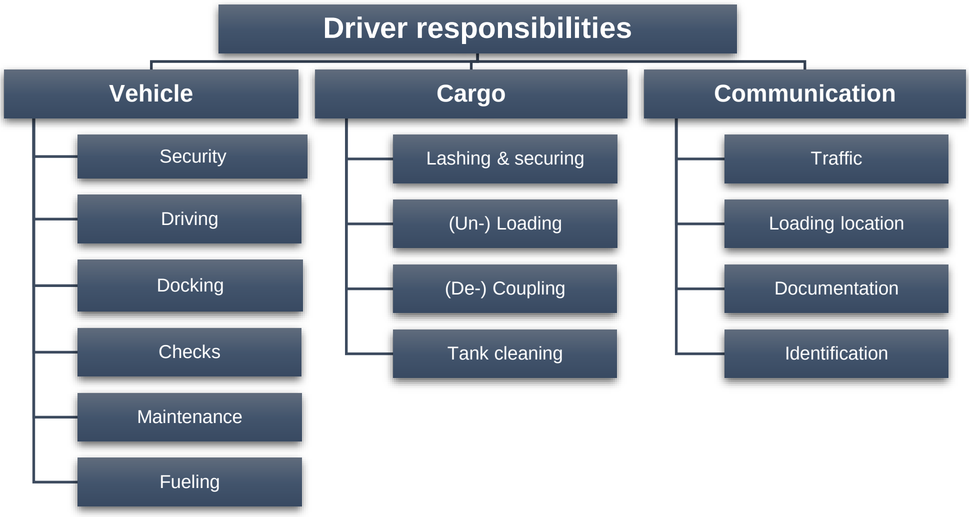

Figure 2 Driver responsibilities

Driver activities can be grouped under three categories of responsibility: vehicle, cargo and communication.

4.1.1 Responsibility for the vehicle

Security - The driver is required to lock truck and trailer when leaving it in a parking lot or fuel station for example. When they are spending the night in their truck, they can use the night lock that closes the truck from within.

Driving – Truck drivers are responsible for bringing the vehicle and its cargo safely from A to B. On the road they are in control of the vehicle and make decisions in relation to speed, steering, positioning and maneuvering. They assess on route situations based on their senses and experience and make their decisions accordingly.

Docking – When docking is required, the driver will open the doors before backing up the vehicle onto the dock. After the loading or unloading of the cargo they close the doors again after moving a couple feet from the dock before moving on to the next destination.

Checks – Truck drivers are responsible for carrying out daily checks on truck and trailer. DAF recommends the following daily checks on their website ("Daf," 2021):

- Truck: Lighting, system alerts (dashboard); fluid levels of fuel, motor oil and windshield washer, air filter indicator, tire profile, tire pressure and wheel mounting.
- Trailer: Fifth wheel mounting; proper connection and working of lighting and brakes; tire profile and tire pressure

Maintenance – Truck drivers handle some smaller maintenance tasks they encounter on the road. They can charge a battery, inflate a tire, change a tire, add fluids when required, replace the windshield wiper blades, replace a light. Last but not least, they keep the truck clean inside and out.

Fueling – The truck driver is responsible for fueling or, possible in the future, charging the battery. This requires the driver to get out of the vehicle connect the truck to the fueling/charging installation and ensure payment at the local fueling/charging station.

4.1.2 Responsibility for the cargo

Lashing & Securing – The truck driver is responsible for safe transportation of the cargo. Depending on the type of cargo and trailer, this can entail different options (EU, 2021).

- Palletized or loose cargo like boxes or bags, need to be secured by use of e.g. antislip mats, air cushions, lashing or cordstraps. After securing the cargo, the driver needs to ensure that cargo is properly locked off by closing the container doors and/or strapping the sails.
- In case of customs requirements, the driver is responsible for sealing the load and will only break it upon arrival after approval of a local operator.
- Container transport has different requirements in accordance with CTU code. Depending on the container type and product, the container is to be lashed or it's anchors are to be locked by use of twistlocks. The driver is responsible for an visual exterior check of the container to see if it is fit for transport and check if the doors are properly closed (CTU, 2021).
- (ISO) Tank transport – The driver ensures that all openings are closed off/sealed thoroughly, they check if all hydraulic lines are decoupled and closed and they perform a visual check of the tank to see if it is fit for transport (evofenedex, 2021).

Loading and unloading – Depending on the cargo type and agreements with the customer, the driver can be responsible for their own loading and unloading.

- Palletized or loose cargo trucks will often be equipped by a forklift or pallet truck to load and unload the cargo at the destination. When loading, the truck driver should take into account the weight distribution over the truck axles and check if the goods are undamaged. The truck driver is responsible for unloading the correct cargo and quantity when delivering less than full truck loads (LTL)
- Containers are mostly loaded with a crane, reach stacker or other Container Handling Equipment (CHE) by a local operator however, in some scenario's, the driver operates the reach stacker as well.
- (ISO) tanks can be loaded or unloaded by the driver or a local operator. In the first scenario, the driver connects the hydraulic lines to the tank after which they control the pump to initiate the loading/unloading process. If the local operator is responsible for loading/unloading, the driver will still need to control the pump as this is a functionality of the vehicle itself.
- If weighing of the cargo is required, the driver will pass the weighing bridge. Depending on the level of automation at the weighing bridge they will either have to register at the local operator with shipping documentation or they are registered automatically.
- In case of temperature-controlled cargo, the driver is required to set the temperature of the trailer correctly.

Coupling and decoupling trailer – The driver is responsible for coupling and decoupling of the trailer, which can be an automated process in case of terminal tractors and MAFIs but for regular trucks and semi-trailer this requires manual handling including backing the truck up under the trailer, doing a visual check of correct connection of the fifth wheel, connecting the hydraulic lines and raising the trailer legs from the ground.

Cleaning – Depending on the product type and agreement with the customer, the (ISO) container, reefer or tank might require cleaning after unloading (CTU, 2021). This could be either a regular sweeping by the driver, or the driver should pass a cleaning station before the next loading. In this case, a cleaning appointment is booked in advance so apart from announcing the truck, the driver will leave the truck at the facility and wait until it is cleaned. A paper cleaning certificate is provided to the driver or is sent digitally to the carrier along with the invoice.

4.1.3 Responsibility for communication

Traffic – When driving the driver is responsible for communication with other traffic participants by signaling lights, hand gestures, nodding or eye contact. If needed they can also use audible signals such as sounding the horn or using their voice. When the truck is malfunctioning and parked at the side of the road, they will place the warning triangle and can communicate with road assistance. The communication is reciprocal, the driver sees signaling lights from other vehicles, can see if the pedestrian spotted them by making eye contact and can hear an approaching ambulance for example.

Loading location – When the driver encounters delays on the road he might inform the carrier, the loading location or adjust his timeslot manually, depending on the agreements made and level of automation/digitization at the loading location.

Upon arrival at the loading site, terminal or warehouse the driver interacts with administration (see below) during check-in and check-out processes and when loading/unloading with operators at the loading dock, with forklift drivers, reach stackers or crane operators. From the gate to the dock, they come across pedestrians or cyclists, who direct them towards the assigned dock.

Documentation – Depending on the location, customer requirements and destination of the cargo, the driver will have to carry a documentation package. Below figure is a snapshot from the report ‘Towards paperless transport within the EU and across its borders’ by the digital transport and logistics forum (DTLF), which analyses the current documentation requirements and possibilities for digitalization (DTLF, 2021).

Table 1 Overview of required road transport documentation

Goods	CMR/e-CMR ADR transport document Notification document for transboundary movements/shipments of waste Transport document live animals
Transport means	Vehicle registration certificate Roadworthiness certificate (PTI) Community License EC Certificate of Conformity Certificate for approval (ADR) Certificate for livestock – animal transport
Personnel/Operations	Driver's license Tachograph drive card Driver certificate of professional competence (CPC), Niche specific certificates: - crane operations, - dangerous goods ADR, - transport of live animals European Health Insurance Card.

The CMR is provided by the shipper or the carrier or is written manually by the driver. In case of container transport, the carrier is also required to provide a CIR/EIR document to the shipper. Other shipping and, in case of export, customs documentation is picked up by the driver when checking out at the loading site. In case of container transport, additional certificates regarding cleaning and weighing are provided to the driver by the station itself. For some cases these packages are already (partially) digitized, e.g., when parties have agreed to use an e-CMR.

Identification – There are many different identification procedures depending on the location at hand. Sometimes the driver is required to physically report to the check-in desk and show identification, drivers' license and license plate card along with the shipping documentation. At other locations the identification procedure is fully automated with license plate recognition and use of the Cargo Card with fingerprint scanner.

4.2 Responsibilities of the teleoperation center

With teleoperation many traditional driver activities will become obsolete as they are simply not suitable to be executed without physical presence. However, this does not entail that these activities are no longer required. To the contrary, these activities will determine the new roles and responsibilities in supply chain processes. Some will need to be covered by digitization and automation, some will need to be covered by audible and visual signals on the vehicle and some will have to be handled by local operators.

The teleoperated road transport process map (Appendix F) provides us with the view of the consortium partners on how teleoperated road transport could be established. If we take a look at the role of the teleoperator, we can conclude that apart from the actual driving, there are no traditional driver activities that the teleoperator would handle. For this reason, the consortium parties concluded that traditional truck drivers would be perfectly capable of becoming a teleoperated truck driver and that a salary increase would not be required since their responsibilities would be limited to driving the truck from a to b. Moreover, expectation is that the required job level of a teleoperated truck driver will decrease due to the diminished complexity of the job.

On the other hand, a new type of role is expected to be created in the form of a teleoperated trucking support operator who is responsible for activities that require interaction with local operations, traffic participants and fueling/charging stations. Although the process for these types of interactions is not specified in the teleoperated road transport process map, we assume that it will be hybrid solutions where manual handlings and audiovisual signals establish a communication between the teleoperated trucking support operator and local individuals.

We will provide an example of these hybrid solutions for two standard driver responsibilities, docking and fueling. As there are many different levels of digitization within the logistics industry, the below communication schemes require no digitization from the local companies.[1] We start after the teleoperated driver has parked the vehicle in accordance with the alleged process.

Table 2 Possible docking communication structure

Sender	Message	Interaction	Receiver
TO Driver	Visual signal for opening doors	Visual	Local operator
Local operator	Open door and press button on vehicle when finished	Manual	TO Driver
TO Driver	Request for docking	Digital	Trucking support operator
Trucking support operator	Ready for docking	Digital	TO Driver
TO Driver	Signal for docking	Visual	Local operator
Local operator	Moves away to safe location	Manual	TO Driver
TO Driver	Provides all clear for docking	Digital	Trucking support operator
Trucking support operator	Execute docking	Digital	TO Driver
TO Driver	Docked	Digital	Trucking support operator
Trucking support operator	All clear for loading	Digital	TO Driver
TO Driver	Signal all clear for loading	Visual	Local operator

[1] Although a training, instruction or manual in advance would be a minimum requirement.

Table 3 Possible fueling communication process

Sender	Message	Interaction	Receiver
TO Driver	Request assistance for fueling	Digital	Trucking support operator
Trucking support operator	Turns on truck screen and requests fueling (e.g., use audio signal if needed)	Audio-visual	Local employee
Local employee	Requests payment method	Audio-visual	Trucking support operator
Trucking support operator	Provides payment method (e.g., credit card, barcode scan for automated invoicing, payment request)	Audio-visual	Local employee
Local employee	Starts fueling	Manual	Vehicle
Vehicle	Indicates when full	Manual	Local employee
Local employee	All clear for departure	Audio-visual	Trucking support operator

Due to the complexity of these activities and the short cycle times, it is preferred to assign this type of tasks to a trucking support operator who can rapidly switch between trucks and situations and who is familiar with the processes and systems in place. Ideally teleoperated truck drivers would move into this position once they have gained a certain level of experience and are comfortable with the teleoperated driving system and the underlying processes and tasks. The additional responsibility that comes along with these interactions is expected to demand a higher job level than that of a traditional truck driver.

Zooming out to the teleoperation center this means that there will be a pool of ‘regular’ teleoperated truck drivers and a pool of ‘specialist’ trucking support operators who all need a real-time connection to the teleoperated vehicle and the control system. This operational model is visualized in Figure 3. It shows that during a standard trip, a teleoperator will be able to control and drive the vehicle without any need for direct interaction with local personnel. Any interaction that is required will be indirectly via the vehicle and the control system. However, should a teleoperator enter a situation where interaction is required, such as loading/unloading checks, docking, fueling, accidents or police checks, they would park the vehicle, log off and request support by a teleoperated trucking support operator. A trucking support operator will be able to turn on audio(-visual) on the vehicle, allowing direct contact with local personnel regarding the task at hand.

As explained earlier, these tasks and the related liability clauses should be defined by law. Once the basics are laid down, the involved parties should agree upon the specific process steps to be taken. Apart from escalations by a teleoperator, a teleoperated trucking support operator would also be responsible for handling direct appeals from the vehicle, for instance when there is no connection to a teleoperator or when the request for take-over has been pending for a certain amount of time. Simultaneously they could take immediate assistance calls from local personnel via the vehicle, phone or otherwise, for example when road assistance has arrived at the site or when a terminal operator needs approval after checking the seal before docking (Appendix A).

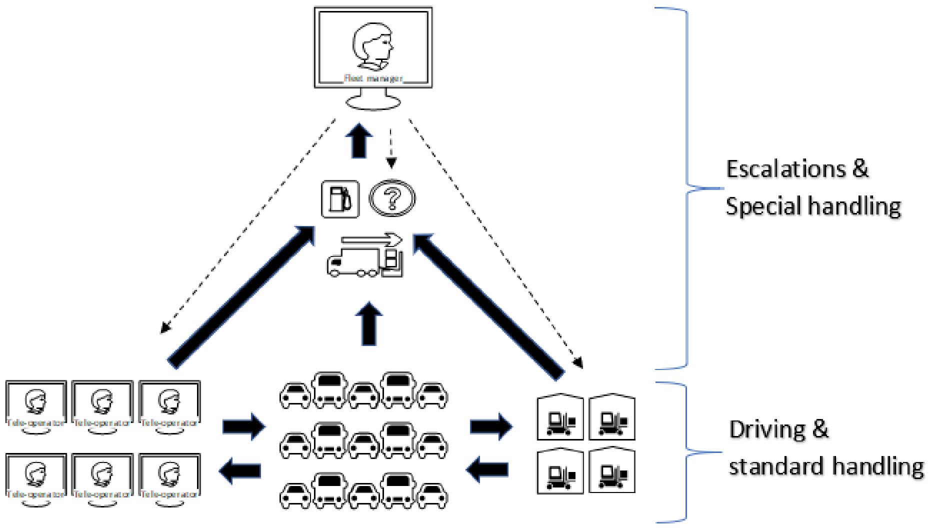

Figure 3 Operational model teleoperation control center

To support the interaction between all parties involved, a fully integrated control system with real time connectivity is a basic need that needs further research and development. As explained earlier, it is yet to be proven if 5G connectivity and together with other systems used in TOD will be able to offer the necessary latency and bandwidth that is needed to uphold this control system.

4.3 Re-allocation of driver responsibilities

After a thorough analysis of the driver activities and the set-up of the teleoperation control center, the remaining driver responsibilities (Figure 2) can be evaluated. For some, one will find a digital solution, for some automation can be explored and others will still require support from local operators or people near the vehicle. The options at hand are listed in Table 4.

Table 4 Re-allocation options

	Driver task	**Re-allocation option 1**	**Re-allocation option 2**
Vehicle	Security	TO vehicle	TO trucking support operator
	Driving	TO driver	TO trucking support operator
	Docking	(Partial) Automation	TO trucking support operator with local operator
	Checks	TO vehicle	TO vehicle parking operator
	Maintenance	TO vehicle parking operator	Maintenance company
	Fueling/ Charging	(Partial) Automation	TO trucking support operator with fueling station clerk
Cargo	Lashing & securing	Automation	Local operator
	(Un-) Loading	Automation	Local operator
	(De-) Coupling	Automation	Local operator
	Tank cleaning	Automation	Cleaning facility operator
Communication	Traffic	TO vehicle	TO trucking support operator
	Loading location	Digital	TO trucking support operator
	Documentation	Digital	TO trucking support operator
	Identification	Digital	

4.3.1 Responsibility for the vehicle

Security – As drivers are no longer required to take a rest, the vehicle can continue driving without the need for overnight stay at a parking lot. Neither will an actual accessible cabin be mounted to the vehicle as there will no longer be a need to accommodate a person. In case of a retrofitted vehicle, the cabin could remain closed/sealed at all times. However, should there be any need to access the truck engine or control system, the vehicle itself could request proper identification first, by for example a passport or fingerprint scanner. If this is not possible, a second option could be that the teleoperated trucking support operator needs to grant access and can for example open or close the bonnet or fueling cap via the control system.

Driving – Driving and standard handling will be the responsibility of the teleoperator or, in special cases, the trucking support operator (see 4.2).

Docking – Docking could become a fully automated process where the truck can open and close the doors automatically and execute the docking without human assistance. Remote controlled and/or hydraulic container doors are under development and could be a good option to manage automated docking (Patent, 2010). However, one of the use cases under the 5G-Blueprint project assumes the principle of tele-operator in-the-loop docking, where some form of human control is applied. In accordance with the docking process described above (Table 2), docking would then become a combined task of the teleoperated trucking support operator and a local operator to open or close the doors when needed. Alternatively, if the doors are automated, the teleoperated trucking support operator could send the command to open or close them via the control system.

Checks – The teleoperated vehicle should be equipped with the necessary sensors and technology to feed the correct parameters to the teleoperation control system. Apart from a built-in check, the teleoperator will be responsible for monitoring these parameters. Checks that cannot be executed by the vehicle itself, should be assigned to local support. Ideally, teleoperated trucks would be parked at specialized parking lots in between trips. Those parking lots could offer maintenance, charging/fueling, road assistance or any other specific need from a teleoperated vehicle, including regular checks.

Maintenance – The aforementioned specialized parking lots could also offer timely checks and more exhaustive maintenance packages. Alternatively, the vehicles could be attended to by a specialized maintenance company.[2]

Fueling/Charging – Fueling/charging could become a fully automated process if the fueling station offers an automatic refueling system. At the moment robotic fueling for passenger cars (Rotec-engineering, 2021) and mining trucks (Scottautomation, 2021) are still under development. In the meantime, the process described in Table 3 could be an alternative solution where communication between the trucking support operator and the fueling station is enabled by an on-vehicle screen.

4.3.2 Responsibility for the cargo

Lashing & Securing – As described earlier, development of automated or remote-controlled container or van doors is an ongoing process. Although some progress was made in relation to automatic twistlocks (Youtube, 2016), most handling in relation to lashing and securing

[2] Required checks and maintenance should be covered under the vehicle's insurance policy.

cargo seems too specific for automation and will require human intervention. Therefore, a local operator either in service of the loading location or assigned by the transportation company will become responsible for these tasks.

Loading and unloading – On those locations where the driver is responsible for loading and unloading the cargo, the obvious solution would be to shift these tasks to the loading location. However, for these scenario's there is an option for (partial) automation of pallets and loose cargo as well by use of rolls and/or chains (Ancra, 2019; Youtube, 2020, 2016). In case of temperature-controlled cargo, either a local operator could set the temperature of the container or it could be set automatically or manually by the trucking support operator via the teleoperation control system. If not automated, weighing could be handled by a trucking support operator by use of an audio-visual connection (see also Table 3).

Coupling and decoupling trailer – Coupling and decoupling of trailers could become an automated handling (Youtube, 2017). Nevertheless, for the moment, most trailers still require manual handling. As long as this is the case, these tasks should be assigned to a local operator. Depending on the (de-)coupling location, this could be either an operator at the (un-)loading location or an operator at the fleet parking.

Cleaning – If sweeping is requested, this should be handled at the loading location by a local operator. If the truck itself requires cleaning or the customer requires a cleaning certificate, the trucking support operator could steer the vehicle towards a nearby cleaning station and leave it there for cleaning. This process could be fully automated if the cleaning station has a connection set-up with the teleoperation control system or it could be handled via the audio-visual communication structure comparable to the fueling and docking process described above in Table 2 and Table 3. Once cleaning is done, a teleoperator could take over control and drive to the next destination.

4.3.3 Responsibility for communication

Traffic – The teleoperated vehicle should be equipped with technology that offers possibility to communicate with traffic in all situations such as light and sound signals. OEMs should also think about ways to transfer sound from the vehicle to the teleoperator so they can hear children near a school, an ambulance approaching or a car honking. In special situations where direct communication is required, an audio-visual connection with the teleoperation control center should be enabled.

Loading location – Depending on the level of integration of the teleoperation control system and the loading location's system, ETA's and timeslot adjustments might be communicated automatically already (PTV, 2021). However, when there is no integration, but communication is required, this could be handled by the trucking support operator by sending an e-mail or calling the local planner.

In accordance with the business process map in Appendix F, the loading location will provide GPS coordinates of the assigned parking/waiting/docking location. This, and a pre-loaded map of the site, should provide the teleoperator with enough information to navigate on the site.

Documentation – For teleoperation to become possible, digitization of all transport documentation would be a basic requirement. The first steps are being made with the uprising of the e-CMR which is expected to become mandatory by 2026 (Transfollow, 2021) which enables paperless transportation within the EU, including ADR information that can be included with the e-CMR (Ilent, 2021). Customs documentation is mostly digitized already due to globalization.

Identification – As shown in Appendix F, before logging on to a vehicle, the teleoperator will need to provide the necessary identification to the control system which should replace manual identification. This combined with the truck and trailer license plate number, and in case of container transport, the container number, should be enough to identify the driver and the goods. In any case this process would have to be stipulated in legislation and contractual agreements.

4.4 Reflection

Although many driver activities could be resolved by automation, robotization and digitization, it is not possible to fully exclude manual tasks within road transport operations. It is to be considered that re-allocating these manual tasks from the driver to a local operator will lead to additional cost for other (logistics) service providers. Outsourcing these tasks would be a good option to agree on a minimum level of service, cost and liability. Proper agreements between the transporting company and the loading locations should be made, incoterms could use a new variant, while insurance companies might have to reconsider their policies.

In addition, teleoperation offers possibilities for new business types such as specialized parking areas, maintenance providers, but also for OEMs and technology developers. Integration of different IT systems and tools is a must. Remote control of temperature, container doors and other trailer connected equipment postulates either a direct connection of the trailer to the vehicles control system or a connected trailer, allowing the teleoperation control center to exercise commands from a distance. It is most likely that for performing critical driving tasks remotely, the connectivity layer will have to be dedicated to these tasks and other less critical tasks will have to go through a second connectivity layer. E.g. when backing up into a loading dock, the command for unlocking the rear door of the trailer may lead to increased latency in the video / sensor feed. Even though this is still to be evaluated in field trials, common views are converging on this situation. Preferably, a similar integration would have to be set between the teleoperation control center and documentation platforms, governmental institutions and supply chain partners.

It is to be stressed that apart from the re-allocation options mentioned under 4.3 there are many other varieties and/or hybrid forms to be thought of to account for any of the processes described above. As an example, one of the hybrid processes discussed during the business process mapping was the possibility for a local teleoperator to take over control once the vehicle enters the site. As long as one would use retrofitted trucks, this could even be a manual take over by a local truck driver. This would require other processes, contractual agreements and regulatory stipulations; therefore, this was not considered for the purpose of this report.

5. TELEOPERATED TRANSPORT PLANNING

The number of teleoperators required to manage a fleet of vehicles with a certain size (i.e., teleoperator-to-vehicle ratio) is one of the defining factors for economic feasibility of teleoperated driving in logistics operations. Reducing the number of teleoperators lowers the labor costs and increases the utilization of the teleoperators, but it introduces waiting times for trucks ready for transport and keeps docks occupied unnecessarily, creating inefficiencies to logistics facilities. The level of service of teleoperated fleet operations can be expressed as the percentage of trips in which the waiting time of teleoperated trucks does not exceed agreed maximum waiting time.

Therefore, we developed a simulation model to assess the impacts of teleoperator-to-vehicle ratios on the level of service for logistics operations. We used three case studies of three different companies to consider specific characteristics of different logistics companies and we used a fourth synthetic case study to generalize the results of the first three case studies to the region of interest in this project, which is the Vlissingen-Rotterdam-Ghent and Antwerp area. In the following subsections, we elaborate on the case studies, the simulation model, and the results.

5.1 Selected case studies

- **Case study 1: LSP_1**
  LSP_1 transport service is located in Terneuzen in the south of the Netherlands. This puts them centrally in the Vlissingen-Rotterdam- Ghent and Antwerp triangle. The company is active in container transport throughout Europe with the main routes located in the Benelux, Germany, and France. The company is mainly specialized in transport to and from France, with a focus on the region of Northwest France (Le Havre, Paris, Quimper, and Brest). The company uses 37 vehicles and container operations constitute more than 90% of its operations.

- **Case study 2: LSP_2**
  LSP_2 is based in the Antwerp region in Belgium. LSP_2 transport group mainly transports maritime containers from the Port of Antwerp to the Benelux, Northern France, Germany, and other regions in Western Europe. The company uses 69 vehicles. Other transport activities of LSP_2 include tank transport, covered transport (curtainside trailers) and flatbed trailer transport. In the analysis only the container transports were included.

- **Case study 3: LSP_3**
  LSP_3 transport group is a specialized logistics service provider with bases in the Netherlands and Belgium. At the operational level, the business is managed from Sas van Ghent, situated by the canal from Ghent to Terneuzen, which is nearby the ports of Ghent, Antwerp, Zeebrugge and Vlissingen. LSP_3 has three different transport departments: dry bulk department with 29 vehicles, which will be referred to in this report as bulk operation, liquid department with 25 vehicles, which we will refer to as tank operation, and container department with 4 vehicles, which will be referred to as container operation. We will simulate each one of these operations separately for this case study.

5.2 Data processing

All vehicles in all companies considered here are equipped with on-board units, which allow recording vehicle status and activities undertaken by the driver such as loading and unloading, driving, and resting. For each vehicle on duty, the sequence of activities and the duration of each activity is recorded. We acquired one month of such data from each company, and we used this data in our simulation to regenerate the activities of each vehicle in each company. However, the recording process is not without flaws. Therefore, the acquired data requires some preprocessing and analysis before being used for simulation.

5.2.1 Data cleaning

The following steps were required to preprocess and prepare the data to be used in simulations.

1. Eliminating irrelevant records: many activities with zero duration (e.g., turning the vehicle on and off) were recorded in the datasets that are not useful for simulation. These activities were eliminated from the datasets.
2. Dealing with missing values: most missing values were related to locations and distances, which were not relevant for the simulation. However, in some cases, the type of activity (vehicle status) was missing. In these cases, when there was a distance or a change in location associated with the activity, we assumed that the activity was moving. Otherwise, we assumed the vehicle's last known status to be the status for the activity.
3. Eliminating or correcting problematic records: there were records with obvious mistakes (e.g., moving activities with no distance and resting with duration of a few seconds). These records were eliminated or corrected in cases where the correct information could be deduced with confidence.
4. Combining consecutive activities: after eliminating incorrect or irrelevant records, in some cases there were consecutive identical activities (e.g., two driving activities with a 20-second break in between). These activities were combined with the duration being the summation of the individual activity durations.

5.2.2 Extraction of activity patterns and distributions

After the initial data preprocessing, we extract the average frequency of each activity per vehicle per day for each case study. Then, we find the most recurring patterns of activities (i.e., common sequence of activities undertaken by the drivers) for each case study's data. Next, we extract the distribution of the durations for each activity in each case study. Finally, we fit a variety of probability distributions to the series of durations extracted for each activity and find the distribution with the best goodness of fit for each activity in each case study.

The common activity patterns and frequencies are used for the simulation process maps and the probability distributions are used in the simulation to regenerate durations for activities. Statistical summaries of activity durations are compared to the ones obtained from the simulation to validate the simulation results. Activity duration distributions and the best fitting probability distributions for the case of LSP_1 are shown in Figures 4-6.

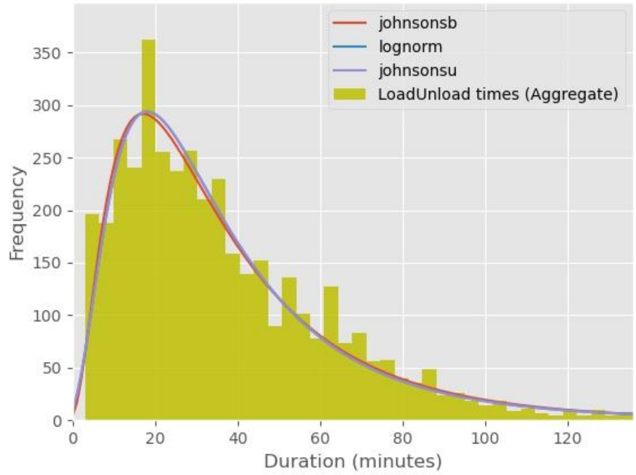

Figure 4 Load/unload durations for LSP_1 (histogram based on real data and lines based on fitted probability distributions)

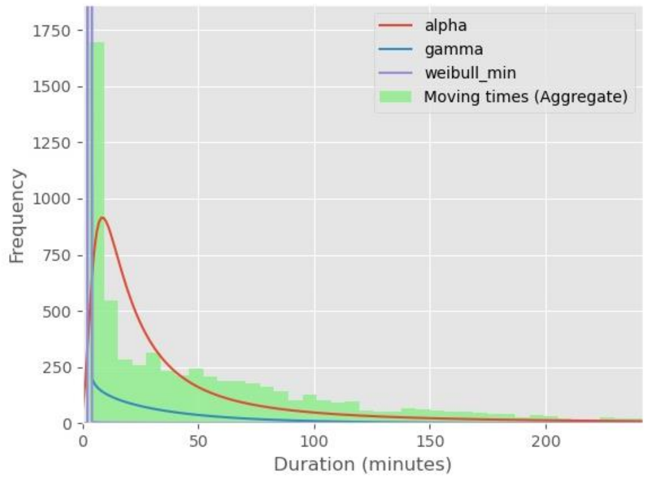

Figure 5 Moving durations for LSP_1 (histogram based on real data and lines based on fitted probability distributions)

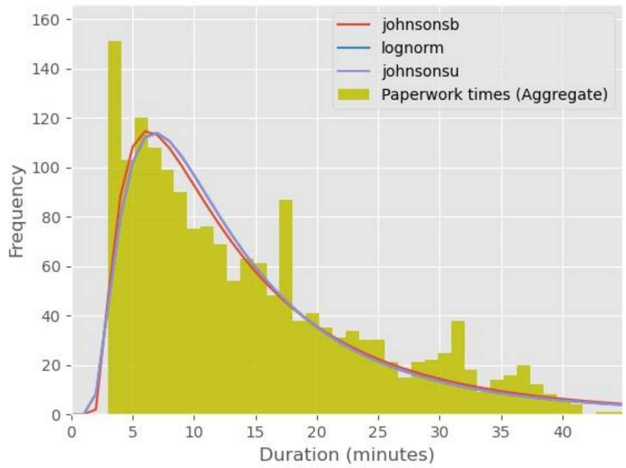

Figure 6 Paperwork durations for LSP_1 (histogram based on real data and lines based on fitted probability distributions)

5.3 Simulation model

We use the most common activity sequences extracted from the data for each company along with the probability distributions fitted to the data to regenerate multiple replications of activities of an average workday for each company and we record relevant statistics. Next, we compare these statistics with statistics extracted from the real data to validate the simulation model. Then we perform multiple simulations with different scenarios to measure the effects of variations in teleoperator-to-vehicle ratio on the level of service of each company. All components of the simulation model and the simulation procedure are explained in the following subsections.

5.3.1 Assumptions

The following assumptions are made in the simulations reported in this study.

- The simulation focuses on the driving tasks performed by teleoperators.
- All other driver responsibilities are managed via digitalization and automation.
- Company operations and activities will stay the same with teleoperation.

5.3.2 Simulation procedure

In this subsection, we elaborate on the simulation procedure and its components.

- **Simulation type:** Discrete event simulation or monte carlo simulation is used to regenerate different variations of an average day with different sequences of random numbers. We used 30 replications for each scenario in each case study and reported summary statistics for each scenario.
- **Objects:** Vehicles represent objects in the simulation and the fleet sizes (i.e. number of objects in each scenario) are based on company data and the number of vehicles available for each company.
- **Resources:** Teleoperators represent the resources in the simulation. Every time a vehicle changes its status to moving, a teleoperator is assigned to (remotely) drive the vehicle. As for the number of teleoperators in each scenario, different numbers are explored to find the best teleoperator-to-vehicle ratio in each case.
- **Queues**: Since a limited number of teleoperators (i.e. resources) are available in each scenario, there might be queues for teleoperators in some cases. The teleoperator queues are handled based on the first in first out (FIFO) rule.
- **Processes**: Activities undertaken by the vehicle (i.e., vehicle status) represent the processes in the simulation. The duration of each process for each case study is sampled from the best probability distribution fitted to the activity data from the corresponding company.
- **Process maps:** Sequences of activities (i.e., activity patterns) extracted from the data for each company determine the process map and sequence of processes in the simulation.

5.3.3 Key performance indicators

The following criteria is used as key performance indicators (KPI) to measure the performance of each company under each scenario.

- **Wait time per vehicle**: duration of time each vehicle spends waiting for a teleoperator to be assigned to remotely drive it, which includes the queue time as well as teleoperator setup time explained in the following section.
- **Queue duration**: duration of time for each queue for a teleoperator.
- **Queue length**: length of the teleoperator queue at each moment in time.
- **Vehicle utilization**: the amount of time each vehicle is moving divided by the simulation time.
- **Teleoperator utilization**: the amount of time each teleoperator is busy divided by the total simulation time.

For each KPI, we report average, standard deviation, minimum, median, and maximum of the indicator for 30 simulation replications.

Since companies work in different shifts for long and often irregular hours every day, we have used a long simulation time (16 hours) to allow all daily activities to finish, yet during the last hours of the simulation (night times), usually there are only a handful of vehicles active, which corresponds to the reality of operations in logistics companies we studied. More evidence for this is provided in the validation section.

5.4 Scenarios

The main variables defining the scenarios are teleoperator-to-vehicle ratio and setup time for teleoperator to take over control of the vehicle.

For teleoperator-to-vehicle ratios, lower ratios can be more cost-effective but might lead to lower level of service because vehicles might have to wait in queue for teleoperators. Therefore, in order to find the best trade-off between the teleoperator resource cost and the level of service, we used a grid of teleoperator-to-vehicle ratios in range of 0.5-1 (i.e., [0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1]) and measured the level of service for each value in each case study. Each value represents a distinct scenario.

Regarding the setup time for teleoperators, our interviews indicated that there might be a short mandatory time required for the teleoperator before taking over a vehicle. This is for safety reasons and to guarantee that the teleoperator has sufficient time to obtain a certain level of situational awareness regarding the vehicle's surroundings before starting to drive the vehicle. We have studied scenarios with values of two minutes and five minutes for the setup time as well as scenarios without this setup time to have a reference point for comparisons.

5.5 Validation of the model

For each case study, we used the scenario with zero setup time for teleoperators and teleoperator-to-vehicle ratio of one as baselines ("as is" scenarios) for comparisons. In these scenarios, every time a vehicle needs to move, a resource is immediately assigned to drive the vehicle without waiting in the queue and without setup time. Moreover, a resource is dedicated to each vehicle for driving in these scenarios. Therefore, these scenarios are practically identical to the existing situation with drivers.

We recorded average frequency of each activity as well as the average, standard deviation, and median of activity durations in each simulation run for the baseline scenarios of each case study. Then, we compared these numbers to the actual numbers obtained from the data to validate the simulation. Tables 4-7 show the results of the comparisons for LSP_1 case study. Similar comparisons for the rest of the case studies are reported in the Appendix H. Overall, the results indicated a satisfactory resemblance between the baseline simulation results and the real data, given the stochasticity of the processes involved.

Table 5 LSP_1 Activity frequencies: real data

	Moving	Load/Unload	Resting	Paperwork
Average frequency per vehicle per day	7.02	4.55	3.08	1.93

Table 6 LSP_1 Activity frequencies: simulation

	Moving	Load/Unload	Resting	Paperwork
Average frequency per vehicle per day	7	4	3	2

Table 7 LSP_1 activity durations: real data

Activity	Duration (minutes)		
	mean	**std**	**median**
Load/Unload	37.90	29.24	31
Moving	55.17	57.86	34
Paperwork	15.07	10.87	12
Resting	25.92	12.47	32

Table 8 LSP_1 activity durations: simulation

Activity	Duration (minutes)		
	mean	**std**	**median**
Load/Unload	37.48	28.90	30
Moving	52.16	48.58	34
Paperwork	14.59	11.33	11
Resting	31.14	37.98	17

5.6 Results and analysis

In this section, we present and elaborate on key performance indicators (KPI) from the simulation results along with optimal teleoperator-to-vehicle ratios based on the desired level of service.

5.6.1 Key Performance Indicators

Figures 7-9 show summaries of simulation events and tables 8-10 provide summaries of KPIs (described previously) for three selected scenarios of LSP_1 case study. Similar information for all case studies is reported in Appendix H. Simulation summary figures for each scenario and case study demonstrate the number of vehicles that are busy with each activity at each point during the simulation time, fleet size, number of busy and idle teleoperators at each point in time, number of available teleoperators, and the teleoperator queue size at each point in time. This provides an overview of all the events during the simulation. KPIs are described previously and are reported here for each scenario and case study to measure the performance of the teleoperation procedure in each case study and scenario.

We have selected scenarios with teleoperator-to-vehicle ratios of 1, 0.75, and 0.5 (all with teleoperator setup time of 0) to shed light on the impacts of this variable on the system performance.

For the case with teleoperator-to-vehicle ratio of 1 (table 8 and figure 7), teleoperator utilization rate and vehicle utilization rates are on average 34 percent, and there is no queue for teleoperators. This case has the highest level of service as there is a teleoperator assigned to each vehicle and there is no waiting time for teleoperators. However, this comes at the cost of low teleoperator utilization rate, thereby having many idle teleoperators at any point in time, which means higher labor cost. Moreover, as shown in figure 7, the number of busy teleoperators in this case never gets close to the number of available teleoperators.

With a teleoperator-to-vehicle ratio of 0.5, the opposite phenomenon is observed (table 10 and figure 9). Teleoperator utilization rate is 70 percent on average, which is more desirable, yet the average queue duration is about 19 minutes and each vehicle spends about 100 minutes on average in queue. This means lower labor cost but also lower level of service.

The teleoperator-to-vehicle ratio of 0.75 represents a situation in between the two scenarios discussed (table 9 and figure 8). In this case, there is a lower number of teleoperators required with average utilization rate of 45 percent, maximum queue duration is about 7 minutes, and each vehicle waits less than a minute on average for teleoperators every day. This implies that there is a trade-off between the labor cost of teleoperators and the level of service, and perhaps there is an optimal teleoperator-to-vehicle ratio that yields the best balance for this trade-off. The following subsection is dedicated to this topic.

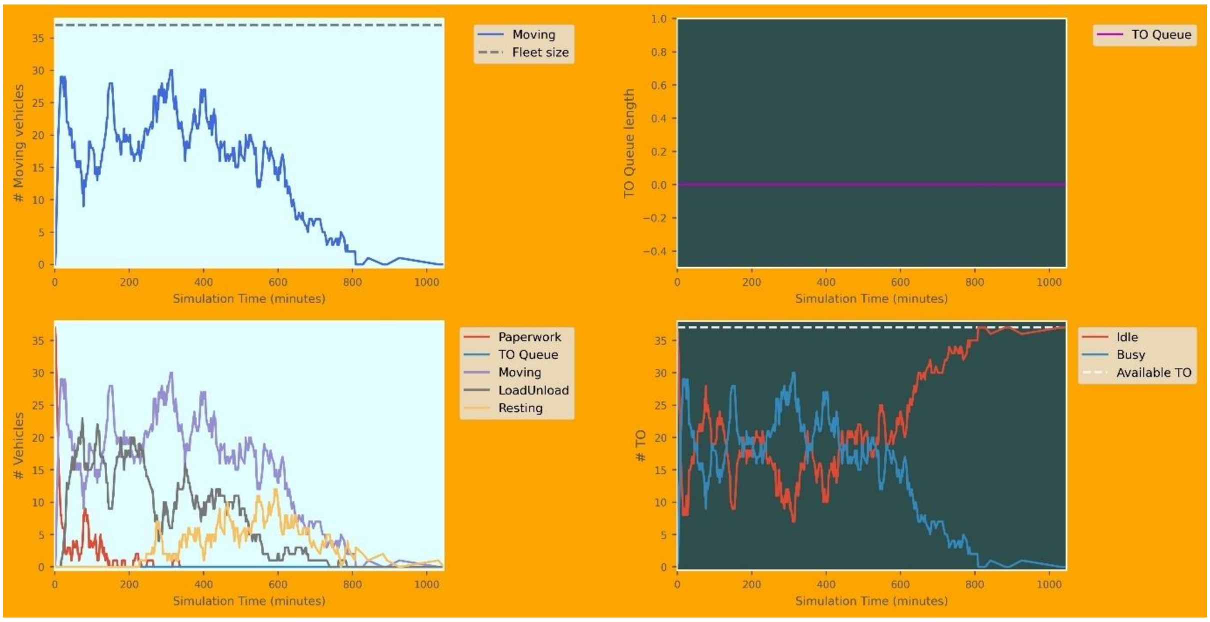

Figure 7 Simulation summary for LSP_1 with TO/V ratio of 1 and TO setup time of 0

Table 9 KPI summary for LSP_1 with TO/V ratio of 1 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.34	0.02	0.31	0.33	0.34	0.35	0.37
AVG TO utilization	30	0.34	0.02	0.31	0.33	0.34	0.35	0.37
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

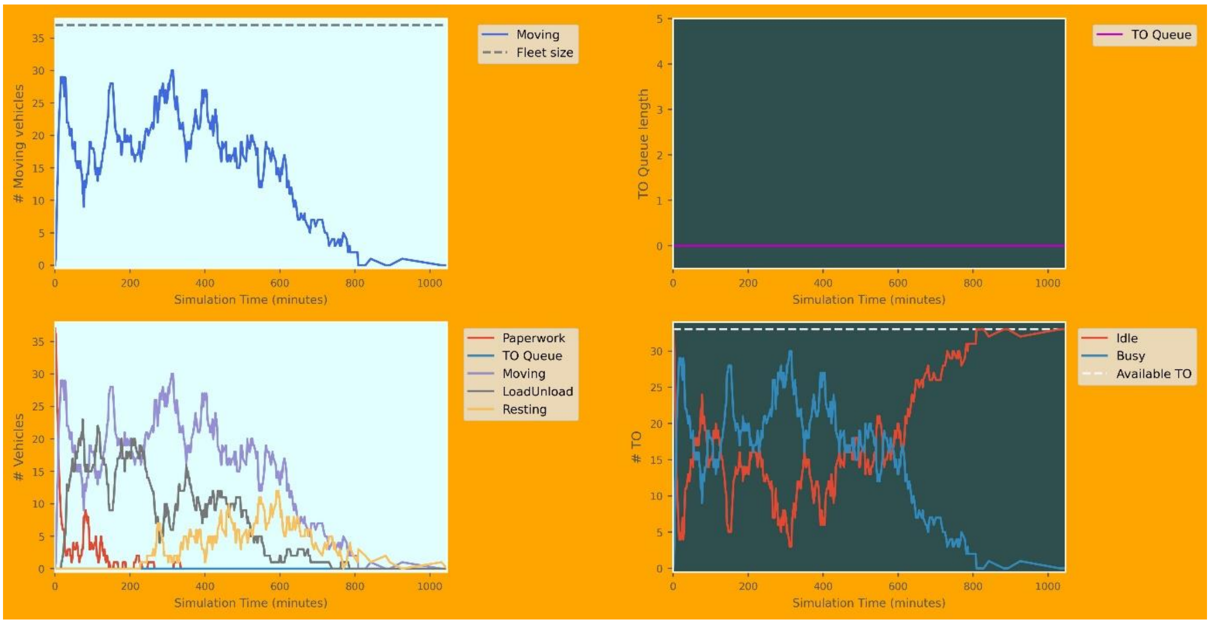

Figure 8 Simulation summary for LSP_1 with TO/V ratio of 0.75 and TO setup time of 0

Table 10 KPI summary for LSP_1 with TO/V ratio of 0.75 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.34	0.02	0.29	0.33	0.34	0.34	0.37
AVG TO utilization	30	0.45	0.02	0.39	0.44	0.45	0.46	0.49
AVG wait time/vehicle	30	0.96	0.75	0.05	0.36	0.80	1.29	2.62
AVG queue duration	30	4.51	2.28	1.40	3.00	3.96	5.84	10.78
MAX queue duration	30	7.37	3.55	2.00	5.00	7.50	9.00	15.00
AVG queue length	30	0.03	0.03	0.00	0.01	0.03	0.04	0.09
MAX queue length	30	3.43	1.77	1.00	2.00	3.00	5.00	7.00

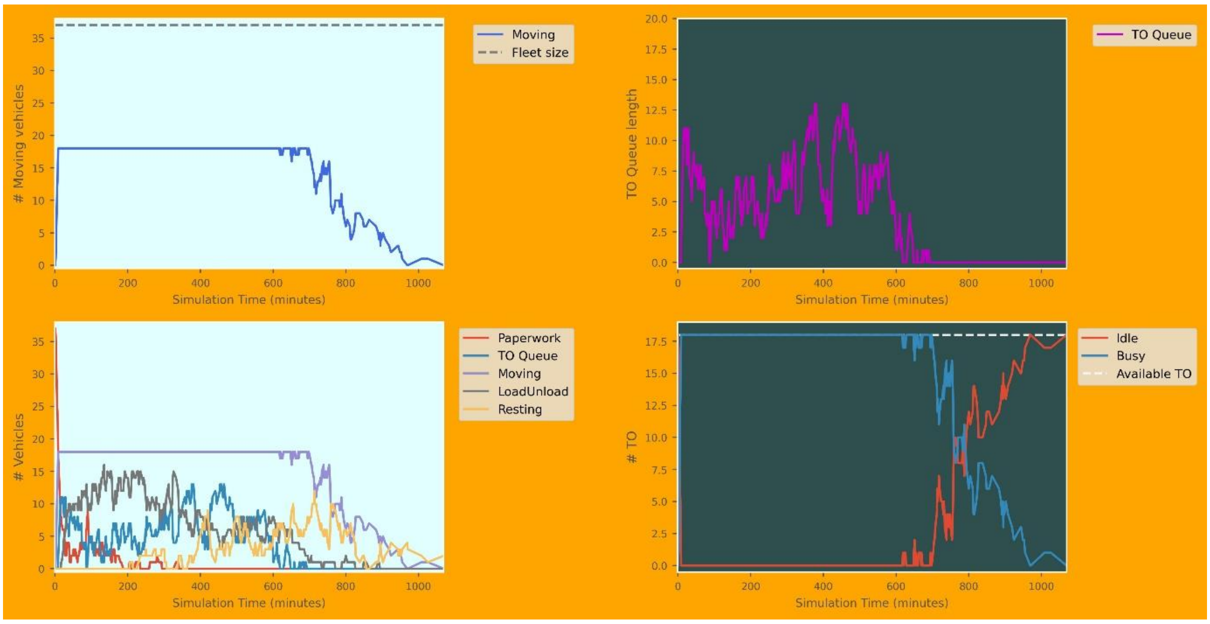

Figure 9 Simulation summary for LSP_1 with TO/V ratio of 0.5 and TO setup time of 0

Table 11 KPI summary for LSP_1 with TO/V ratio of 0.5 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.34	0.02	0.30	0.33	0.34	0.36	0.38
AVG TO utilization	30	0.70	0.04	0.62	0.68	0.70	0.73	0.77
AVG wait time/vehicle	30	99.31	24.22	52.84	79.50	102.60	110.90	156.89
AVG queue duration	30	18.84	3.97	10.86	15.13	19.69	21.11	27.25
MAX queue duration	30	47.60	8.76	31.00	41.25	47.00	52.75	70.00
AVG queue length	30	3.40	0.83	1.81	2.73	3.52	3.80	5.38
MAX queue length	30	14.33	1.52	11.00	13.25	14.50	15.00	17.00

5.6.2 Teleoperator-to-vehicle ratio

In this section, we analyze time spent in queue as well as waiting times for different ratios of teleoperator to vehicle. Maximum queue duration for every time a vehicle has to wait in queue for a teleoperator is considered as a proxy for the level of service. Using this proxy, the business case model that is presented in the next chapter of this report can be used to determine the optimal ratio of teleoperator-to-vehicle that leads to the lowest labor cost regarding teleoperators while guaranteeing a certain level of service.

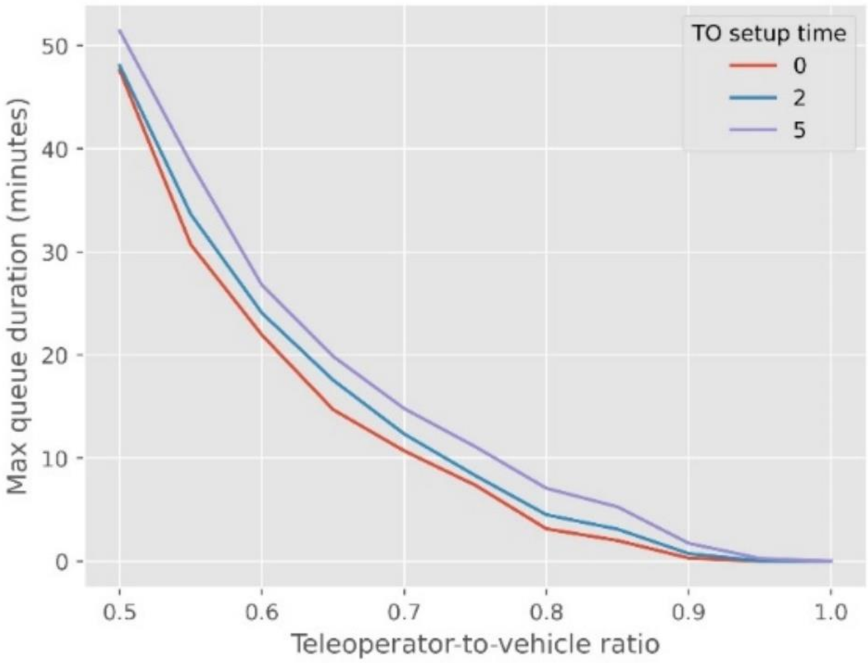

Figure 10 Maximum queue duration for LSP_1 case study

Figures 10-13 show that in most cases, given a minimum level of service of 10 minutes (maximum 10-minute teleoperator queue time), teleoperator-to-vehicle ratio of 0.75 is sufficient to guarantee this level of service. Moreover, operation type does not appear to have a significant impact on the optimal ratio since there is no statistically significant difference between the optimal ratios for cases with different operations.

The exception is the case of LSP_2 (Figure 11) where the required teleoperator-to-vehicle ratio for guaranteeing the required level of service is 0.95. This is due to the fact that in this case, all vehicles start moving at the same time at the beginning of the day and this creates a peak demand for teleoperators, which leads to longer waiting times in queues. However, after this initial peak period, no major queues are observed in the scenario with teleoperator-to-vehicle-ratio of 0.75 for this case study, and the average teleoperator utilization rate in this case is 52 percent (Appendix H). This indicates that a minor rearrangement of the operations in this case (for instance, if half the vehicles start later) can lead to significantly better teleoperator utilization and higher level of service.

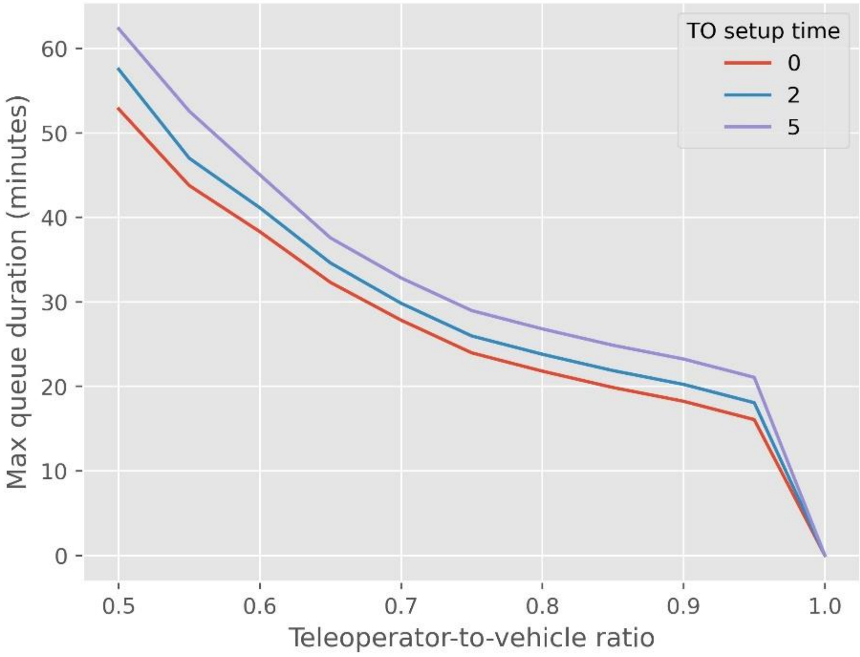

Figure 11 Maximum queue duration for LSP_2 case study

Teleoperator setup times have an impact on the waiting times as well, since the vehicle has to wait during this time and it also contributes to overall longer queue lengths. We studied different scenarios with the values of 0, two minutes and five minutes for this variable to measure its impacts on the level of service. As it can be observed from figures 10-13, this setup time does not have a significant impact on queue durations, and it does not cause backlogs in demand for teleoperators. However, this factor affects average waiting times per vehicle, which includes the time that the vehicle has to wait for the teleoperator to take control of the vehicle (tables 8-10). This setup time might be defined by law or industry standard to ensure safety but in case it is defined by teleoperation planners, its impacts on overall vehicle waiting times should be taken into account. In practice, drivers may also require a set up time to do some checks, but if these checks are performed by other supply chain actors or systems, the teleoperator has to verity these checks. This may require an additional set-up time.

We analyzed the scenario where maximum 10 minutes is considered the minimum required level of service for teleoperation. However, the results presented in this section (figures 10-13) are sufficient to determine the optimal teleoperator-to-vehicle ratio for any level of service for different values of teleoperator setup time. The intercept between the required level of service on the vertical access of figures 10-13 and the curve with the relevant teleoperator setup time determines the optimal teleoperator-to-vehicle ratio in each case.

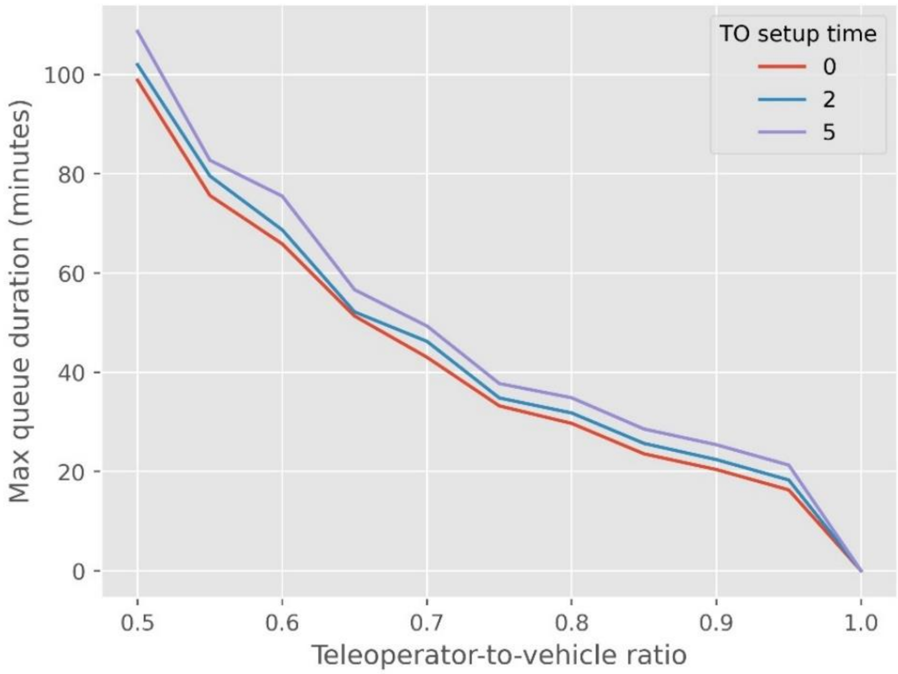

Figure 12 Maximum queue duration for LSP_3 (Bulk operation)

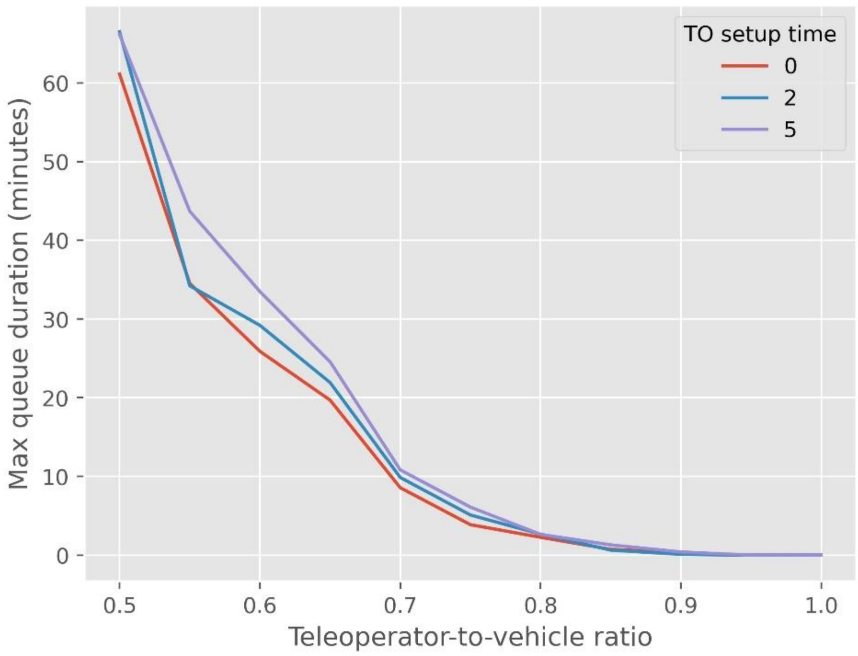

Figure 13 Maximum queue duration for LSP_3 (tank operation)

5.6.3 Impact of a shared teleoperation center

In this case study, we consider the case of a teleoperation center. Since the number of vehicles that a teleoperation center needs to serve depends on the number of customers the teleoperation center can acquire, we considered a synthetic case study with 150 vehicles dedicated to container operation, 150 vehicles dedicated to bulk operations, and 150 vehicles dedicated to tank operations. For each type of operation, we used activity sequences and the distributions of activity durations from one of the previous case studies with corresponding operation.

KPI and simulation summaries for scenarios with teleoperator-to-vehicle ratios of 1, 0.75 and 0.5, and teleoperator setup time of 0 are reported in tables 11-13 and figures 14-17. Detailed statistics regarding queue durations for all scenarios of this case study is presented in Appendix H. It is evident from the results that the moving activities in this case study (i.e., calls for teleoperators) are more spread throughout the day due to a larger number of vehicles and variety of operation types. Unlike previous case studies, in this case study, there is no teleoperator queue when the teleoperator-to-vehicle ratio is 0.75. Even when this ratio is 0.5, average queue duration is about 14 minutes and maximum queue duration is 26 minutes, which is considerably lower than the corresponding scenario in the first three case studies.

Furthermore, in this case study, lower teleoperator-to-vehicle ratios are required to ensure any level of service compared to the previous case studies. For instance, according to figure 17, there is no queue for teleoperators for teleoperator-to-vehicle ratios above 0.7 and the ratio of 0.6 leads to a maximum queue duration of 5 minutes. Besides, in this case teleoperator setup times do not have a significant impact on queue durations and waiting times. These results suggest that the number of vehicles and the diversity of operation types play a crucial role in determining the optimal teleoperator-to-vehicle ratios.

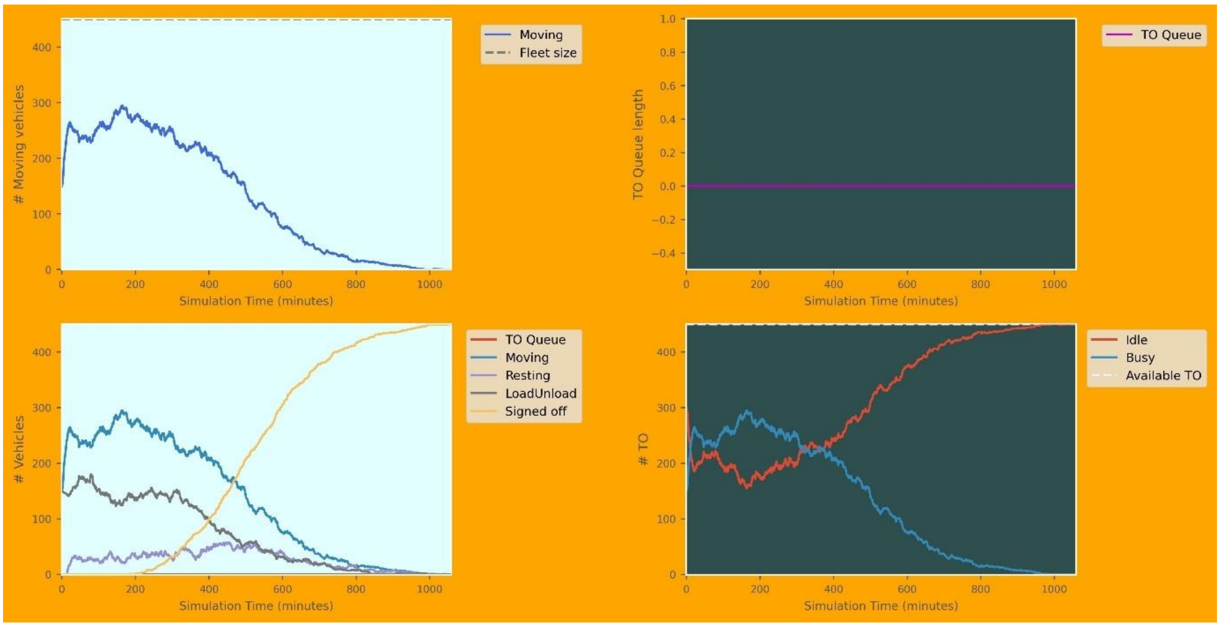

Figure 14 Simulation summary for teleoperation center with TO/V ratio of 1 and TO setup time of 0

Table 12 KPI summary for teleoperation center with TO/V ratio of 1 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.27	0.01	0.27	0.27	0.27	0.28	0.29
AVG TO utilization	30	0.27	0.01	0.27	0.27	0.27	0.28	0.29
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

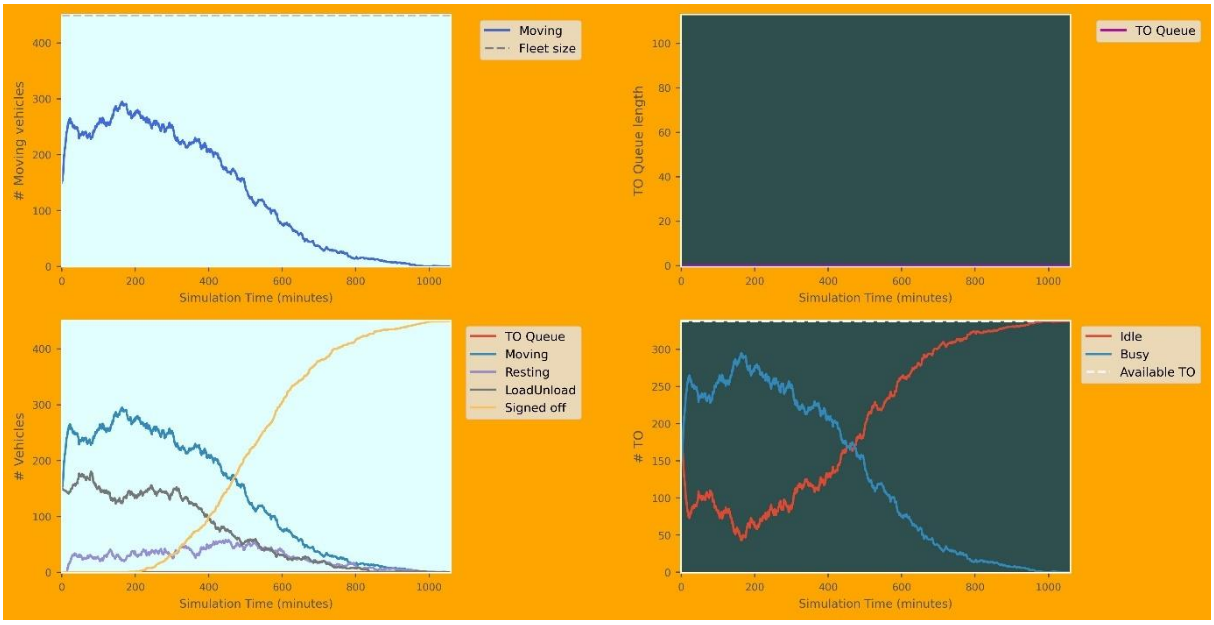

Figure 15 Simulation summary for teleoperation center with TO/V ratio of 0.75 and TO setup time of 0

Table 13 KPI summary for teleoperation center with TO/V ratio of 0.75 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.27	0.01	0.27	0.27	0.27	0.28	0.29
AVG TO utilization	30	0.36	0.01	0.35	0.36	0.36	0.37	0.38
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

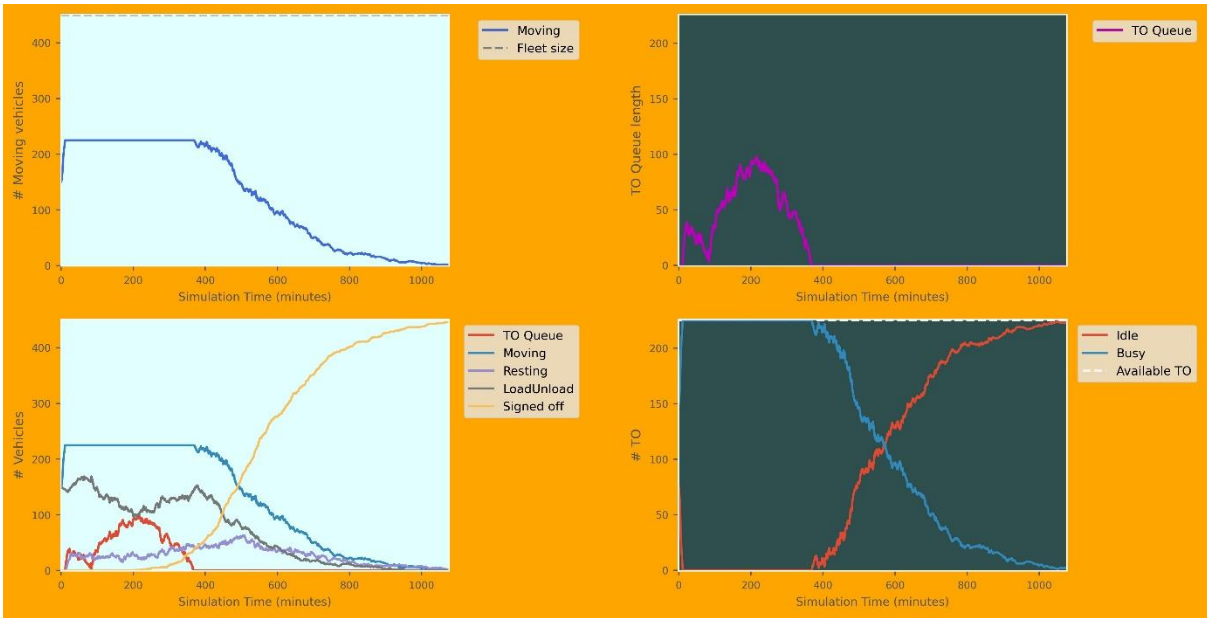

Figure 16 Simulation summary for teleoperation center with TO/V ratio of 0.5 and TO setup time of 0

Table 14 KPI summary for teleoperation center with TO/V ratio of 0.5 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.27	0.01	0.26	0.27	0.27	0.28	0.28
AVG TO utilization	30	0.55	0.01	0.53	0.54	0.55	0.55	0.56
AVG wait time/vehicle	30	39.24	4.93	26.24	36.60	40.45	42.05	49.08
AVG queue duration	30	13.77	1.64	10.16	12.84	13.95	14.89	16.77
MAX queue duration	30	26.57	3.44	19.00	25.00	26.00	29.00	33.00
AVG queue length	30	16.35	2.05	10.93	15.26	16.86	17.52	20.45
MAX queue length	30	89.30	9.90	66.00	83.50	89.50	97.00	106.00

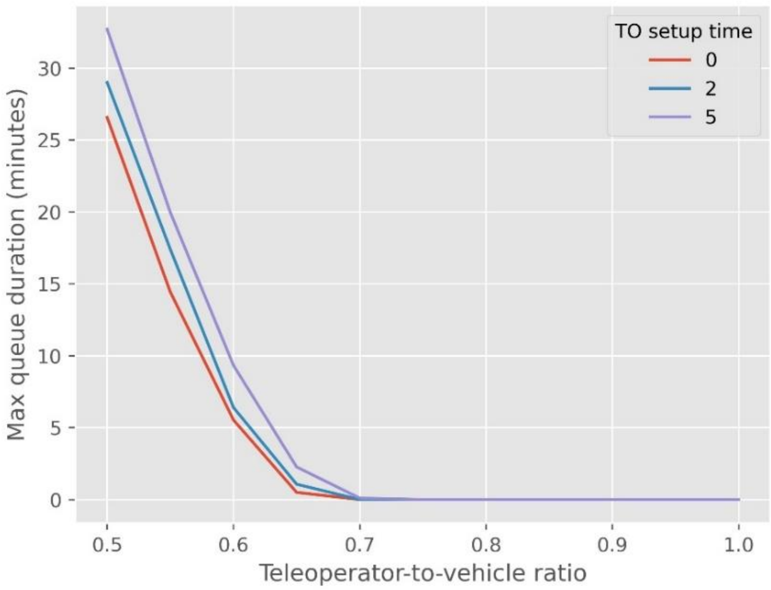

Figure 17 Maximum queue duration for teleoperation center case study

5.7 Conclusions on transport planning with teleoperated driving

The Tele Operator to Vehicle ratio (TO/V) is important for the evaluation of the business case of teleoperated transport. Benefits of teleoperation increase if the capacity of teleoperators can be efficiently utilized by switching from an idle vehicle to a vehicle in need for a driver with short idle times of the teleoperators. The simulation indicates that the TO/V ration is dependent on the type of operation, more in particular the distribution of the waiting and the (un)loading times, the size of the fleet and the service level (including a fixed start-up/vehicle take over time).

The latter two variables are in control of logistics service providers and can be used to optimize the business case for teleoperation. The results of the simulation show that a service level of TOD, defined by the maximum waiting time that a vehicle may experience, has a significant impact on the TO/V ratio. In the example of a fictitious operation of 150 trucks, a reduction of the maximum waiting time from 25 to 15 minutes increases the TO/V ration with percent points. Above a ratio of 0,7 TO/V the impact of the service level is negligible because the trucks do not experience any waiting time and the service level is practically 100%.

Due to the stochastic nature of the duration of all activities, the benefits of a shared tele-operating center increase with the number of vehicles operated. With a larger number of vehicles, the probability of a teleoperator becoming available increases. As a consequence, trucks will experience lower waiting times.

6. BUSINESS CASE TELEOPERATED ROAD TRANSPORT

6.1 Business case calculation tool

To assess the benefits of teleoperated transport for a particular transport company or fleet of vehicles in a particular operation a business case calculation tool has been developed. The tool calculates the difference between the capital and operational cost of the traditional road transportation company and teleoperated road transport. It is to be noted that the tool provides the difference between traditional transport and teleoperated transport, therefore the following applies:

Business case = Traditional operation – Teleoperation

The business case calculation tool consists of a front-end page where a logistics operating environment (indicated as a scenario) and specific data can be entered, and the outcome of the business case calculations is shown; and a back-end page where the business case is calculated based on pre-entered formulas and a source page where the input for different scenario's is presented. An illustration of outcomes on the front-end page is presented in Figure 18.

Business case

Environmental impact	Long range	Medium range	Short range	Total
Co2 (kg)	-280.800	-122.850	-9.360	-413.010
Fuel consumption (l)	-108.000	-47.250	-3.600	-158.850

Socio-economic impact	Long range	Medium range	Short range	Total
Required FTE (number)	-123,33	-59,24	-27,14	-209,72
Required trucks (number)	-6,24	-3,12	-3,12	-12,48

Cost differentiation	Long range	Medium range	Short range	Total
Non-TO activities (euro)	€ 23.280	€ 10.185	€ 776	€ 34.241
Total truck operation (euro)	-€ 1.142.496	-€ 884.767	-€ 971.879	-€ 2.999.142
Total Fuel cost (euro)	-€ 118.800	-€ 51.975	-€ 3.960	-€ 174.735
Total equipment (euro)	€ 199.033	€ 159.719	€ 2.071	€ 360.823
TOTAL (euro)	-€ 1.038.983	-€ 766.838	-€ 972.992	-€ 2.778.813

Figure 18 Presentation of the outcomes on the front end of the dashboard

The business case table on the front-end page provides immediate insight in the impact of a switch to teleoperated transport:

- ***The environmental impact*** provides the impact on fuel consumption and CO2 emission. Due to the enabling functions incorporated in the teleoperation dashboard advising on speed and timeslot booking at intersections, a 3% decrease in fuel consumption is expected. Therefore, it can be concluded that teleoperation will always have a positive environmental impact.

- ***The socio-economic impact*** provides insight in the resources required. Firstly, it specifies how many vehicles would be required to carry out the specified operation. As teleoperators can hand-over trips to each other during shift changes, resting time would become obsolete. Trucks could continue driving at all times and therefore could carry out more trips. Due to this fleet capacity increase, a transportation company could either downsize their fleet or expand their services.
  Secondly, it specifies how many teleoperators would be required to steer a fleet. Teleoperators will not required to stay with the truck during waiting hours or loading which will therefore lead to a big efficiency increase. Consequently, the driver shortage within Europe could be decreased or even resolved with implementation of teleoperated transport.

- ***The cost differentiation*** provides an overview of potential savings and/or extra costs. First, it calculates the extra cost of activities that used to be carried out by the truck driver but will now have to be carried out by local 'hands' such as fueling station clerks or warehouse operators. As this is a new cost element to consider, the impact on the business case will always be negative.
  Second, it shows the cost difference for truck operation based on the cost for:
  - Teleoperation control kits for the teleoperated truck drivers and trucking support operators including yearly dashboard service fee, 5G connectivity fee and equipment.
  - Teleoperation control center based on working hours of teleoperated truck drivers and trucking support operators.

  Third, it provides the saving on fuel cost based on the decreased fuel consumption (3% reduction using teleoperation).
  Last, it determines the cost for equipment based on the cost for:
  - The truck itself, being either a regular truck with a teleoperation kit installed on it later on; or a newly built truck with integrated teleoperation functionality, depending on the chosen scenario.
  - Truck maintenance on yearly basis
  - Truck insurance on yearly basis.

  Since the cost for equipment of a teleoperated truck will always be higher than the cost for a traditional truck, the required investment will always have a negative impact on the business case.

6.2 Business case inputs and calculations

6.2.1 Inputs

The business case tool uses the following inputs:

- **Current logistics processes;** the main inputs describing a logistics operation to be provided are: average transit (trip) distance per day per vehicle, the size of the fleet, the average waiting time at logistics facilities before (un)loading, average duration of loading/unloading activities, average resting times per transit (trip). The user of the model can decide himself whether a trip is defined as a single leg from origin to

destination or a complete roundtrip of a particular day included all transport orders and stops.
- **Ratio of vehicles to teleoperator**; The ratio can be determined by the user based on an analysis of executed trips of a transport company or on a simulation based on empirical data, as presented in this report.
- **Proposed reallocation of driver activities**; The Organizational changes throughout the supply chain due to the changing role of the truck driver and the set-up of a teleoperation center; The user can indicate what time and effort is likely to be required from local operator in loading or unloading a vehicle or refueling it.
- **Cost elements**; various cost estimations (trucks, drivers, fuel, teleoperation kits) are used to calculate the costs. In current dashboard, the key elements are provided by consortium partners (Appendix A-E).

To improve user friendliness of the business case tools, a number of operating environments have been predefined: container transport, tank transport, cargo (pallets) and specialized cargo. Based on the specific characteristics of the transport operation, parameter settings for the cost of trailers, (un)loading times, need for local support, trucking support operator support and the type of trucking support operator activity have been specified.

Table 15 Predefined scenarios for operational environments

Scenario	Cost trailer (buying price)	(un)loading time (h)	local (un)loading support (h)	Trucking support operator support (h)	Trucking support operator activity
Container	€ 20.000	0,5	0	0,1	Temperature control (I/A)
Cargo (pallets)	€ 50.000	2	2	0,25	Docking
(ISO) Tank	€ 100.000	2	0,5	0,25	Pump
Special	€ 200.000	4	3	0,25	General

6.2.2 Calculations

Basically, the calculation of the business cases contains the following effects:

- Required deployment of a truck is determined by the pure driving time required to cover the distance of a trip plus the time that trucks stand still waiting to be loaded or unloaded, time required for service en route (e.g., refueling) and the time required for loading and unloading. The time that trucks normally stand still due to need for a driver to rest can be saved by assigning another teleoperator to the truck. This increases the productive hours per truck. This effect is larger for long-distance transport where the hours of standstill due to the overnight rest can be made productive compared to regional or domestic transport where the deployment during the night is limited by the possibilities for unloading and unloading at logistics centers.

- The main advantage of teleoperated driving is that a driver can be deployed to drive another vehicle while a vehicle becomes stationary. In the business case tool, it is assumed during waiting times and loading and unloading, the teleoperating driver is not necessary. How many operators are needed to keep a fleet of vehicles continuously moving is indicated by the teleoperator to vehicle ration (TO/V). The TO/V ratio depends on the specific logistics operation being evaluated can be determined by analysis of existing driving patterns or, as in this study, with simulation. In principle, the utilization and availability of the trucking support operator also depends on the characteristics of the logistics operations and can be analyzed or predicted in similar approach.

- The business case of teleoperated driving is also dependent on the differences in wages of the various actors taking over tasks of the traditional driver, like logistics employees at logistics facilities, service employees at fueling stations or the trucking support operator taking care of administrative and coordination tasks related to the transports being executed. In the current set-up of the business case, the assumption that the wages for local support are lower than the costs of a traditional driver and that it is beneficial to have these activities carried out locally. The wage costs of a trucking support operator are expected to be higher than the wage costs of a driver.

Calculations and assumptions used in the business case tool are presented in Appendix I.

6.2.3 Limitations

The tool was created with the information available at the time of creation (April 2021) and should not be considered binding in any way. It aims to provide a rough estimate of economic benefits. These estimated will be refined during the project. Actual implementation projects will require further research and calculations for the specific operation at hand. It does not provide the actual cost of implementation and therefore does not include:

- Cost for infrastructural changes such as placing 5G network points;
- Cost for integration of IT systems such as ERP and TM- systems;
- Cost for regulatory and/or contractual adjustments;
- Cost for office buildings to facilitate a teleoperation control center;
- Cost for automation of certain processes;
- Cost for digitization of transportation documentation;
- Any other cost that may result from actual implementation of teleoperated vehicles.
- Cost of use of teleoperators during the night (overtime premiums).

6.3 Three reference cases

To demonstrate the use of the model, three reference cases were calculated using the empirical data analyzed for each of the companies. The characteristics of the logistics operations are presented in Table 16. The logistics operations are expressed in the average number of trips (or transport orders) that is executed per day. The average trip duration and average length of the trips were calculated, since no information on transport orders was available.

Table 16 Input data for the three reference cases of LSP_1, LSP_3 Tank and LSP_2

Logistic operations	AC Rijnberg	Van Opdorp	Roosens
Trips (average no./day)	74	29	276
Trip duration (h)	3,0	4,6	1,5
Distance/ trip (km)	225	320,0	105
Waiting time/ trip (h)	0,25	0,25	0,5
Resting time/ trip (h)	0,75	0,70	0,3
Shifts (no./day)	1,0	1,0	1,5
shift duration (h/shift)	10	8	10
Operational days (no./year)	300	300,0	300

The calculate the business case of LSP_1 and LSP_3 the calculations for medium sized trips were applied. For LSP_2 the calculation for short range trips was used. In case of LSP_1 and LSP_3 the Dutch wage settings were applied. For LSP_2 the Belgian wages for truck drivers were used.

The outcome of the business case calculations is presented in Table 17. The calculations were performed for different TO/V-ratio's varying from 0,7 to 0,9 for each of the companies. With present settings of cost levels, the business case for teleoperation for all companies is positive for TO/V-ratios considered in the range between 0.7 and 0.9. The profit per truck operated by the transport companies was calculated. The annual profit ranges between 7000 euros to 11.500 euro per year (Table 18).

Table 17 Outcome of the business cases with different service levels.

AC Rijnberg - Containers	TO/V = 0,7	TO/V = 0,8	TO/V=0,9
Non-TO activities	€ 9.433	€ 9.433	€ 9.433
Total truck operation	-€ 431.449	-€ 408.414	-€ 385.379
Total Fuel cost	-€ 48.136	-€ 48.136	-€ 48.136
Total equipment	€ 183.728	€ 183.728	€ 183.728
TOTAL	-€ 286.424	-€ 263.390	-€ 240.355

Van Opdorp - Tank	TO/V = 0,7	TO/V = 0,8	TO/V=0,9
Non-TO activities	€ 6.301	€ 115.051	€ 115.051
Total truck operation	-€ 159.819	-€ 489.099	-€ 469.618
Total Fuel cost	-€ 32.155	-€ 32.155	-€ 32.155
Total equipment	€ 156.167	€ 200.862	€ 200.862
TOTAL	-€ 29.506	-€ 205.341	-€ 185.859

Roosens - Containers	TO/V = 0,7	TO/V = 0,8	TO/V=0,9
Non-TO activities	€ 18.806	€ 18.806	€ 18.806
Total truck operation	-€ 1.236.461	-€ 1.197.475	-€ 1.158.490
Total Fuel cost	-€ 95.969	-€ 95.969	-€ 95.969
Total equipment	€ 442.167	€ 442.167	€ 442.167
TOTAL	-€ 871.457	-€ 832.471	-€ 793.486

Table 18 Profit of teleoperation based on the number of vehicles operated currently (TO/V=0.9).

	LSP_1	LSP_3	LSP_2
Number of Vehicles	37	29	69
Profit per vehicle	-€ 7.741	-€ 7.081	-€ 11.500

6.4 Discussion on business cases

In this research we made a first comprehensive approach to teleoperated transport at lower levels of autonomy in logistics and transport focusing on the business case and organizational issues, mainly from an operational perspective. The business case drawn up in this study is the first business case model for teleoperation in road transport logistics. It captures the essence of the main advantages of teleoperation at lower levels of autonomy of trucks: (1) higher vehicle utilization through a 24/7 deployment if the logistics operation facilitates 24/7 activities, (2) increasing operator productivity by allowing them to designate other vehicles as vehicles stationary for waiting, loading and unloading, (3) fuel savings by reducing time constraints on driving times and other needs of a driver on the road.

The business case can be further refined by refining the characteristics of a specific operation and the associated cost structure. For example, the cost structure of deploying teleoperators at night to vehicles on long journeys, elaboration of the service level agreements allowing differentiation in service levels for different types of logistics facilities, taking into account specific features, skills and regulations that teleoperators must comply with in the planning and assignment of teleoperators, etc.

The business model does not cover the typical characteristics of truck platooning. However, the business case model can be easily adapted to capture the benefits of a replacing a driver of the second or third truck within a platoon with a teleoperator. The teleoperator is responsible for driving the truck towards the platoon or taking over the truck when a platoon is terminated. Replacing the driver of the second or third truck can be modelled by modelling the duration of the driving time of the truck in platooning mode as waiting time for the drivers/teleoperators. This allows the operator to be allocated to another truck. However, a new simulation model needs to be developed to analyze the impact of platooning on the vehicle operator/vehicle ratio.

The analysis also shows that in addition to the development of the technology for teleoperation itself, technical solutions and organizational adjustments are also required in the logistics chain in order to properly facilitate teleoperated vehicles. These adjustments still need to be further developed and refined into practically applicable solutions to get a better understanding of the costs of execution and coordination. It is not possible to indicate in what conditions these activities can be organized more or less efficiently than in the current situation.

An equally challenging issue is the roadmap for the option of these solutions within the logistics sector. Trucks are very flexible logistics mode of transport and may visit multiple logistics facilities on a day or a week and each of these locations will need to have the necessary support services. The operators of these facilities will also require a positive business case to justify their investments. This perspective is not yet included in the current business case design.

Besides these limitation of the current research, we also propose the following questions for further research to increase the insight into the application possibilities and the impact of teleoperated transport:

- More empirical research into the characteristics and business cases of various segments of the transport market or typical logistics facilities. The benefits of teleoperations are driven by specific characteristic of each segment. More insight into these factors for different segments makes it possible to derive a number of rules of thumb with which companies can easily estimate the benefits of teleoperation for their company.

- The insight in the business cases of various segments of the transport market could be used to estimate the size of the market for teleoperated services and also the need for telecommunication services to connect the teleoperator to the vehicles. A market size analysis was not included in this study. Once an overview of most promising segments of the transport sector are known, statistical data on trips and routes (available from the statistical bureaus in all EU Member States) can be used to estimate the number of vehicles that are active in a region.

- Teleoperations can reduce lead times in European supply chains since it allows 24/7 operations for all vehicles in international transport operations without the need for two drivers on a truck or having several drivers in which drivers take over a trailer or truck for the next leg. This provides shippers and logistics service providers with the opportunity to centralize stocks and to reduce the number of stock locations in Europe. Furthermore, a significant reduction in costs could also have an impact on the competitive position of barge transport and rail transport since the cost reduction per unit of cargo transported is much larger in road transport than in the other modes. To further analyze these hypotheses more research is needed into the conditions and costs of teleoperation in international transports is needed to compare the costs of two-driver operations. A more detailed analysis and comparison of transport costs of various modes with various levels of autonomy is required to gain insight into the impacts on the competitive position on transport modes.

7. INITIAL VALUE NETWORK ANALYSIS ON TELEOPERATED TRANSPORT

7.1 Introduction and purpose

To be able to assess the economic impact of teleoperation in cross-border logistics settings, as well as to draft sensible business and governance models, first we need a solid understanding of the entire value network. The entire value network for the use cases studied in 5G-Blueprint covers different relevant layers that go beyond the specific supply chains of both logistics and telecommunications services. More specifically, 5G-Blueprint covers different deployment environments (roads and waterways) and aims to explore different technologies (automation, CACC-based platooning, 5G connectivity) in different novel operational and locational settings (teleoperation, cross-border areas).

In the sections below, we provide an extended summary of the findings from the 'Value network identification' analysis, which was performed during the first eight months of 5G-Blueprint. The full analysis, comprising also a description of each individual value network role, can be found in Appendix G.

This analysis will be further extended and complemented in Task 3.2 of the project. There, we will look at the value network in more depth, in order to assess the impact of future teleoperation use cases on the current situation.

7.2 Methodology

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

This role identification also suggested an allocation of certain roles to actors who are potentially willing and able to fulfil them, for the clearest cases. For most roles, these potential actors are still unknown, even though in several cases multiple logical stakeholders could be hypothesized to be the relevant ones. However, relying on feedback from our industrial project partners in a later stage will help deliver a more appropriate and confident assessment. In addition, the allocation of some roles to possible stakeholders would be contingent on a particular business model and value network configuration.

7.3 Summary of results

The architecture in the figure identifies six different layers (in green) of roles involved in the teleoperation use cases (in blue boxes), together with an incipient allocation of each role to the actors potentially willing and able to fulfil it in the future (in white boxes). As it can be seen, several roles remain unclear. Next, we also discuss the individual layers and provide a brief description of the identified roles.

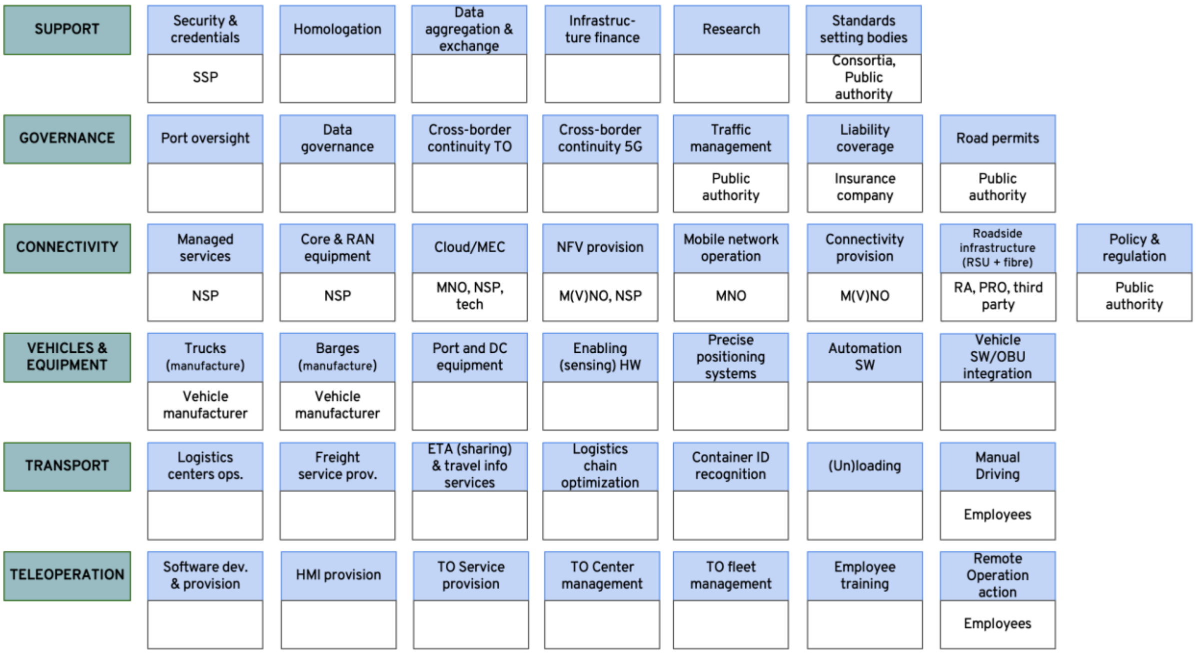

Figure 19 Layers of the value network

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

- Technology (software and HMI). This refers to technology for the vehicle and for the control room from which a teleoperation driver can control the vehicle or vessel. On the one hand, this consists of the technology aimed at creating and increasing the situational awareness and on the other hand creating the optimal human machine interface (HMI) to allow the teleoperated driver to function optimally. The HMI includes a dashboard where messages on speed advice, warnings, navigation and routing features are shown to the remote operator employee.
- Remote operation service provision. This refers to the provision of teleoperation services, i.e., those services where a transport company requests, on-demand, a driver from a service operator to drive a vehicle from a certain point to another. This service can be expected to be provided from a teleoperation (TO) center by a service provider.
- Teleoperation (TO) Center. This role refers to the ownership and management of the physical center from which teleoperation is performed. This center may be owned by the owner of a site or area where the TO service is offered (e.g., a port or road authority). Alternatively, these entities can outsource this role to companies that specialize in it.
- Teleoperated fleet management is a new role responsible for activities that require interaction with local operations, road users and fueling/charging stations. For example, it entails communicating via audiovisual signals when a vehicle is ready for docking or loading, or communicating with an employee of a gas/charging station that the truck is requesting fuel. The responsibility for this role would likely fall under the TO center manager.
- Remote operation action. This refers to the tasks and responsibilities with respect to driving and cargo handover that will be taken over by employees at a logistics center. Even though we group them into one single role for simplicity, different types of vehicles or equipment may require different skills, workplace settings, permits, etc.

- Training of employees. Teleoperation entails a radical change in the nature of work for drivers, skippers or port equipment operators. At an initial stage, new or current employees must be (re)trained to acquire the necessary skills and know-how.

The **logistics layer** covers the journey from the point where cargo arrives at a port by ship until it reaches the motorway with a truck. Some straightforward roles entail loading and unloading, identifying and assigning containers in real-time, and providing navigation, localization and estimated time of arrival (ETA). We describe others in a bit more detail below.

- To further optimize travel times, the logistics chain optimization role takes into account different enabling functions. First, in the case of non-cooperative driving, reserving and reassigning slots to trucks when there are conflicting requests for a green light can improve traffic flow, as trucks can adapt their speed in order to reach an intersection at a more optimal time. Second, assessing and communicating parking availability to trucks can also make a journey more time efficient. Furthermore, other enabling functions involve detecting anomalies or unforeseen events such as road hazards and accidents ahead.
- The freight role will likely be played by traditional transport companies, who are responsible for transporting goods with a fleet of owned or leased vehicles.
- In logistics centers (warehouses and terminals), teleoperated vehicles and barges load and unload goods. These locations must be adapted to receive and handle teleoperated vehicles. This requires adjustments in communication with the teleoperation driver and solutions for the tasks that are currently still being performed by drivers.

The **vehicles and equipment layer** covers the provision of those physical elements that will make it possible for vehicles, machines and port infrastructure to be remotely operated. The roles below describe components that will be included in either trucks, barges, cranes, reach stackers or forklifts, in order to enable them with teleoperation capabilities.

- Enabling (sensing) hardware. There are different types of sensing components, for instance cameras, ultrasonic sensors, radars, and lidars. Combined, they help the vehicle's software system map its driving environment in detail and identify surrounding objects.
- Precise positioning. This role implies the provision of high-accuracy vehicle positioning, for instance via GNSS receivers in vehicles and roadside infrastructure.
- Vehicle software. Enabling teleoperation will require vehicles to have an updated set of artificial intelligence and computing capabilities compared to the status quo.
- Vehicle SW/OBU integration. In order to be remotely operated, current trucks and barges must be adapted. More specifically, hardware built on top of current vehicles may include on-board units, which contain telecommunications and computing elements. As the technology matures, OEMs will manufacture vehicles teleoperation ready.

The **connectivity or communications layer** must in turn take several elements and types of actors into account. We summarize some of the specific roles below:

- Connectivity provision will refer to the service of offering long-range and short-range 5G communication, for instance via a connectivity subscription.

- The mobile network operation role refers to the deployment, operation and maintenance of the mobile networks that support the provision of long-range (5G) connectivity.
- Radio access networks (RAN) will be deployed for 5G public and private networks by equipment vendors (NSPs).
- NSPs will also supply (non)standalone 5G core technology to MNOs, as well as offer AI-based managed services to optimize the operation and management of 5G networks.
- Provision of network function virtualization (NFV). This can include network slice orchestration and management. More digitalized networks enable decoupling hardware from software elements, hence making some network functions 'virtual'. NFV providers could be MNOs, equipment vendors, or new companies (SW developers). However, this NFV role does not include the provision of network slices, which falls under the 'Connectivity provision role'.
- (Edge) cloud providers will offer data storage and processing, whether in centralized locations or at the edge of the network. Cloud computing capabilities can be offered as a service or built-in proprietary data centers at a customer's premises.

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

- Port and road authorities can expect to keep playing their traditional oversight roles. In addition, besides managing traffic, road authorities may be responsible to hand out permits for teleoperation in public roads.
- Liability for damages may shift hands with new actors being directly involved in the driving and operating tasks of vehicles and machinery, specifically in the case of open road use cases. As remote operators take control of vehicles, they may be considered responsible in case of accidents. Moreover, damages may be attributed to the connectivity provision, or may be considered the consequence of the underperformance of sensors or remote operation software systems. As many parties may be subject to liability claims, it needs to be defined which partners are legally required to cover such claims or contract insurance.
- Cross-border continuity of service: teleoperation. This role and the next have the responsibility to guarantee the seamless continuity of the teleoperations service as a vehicle crosses the border. This specific role refers to the responsibility of guaranteeing cooperation between actors, for instance regarding the 'handing' of control and supervision of a remotely operated vehicle by a TO center to another.
- Cross-border continuity of service: connectivity. The coverage of a given telecommunications network will not reach the entire teleoperated trip for some of the scenarios discussed in WP3, or at least the network will not be able to cover the entire area while meeting the defined performance KPIs. Therefore, continuity of service will require a handover between 5G networks of different national MNOs or between public and private networks. This role may rely on market agreements between MNOs (e.g., SLAs) and/or supervision and action by public entities (e.g., supranational regulatory bodies).

- Data governance. This role has the responsibility to ensure that data crucial to the project use cases are exchanged and shared in fair terms between data owners. It may entail defining data ownership and sharing rules and terms, including the definition of standardized formats. It may also entail building and/or operating a centralized platform that aggregates data sets and makes them accessible, which would mean effectively merging this role with the supporting 'data exchange & aggregation' role.

Finally, we must also consider other 'supporting' roles. The **support layer** determines those roles that, while more indirect, are still necessary or useful to enable the project's use cases in practice. For instance, setting standards may be necessary for teleoperation technology (both hardware and software) to be built according to similar and interoperable specifications. Relatedly, homologation refers to certifying vehicles and equipment to ensure minimum quality requirements are met, and hence that they are safe to be operated remotely in potentially dangerous environments. Both these roles can be played by public entities or third parties such as an industry association.

8. DISCUSSION & GENERALIZATION

8.1 Introduction

In other mobility sectors teleoperation can be applied and new services can emerge. In

Traditional services	Opportunities for teleoperation
Private car	Parents can drive their kids to violin lessons in tele-operation mode from home (if they own a control set) or hire a tele-operator to drive their car.
Taxi-services	Tele-operators in taxi-services can operate taxis from taxi stands when passengers request a ride or drive a taxi to a pick-up point. After a journey, a tele-operator can switch from taxi to taxi saving time while the vehicle is waiting for a new passenger at a specific location
Bus-services (public transport)	In bus services tele-operators can replace a traditional driver operating a bus line, but tele-operators are able to switch from one bus line to another bus line elsewhere in the city to create optimal daily schedules for tele-operators .
Coach-services (day trips)	Tele-operators can perform the task of coach drivers taking groups of tourist to a museum or other visits, but do not have to wait until the passengers are returning. Meanwhile the teleoperator can drive other vehicles.
Rental car services	Car rental services can bring a rental car to your home using a tele-operator providing additional service to their clients.
Driver-services	Business people that use a private driver can use tele-operators to drive them. A tele-operator does not have to wait until the end of a meeting attended by a client and can drive other clients during a meeting.

In this chapter we generalize the results and insights from the analysis of road transport to other modes of transport: teleoperated barge, taxi (robo-taxi) and public transport (buses). For each of the modes we present the existing literature first and indicate how the findings of our research aligns with existing literature or give rise to the formulation of new hypotheses on the application of teleoperation in these modalities.

8.2 Generalization to teleoperated taxi services

The business potential of autonomous or teleoperated taxis was the main driver for several tech-companies to start the development of autonomous vehicles. E.g., Uber began its work on autonomous vehicles around 2015 when it announced a partnership with Carnegie Mellon University’s National Robotics Center. Now, in 2021, artificial intelligence giant Baidu just launched a commercial driverless robo-taxi service in Beijing. Baidu’s Apollo Go Robo-taxi service is the first paid autonomous vehicle service where users can hop in a taxi without a backup driver to intervene. Customers will be able to hail a ride using an app, which allows them to locate a taxi within their vicinity (Crisara, 2021).

8.2.1 Literature review

Although large tech-companies have acknowledged the business potential of autonomous or teleoperated taxi's, literature on the business case and factors for successful deployment of autonomous or teleoperated taxi's is scarce. D'Orey et al. (2016) focus on the costs savings by analyzing the number of teleoperated drivers compared to the number of vehicle drivers. Vosooghi et al. (2019) analyze the required fleet size of autonomous robo-taxis given traveler preferences Keller et al. (2021) focus on the relative importance of specific service attributes of tele-operated robo-taxi's, while Lee et al. (2020) analyze the influence of user experiences on user acceptance of robo-taxi's. Cummings et al. (2020) consider the design of control centers for robo-taxi's. The literature on robo-taxi's focuses on different levels of autonomy. D'Orey et al. and Keller et al. focus on teleoperated robo-taxis at autonomy levels 2-3 in which teleoperators are driving or actively monitoring the driving process, while other scholars focus on level 4-5 in which teleoperators focus primarily on management of exceptions or communication with passengers.

D'Orey et al. (2016) present a large-scale empirical evaluation study to assess the operational efficiency of a teleoperated taxi fleet in the city of Porto. In the design of the teleoperated taxi service, the in-car drivers are replaced by teleoperators located at a taxi dispatch center, which remotely drive taxis at slow speeds during passenger pickup and drop-off trips. The standard service mode considers that a passenger with a valid driver's license will operate the vehicle until its final destination, limiting the operation of teleoperators to pick-up and after drop-off trips (status Free or Pickup). D'Orey et al. indicate that 95% of taxi rides involves a passenger that holds a driver's license. Alternatively, a premium service could be offered at an additional cost in which the teleoperation driver also drives the taxi from the pickup point to the destination (status Busy). The interaction between the passenger and the dispatch center is done through teleconference, either through the passenger's smartphone or equipment installed in the vehicle. After the passenger arrives to its destination, the operator drives the vehicle to a selected taxi stand or to a new passenger.

REQUIRED NUMBER OF OPERATORS FOR REMOTE DRIVING

State \ Period	Average				Maximum
	Peak (7-18h)		Off-peak		Overall
Free | Pickup	45	**15%**	29	**17%**	78
Busy	78	**27%**	42	**24%**	164
Pickup, Busy & Free	115	**39%**	64	**37%**	224

Figure 20 Required number of operators for remote driving (D'Orey et al, 2016)

D'Orey et al. (2016) performed an analysis of empirical data of a large-scale taxi operation generated by 443 taxis from the biggest taxi fleet in Porto. The dataset consists of 172340 trips records over a period of one month (September of 2015). When comparing the requirements in terms of number of operators with the number of in-car drivers, they conclude that teleoperation allows a significant reduction in the number of hired drivers (between 15 and 39 %) for all the considered scenarios. The implementation of teleoperation of taxi fleets leads to improved efficiency for taxi operators since virtual drivers are shared between different vehicles. These reductions will have a profound impact on reducing operational expenditures and improving the profitability of taxi operators as taxi drivers' wages are one of the main expenditures.

Keller et al. (2020) aim to deepen the understanding of the factors in consumers' acceptance of teleoperable robo-taxis. They scored customer preferences on four attributes of robo-taxi services. The first attribute is the possibility of intervention with three attribute levels representing varying levels of options to intervene in teleoperation of robo-taxis. At the lowest level, the user has no means to intervene in teleoperation. At the middle level, the user can communicate with the remote pilot, and at the highest level, the user can actively intervene and override the pilot's decisions. The second attribute relates to the pilot and user trust in the pilot. They use three levels of automation regarding the remote pilot. The lowest level is a trained human pilot. The highest level with full automation is a specialized artificial intelligence (AI) in the backend, which can access more data and larger computing capacities than the control logic inside the vehicle. The middle level is characterized by a combination of the previous ones so that the AI controls the vehicle while a human pilot monitors it and intervenes when necessary. The third attribute concerns interior monitoring of the vehicle, e.g., by cameras or other sensors. The researchers identified three levels with the lowest representing an always-on mode of monitoring. In the middle level, interior monitoring is only activated during teleoperation. In the highest level, interior monitoring is switched off by default but can be activated by the user. As a fourth attribute they selected is price that passengers are willing to pay for taxi services. They used three price levels: similar to conventional taxi's, price in between taxi and public transport and the price of public transport.

Table 19 attributes and attribute levels (Keller et al, 2020)

Attributes	Range	Levels
Possibility of intervention	3	No possibility of passenger intervention; Communication channel between the pilot and passengers; Passengers can override pilot decisions
Pilot	3	Trained human pilot; Specialized artificial intelligence (AI); AI under human supervision
Interior monitoring	3	Always; During remote control; Only after activation by passenger
Price per kilometer	3	2.50€/km (similar to taxi); 1.50€/km (price between public transport and taxi); 0.5€/km (similar to public transport)

The importance of these attributes was examined using a survey with 546 completed questionnaires. In this survey, price is the most crucial attribute in the purchase decision (34.81%). At the same time, it also has the largest standard deviation (26.34%), indicating heterogeneous preferences. The second most important attribute is the possibility of intervention (30.82% average importance weight, 18.52% standard deviation), followed by trust in the pilot (22,3%) and interior monitoring (12%). Keller et al. also analyzed the influence of taxi design on the willingness to pay. They estimate the equalization prices between the least and the most preferred attribute levels based on the average parameter values. To maintain a communication channel between the teleoperator and the passengers instead of no possibility of passenger intervention, the respondents are willing to pay the highest premium (2.76€ per km). The respondents are willing to pay 1.54€ per km extra for a human pilot instead of a specialized AI (i.e. an autonomous system). The willingness to pay for control over interior monitoring is rather low (i.e. to pay to have the monitoring to be switched off). The price that respondents are willing to pay is 0.12€ per km. More analysis of consumer preferences, including price, is presented by Stoiber et al. (2019). Their study assumes autonomy level 4 or 5.

Cummings et al. (2020) focus on concepts of operations for autonomous vehicle dispatch operations. They indicate that with the arrival of AVs as robo-taxis that operate as either level-4 or level-5, any On Demand Mobility company will need to develop a dispatch center that focuses primarily on monitoring overall fleet conditions and status and efficiency in scheduling, customer-interfacing communications and intervening in contingency operations. They indicate that Waymo is the only robo-taxi company that has acknowledged the development of such a capability. Waymo has decided to split their robo-taxi dispatch functions across three different roles: traditional dispatch, fleet response and rider support (Madrigal 2018). Scheduling and navigation functions are handled by the dispatcher, remote control and fleet management are handled by the fleet response person, and the rider support person deals with passenger communications. Cummings et al. indicate that the size of the fleet under supervision, the number of functions and the task frequency that dispatchers are required to perform drive overall optimal numbers of operators and job assignments.

The impact of automation on the cost structure of taxis and other modes of transport in Switzerland is explored by Bosch et al. (2019). First, they clarify the cost structure of teleoperated taxis. Cleary, the cost of the driver is the dominant cost in conventional individual taxi services (single passenger). The cost structure of teleoperated taxis looks more similar to the cost structure of a private car. Besides the costs of teleoperations, a big difference are the costs of cleaning. Given the absence of a driver and fellow passengers, customers of such taxi services are expected to show more irresponsible behavior in the vehicle (e.g. by eating) resulting in a faster soiling of the vehicle. In their analysis even minimum assumptions on additional cleaning result in substantial cleaning efforts, which would rapidly account for almost one-third of automated taxi's operating costs. Combined with an estimated share of 20% due to overhead cost, this means that more than half of autonomous vehicle fleets' operating costs will be service and management costs. Hence, by optimizing their operations processes, providers may realize substantial efficiency gains, allowing them to be competitive with private cars.

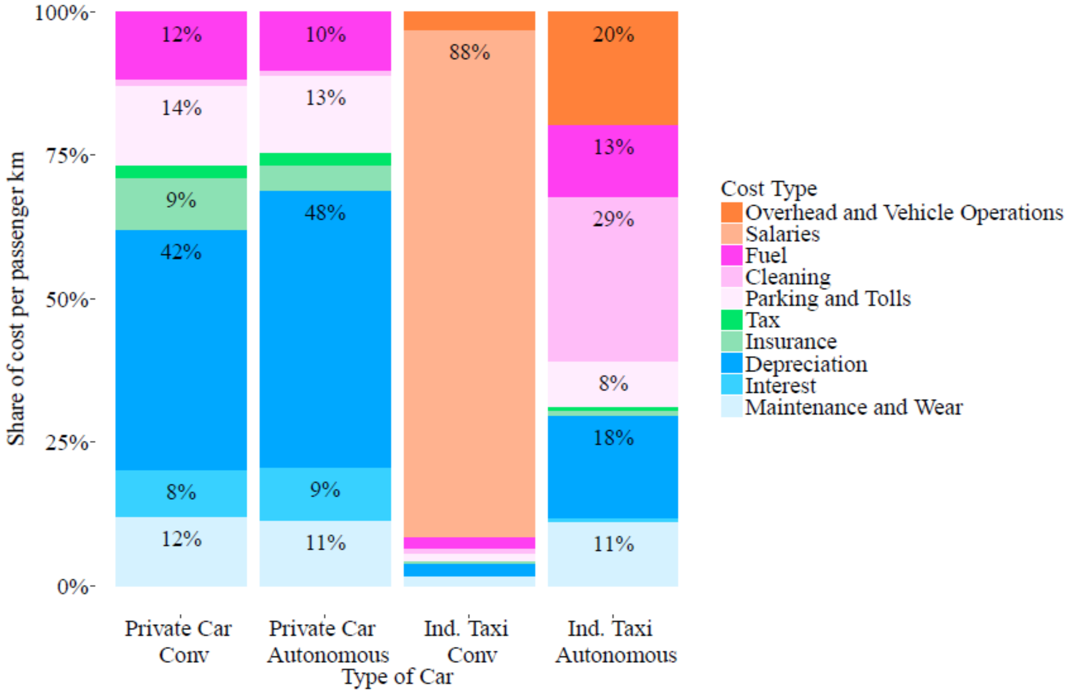

Figure 21 cost structure of automated private cars and taxis compared to conventional vehicles (Bosch et al, 2019)

"Without automation, the private car has the lowest operating cost per passenger-kilometer. Because of the paid driver, taxi services are substantially more expensive. In the current transportation system, they are used for convenience or in situations without alternatives, not because of their cost competitiveness. The picture changes substantially with the automation of vehicles. While the cost of private cars and rail services changes only marginally, autonomous driving technology allows taxi services to be operated at substantially lower cost, even more cheaply than private cars. In an urban setting, taxis become cheaper than conventional buses, yet they remain more expensive than automated buses" (Bosch et al., 2019).

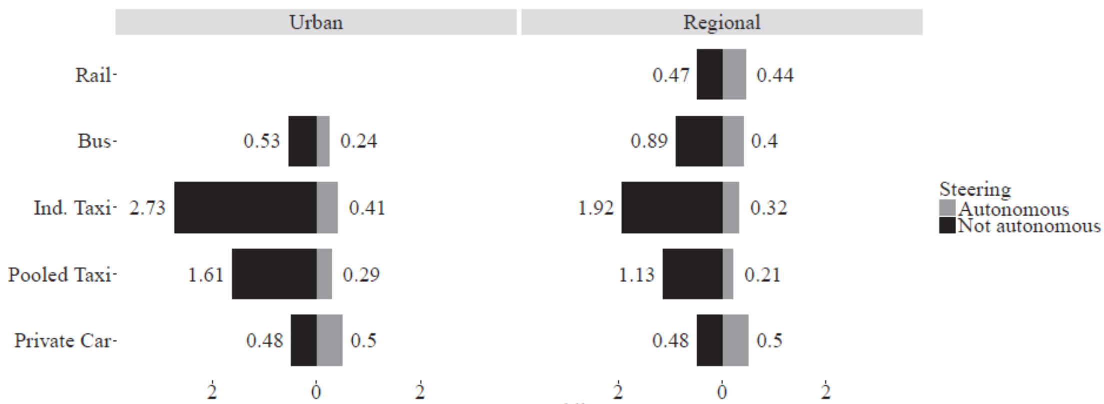

Figure 22 Costs per passenger kilometer (Bosch et al, 2019)

8.2.2 Business case & organizational changes in teleoperated taxi services

In this section we assess the impact of teleoperation on the responsibilities of the driver, the business case and the business models of taxi-services.

Table 20 Responsibilities of teleoperating taxi drivers and organizational changes and system requirements

vehicle	- The tasks and responsibilities of taxi drivers in traffic are similar to those of truck drivers; - Finding a safe place in traffic for pickup or exit of passengers requires teleoperators to have 360-degree visibility - Opening and closing of doors can in principle be performed by the passenger; the teleoperator needs to check if all doors & trunk are closed before departure; alternative is that the teleoperator can operator can operate doors and trunk also from the control room (as is already possible in luxury cars) - Taxis operate mainly locally or regionally, and a teleoperator can return a vehicle to a fuel station that is operated by a (taxi) service provider. - In case of a need for small repairs (lights, cooling fluid): taxis can return a service station during off-peak hours; If needed services for roadside assistance are already available and well developed. Conclusion: the task and responsibilities related to the operation of the vehicle can either be taken over by the teleoperator or by automation.
passenger	- The need of passengers for physical support and assistance from a driver when they use a taxi may differ across segments: on the one hand, business people may need a relatively short drive between an office and an hotel requiring little physical support from a driver or on the other hand elderly people travelling to a hospital from home that need support in carrying luggage or assistance with walking or finding the right location in a building. - Monitoring of well-being of passengers, before, during and after a trip a regular taxi driver also takes a role in the well-being of passengers. Taxi drivers are also trained to provide first-aid medical support. - Monitoring the need for cleaning of the inside of the vehicle and service provider to perform cleaning if necessary, during operation - Monitoring for misuse of the taxi by passengers (damage, eating, violence, etc..) Conclusion: in markets in which passengers require physical assistance the teleoperated service cannot fulfill customer needs. However, in other segments like business travelers or nightlife teleoperated services are feasible.
information	- The most import communication between a passenger and the teleoperator is the confirmations of the destination. The communication between the passenger and the teleoperator can be facilitated with an in vehicle communication system (with video). - Well-developed apps are available for communication and interaction with passenger for pre-trip booking and payment (e.g. Uber app). - There may be a need for interaction between the teleoperator and the passenger for safe entry and exit, e.g. pre-trip: finding the taxi - verbal communication by cell phone; on-trip: determining precise drop-off point: verbal communication between passenger and teleoperator with in-vehicle communication system. - Social chat could be made available with in-vehicle communication system (if this is valued by passengers)

	- In case of accidents there is a need for a protocol taking care of: (a) identification of the teleoperating driver and availability to authorities, (b) communication platform to facilitate communicate between driver, company and the authorities, (3) criteria for the need for local presence on behalf of the driver/company and response time. Conclusion: in addition to existing apps for pre-trip booking and payment, an in vehicle communication system (with video) is required for optimal communication between passenger and teleoperator during the trip.

Table 21 The business case of teleoperated taxis and applicability of the business case model to taxis

Business case	Business case calculation model
The applicability and profitability of teleoperation is highly dependent on the needs and preferences of the various segments of passengers in the taxi markets. E.g. elderly people and people that will be or have been treated in hospitals may need or want the assistance of a driver entering or leaving the taxi, carrying luggage or accompanying them from door to door. In other market segments, e.g. business travelers or nightlife travelers, passengers may not need the assistance of a driver. The size or share of each segment of passengers can be different in cities and rural areas and may be different during the week, evenings and weekends. At some specific locations support for entry and exit of passengers and handling of luggage could be supported locally, e.g. at hospitals, airports, railways stations, elderly homes, etc. These services could also be offered by independent service providers as additional services offered in a MaaS platform. Assuming that teleoperated taxi services can be offered to a market segment in a region, the main benefit of teleoperation is the reduction of waiting times before the arrival of a new passenger or passenger request. The teleoperator/vehicle ratio determines the profitability of a teleoperated taxi service. The ratio depends on the specific characteristics of a region and the demand patterns. It seems to be more beneficial to road transport in	Business case calculation can be applied with modification of the major cost elements (e.g. cost of drivers, cost of fuel, cost of vehicles, maintenance, etc.); Compared to road transport, taxi services have peak and off-peak hours. The peak and off-peak hours need to be calculated separately to avoid the calculation of a daily averages. If the business model of self-driving passengers is adopted the simulation model and business case calculation needs to be adjusted to incorporate the additional ‘waiting time’ when the passenger is driving the vehicle. The cost structures for the teleoperation kit, control room etc. for taxis are expected to be similar to the cost structure for road transport/logistics.

logistics. Example of an analysis of the teleoperator/vehicle ratio is presented by D'Orey et al. (2016), with a value of 0,4. Some specific segments of the taxi business have high peaks and low demand in off-peak hours. During the peak hours all vehicles required a teleoperator and the benefits of teleoperation are limited, e.g. school transport. However if teleoperators in these market segments could be mae available to drive buses during their low demand hours, cross-sectoral benefits can be realized. The teleoperators that are appointed to should be trained and certified to work in e.g. taxi-transport, logistics or public transport. The concept of a support operator is already applied by Waymo for fully autonomous taxis, although Waymo recognized three roles: traditional dispatch, fleet response and rider support (Madrigal 2018).	

Table 22 Impact of teleoperation on business models in taxi services

Impact of teleoperation on business models in taxi services
The introduction of shared, pooled, autonomous or teleoperated vehicles blurs the boundaries of traditional services of offered by private vehicles, car rental services, private driver services and taxi services. D'Oray et al. (2016) present a taxi-service in which teleoperators drive a vehicle to the location of the passenger but the passenger drives the car himself to his/her destination. From the destination the teleoperator takes over again to drive the vehicle to the next passenger or a parking. There are no examples of services already offered commercially and show that passengers also have the desire to drive themselves in a strange environment in order to be able to travel at a lower cost. However, new entrants to the market could proof that there is a market for low-cost self-drive taxi services. Teleoperated taxi services can drive the next disruptive phase in the taxi market. Currently drivers bring in their labor and their own car. In a teleoperation scenario, the link between the teleoperator and vehicle is no longer fixed. Platforms have multiple options in defining the role of the teleoperator and ownership of the vehicles. Option A would be to insource both the teleoperation center and take ownership/lease of the vehicles. Option B would be to contract independent teleoperators working from home but taking the ownership/lease of the cars. Taking ownership/lease of the cars allows cleaning and fueling of the cars to be organized centrally.

8.3 Generalization to bus transport/public transport

8.3.1 Literature overview

Although various European projects, like CityMobil2, SHOW and AVENUE in which field labs were performed and various OEMs are conducting trials in European cities, the number of published studies on business cases and success factors for deployment of automated busses in public transport or other transport services is limited.

Hjelt (2021) studied the total cost of ownership of autonomously operated buses at autonomy level 4 and 5 supported by remote operators. Data were obtained from three different robot bus trials conducted in three different locations in Finland. The goal of analyzing the data from the robot bus trials was to establish what type of incidents automated buses typically encounter, how often those incidents occur and how they are resolved and how much time and effort of remote operators was allocated to these incidents. Knowing the number of the incidents and the kilometers traveled during the robot bus trials allowed determining an incident ratio for each trial. An incident ratio describes the ratio at which a robot bus on average encounters an incident per each kilometer it travels. To study how many robot buses a single operator could remotely supervise simultaneously while the buses still maintain an acceptable average speed, a simulation was conducted where a variable number of buses drove a route and encountered incidents at random intervals.

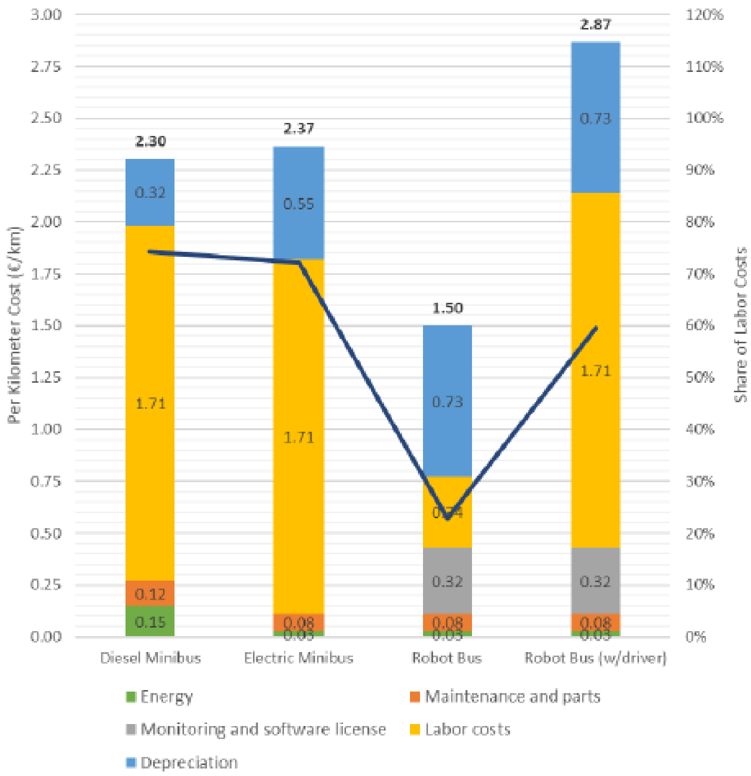

Figure 23 comparison of the total costs of ownership for buses (Hjelt, 2021)

The results of his thesis demonstrate that no insurmountable barriers exist for remotely operating several automated buses at the same time by a single operator. The number of buses that can still be reasonably supervised by one operator depends on the frequency and duration of human interventions required by the fleet of automated buses. For the class of automated buses examined by Hjelt, the operator capacity is estimated to be a maximum of five buses. The capacity is expected to increase once automated buses become more autonomous and less reliant on human operators. Although automated buses have higher purchase prices than conventional buses, their total cost of ownership is already lower when at least two buses are designated to the same operator. This means that once regulations allow vehicles without designated drivers and automated driving technology reaches sufficient reliability, automated buses can provide a compelling and cost-effective option to conventional buses.

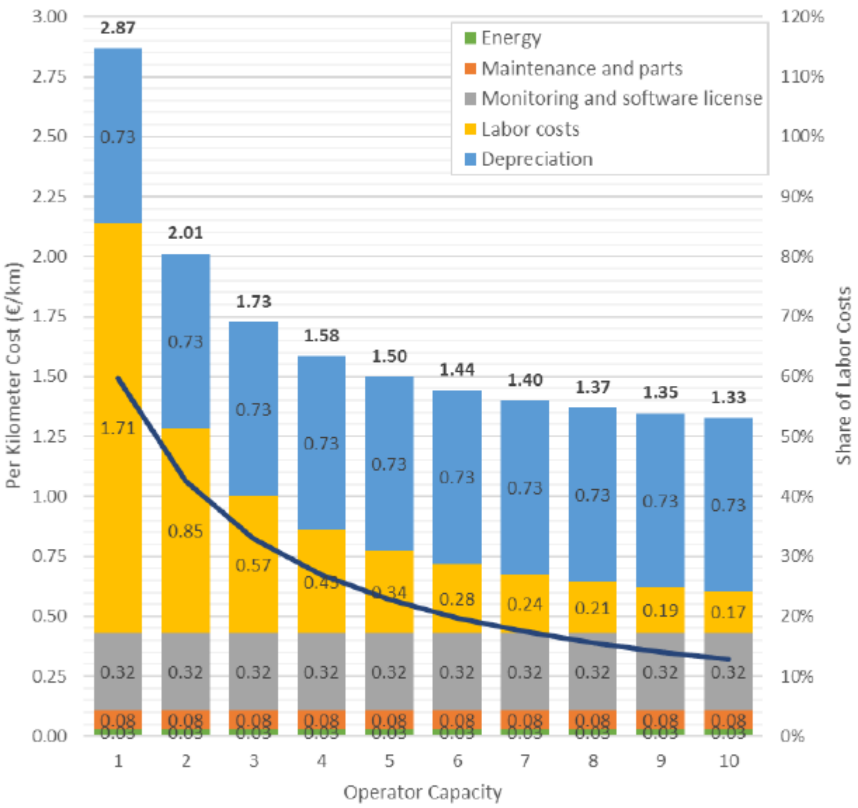

Figure 24 impact of operator capacity on costs (Hjelt, 2021)

As discussed in the section on teleoperated taxis, the impact of automation on the cost structure of buses is explored by Bosch et al. (2019). Non-automated urban buses and regional rail lines operate at similar costs per passenger kilometer as private cars (see Figure 22). The picture changes substantially with the automation of vehicles. While the cost of private cars and rail services changes only marginally, autonomous driving technology allows taxi services and buses to be operated at substantially lower cost, even more cheaply than private cars. In an urban setting, taxis become cheaper than conventional buses, yet they remain more expensive than automated buses. The absolute cost difference between buses and taxis, however, is reduced substantially through automation from 2.20 CHF/km to 0.17 CHF/km for individual taxis. Even in relative terms, automated taxis will be only 71% more expensive for individual and 21% more expensive for pooled use than automated buses (compared to 415% and 204% before automation). In regional settings, defined as suburban and exurban trips, automated taxis and buses become cheaper than private vehicles and rail services. Here, pooled taxis are the cheapest mode (0.21 CHF/km), followed by individual taxis (0.32 CHF/km). In a regional setting, based on operating cost, automated buses and trains no longer seem to be competitive (0.40 and 0.44 CHF/km).

Both Hjelt and Bosch et al. focus primarily on level-4 and level-5 and do not focus on teleoperated bus services at level-0 of automation.

8.3.1 Business case & organizational changes in teleoperated bus services

Table 23 Responsibilities of teleoperating bus drivers and organizational changes and system requirements

vehicle	the tasks and responsibilities of (teleoperating) bus drivers in traffic are similar to those of truck drivers. fueling and maintenance: buses are predominantly operating locally or regionally and can be refueled at existing depots. Busses are generally returned to a depot for service and to avoid vandalism. Fueling and repairs/maintenance can be performed at the depot. the need for assistance for fueling and small repairs for busses exploited in long distance bus services is similar to the needs in long haul logistics operations, e.g. international bus routes or holiday travel. need for teleoperation controls for opening/closing of doors and cargo holds (in case of touring car/coach services) **Conclusion:** there are no barriers in transferring the tasks and responsibilities of a bus driver to a teleoperator or technology on the vehicle.
passenger	inside cameras are required to monitor safe entry and exit of passengers during stops connecting the signal that passengers want to exit at the next stop to the teleoperation control system internal video surveillance system to monitor the safety and well-being of the passengers. Although surveillance systems are already present in most buses in public transport, the lack of a driver may reduce the perception of safety to passengers. Passengers' perception of lack of personal security on board is a concern to anticipate when mainstreaming driverless shuttle bus mobility (Salonen, 2018).. In case of incidents with passengers, drivers are training to provide first-aid to passengers or other traffic participants if necessary. Bus drivers are trained to provide this service (transport companies are not legally or contractually obliged to provide first aid services). This is not possible in case of teleoperation. **Conclusion:** in public transport there are no barriers to the use of teleoperators. All tasks performed by a regular driver supporting and facilitating passengers can be taken over by a teleoperator or technology.

information	all basic information exchange between passengers and teleoperation driver could be facilitated with an in-vehicle information & communication system, although bus operators generally aim to minimize the interaction between passengers and drivers when the bus is moving. the task of selling tickets is already shifted to vending machines in the vehicle or at the bus stops or is organized digitally with contactless cards and MaaS-apps. The routes of buses and the allocation to platforms at bus stations are already predetermined. The information on routes and platforms can be made visible for teleoperators because it is already digitally available in the bus and could be integrated in the teleoperator control system. in case of accidents there is a need for a protocol taking care of: (a) identification of the teleoperating driver and availability to authorities, (b) communication platform to facilitate communicate between driver, company and the authorities, (3) criteria for the need for local presence on behalf of the driver/company and response time. **Conclusion:** the driver does not perform essential information services to passengers or other stakeholders (except in cases of incidents). The exchange of information is already transferred to apps and MaaS-platforms.

Table 24 The business case of teleoperated busses and applicability of the business case model to bus services

Business case	Business case calculation model
In public transport, the service providers design their bus schedules optimizing the utilization of the buses and maximizing passenger-kilometers. After that, drivers are allocated to the schedules. Teleoperation will allow public transport operators to optimize the drivers' schedules. Because the location of the driver no longer plays a role, the operator can easily assign the driver to a service that better matches the remaining working time of a driver. Utilization of the drivers' time may increase with only 1%, but may have considering impact of profitability of a public transport operator because of the low margins. compared to road transport/logistics, the duration of the stops for entry-exit of passengers are small and shifting a teleoperator to another bus does not provide efficiency gains.	The business case model cannot be applied without major redesign: (1) the trucking support operator needs to be specified or eliminated from the model, (2) the model does not take into account that bus services are predetermined. Bus productivity cannot be increased by eliminating all waiting times in schedules by allocating another driver. These waiting times are included in schedules to make them more reliable. Data on the cost structure of bus operation should replace the costs of truck operations Costs of teleoperation system, etc. is similar to costs in logistics operations

making a split in the tasks and responsibilities between a driver and a support operator for guidance of the passenger does not provide efficiency gains either if the driver is waiting to pursue his route. no efficiency gains in deployment of the buses. Teleoperation does not provide clear opportunities to change the schedules and routes. For both bus and taxi transport a significant improvement of the business case could be realized if teleoperators can be shared across mobility markets, i.e. taxi and bus drivers required in the morning and evening peaks may be used in for instance container transports for trips that do not have strict time constraints and can be planned in a flexible way (e.g. inter terminal transports). This may require that teleoperators are trained or certified for operation in multiple markets (i.e. Code95 for transport and logistics).Furthermore, unions might not be in favor of more flexibility in the deployment of teleoperators because it will have an impact on the number of jobs in the taxi, bus or logistics industry.	

Table 25 Impact of teleoperation on business models in bus services

Business models
The focus on research and innovation is mainly focusing on level-4 and level-5 automation. Change in business models using teleoperated driving at Level-0/1/2 has received very little attention from scholars. In many public transport networks, the bus capacity is hardly used during off-peak hours and buses are largely empty. In many cases, bus companies keep operating these services because it has been contracted by authorities in the concession. With teleoperation a more flexible service on demand services could be offered with smaller buses. Teleoperator can switch between buses strategically positioned in the network when passengers request a ride.

8.4 Generalization to teleoperated barge transport

Table 26 Responsibilities of teleoperators in barging and organizational changes

Barge	The main task of the teleoperator is to steer the ship safely from port of origin to port of destination and communicating with all relevant authorities during the journey to follow instructions in locks, at bridges, in waterways and in ports. A captain of the ship is legally responsible for the stability of the ships and the stowage plan of the cargo. If all the information is available to the teleoperator, he can make the stowage plan and give instructions to the crew or ask one of the crew member with sufficient skills and experiences to make the stowage plan en oversee the loading process. If the teleoperator services are offered as a service, the teleoperator is liable for any damage and incidents. In contract to the driver in road transport, physical activities necessary during mooring of the ship and opening of hatches and cargo holds are generally not carried out by the captain or skipper, but by the crew of the ship. This means that no transfer or automation of tasks is required. There are no regulations or job requirements defined for teleoperators in barge transport. Currently, service operators require teleoperators to have or build practical experiences as a captain on a barge.
Cargo	The teleoperator is also responsible as acting captain for the cargo transported by the ship. The teleoperator can transfer tasks for inspection of the cargo and monitoring of the loading or unloading process to a crew member, but he remains responsible. If the teleoperator wants to inspect the loading process himself, then cameras or other sensors need to be installed. In some Preparing and monitoring the (un)loading process could be allocated as separate task to a load master that is facilitating their process for multiple ships in parallel and allows the captain to be assigned to navigate another ship.
Information	Although the captain is responsible for availability of the documentation and provision of information to authorities this task can be allocated to crew members or a remote load master supporting the teleoperator. Communication with authorities while navigating the ship can be done as in the current situation: by the teleoperator himself or a crew member. The teleoperator should be able to communicate with authorities through the ship's communication systems to allow the crew members to follow the conversation if necessary.

Table 27 Business case of teleoperated barges and applicability of the business case model

Business case	Business case calculation model
the business case for teleoperated inland navigation is driven by savings on the wage costs of a captain during the time that a ship is not sailing and the specific conditions for captain on board do not apply. A second potential saving is a reduction in energy consumption because a teleoperated captain can maintain the optimal speed and is less likely to be distracted by non-business considerations that do play a role in an owner-operator who occasionally also disembarks. wants to finish and has to make time for it. Like in road transport the business case depends heavily on the characteristics of the barge operations, however since (un)loading may take several hours the benefits are significant. The costs of implementing a retrofit-teleoperation kit on a vessel depends on the type of ship and its age. The commercial viability of teleoperated barge services is already proven by Seafar.	The TO/V ratio also applies to barge transportation. As most barges already operate 24/7, there are no additional benefits of additional deployment of ships during the night in international transports. This effect needs to be excluded from the calculations in the model. The allocation of teleoperators could be limited because certain experiences and skills are needed to navigate a specific (type) of ships. The wages of a teleoperator are most likely to be in the same range of regular captains. the first operators who have started have extensive experience as captains in inland navigation and will want to continue to earn the same salary even though working conditions are more attractive.

Table 28 Impact of teleoperation on business models in barge transport

Business models
The business model of teleoperated captain services is already introduced in the market by Seafar. In barge transport there are many owner-operators operating a single ship. Independent teleoperator services providing service to multiple owner-operators are capable of generating beneficial TO/V ratios. Alternative barge operators that own multiple ships with company staff are in a position to create a teleoperated fleet on their own.

9. CONCLUSIONS

9.1 Role of teleoperated transport

Teleoperated transport can be an important enabler for the introduction of autonomous transport. Teleoperation makes the move to driver-less vehicles possible, but still offers the possibility to drive and support vehicles in complex situations in which autonomous systems are not yet able to steer a vehicle safely through traffic or in traffic situations in which there is no social support to allow vehicles to drive completely autonomously. A first step in the introduction of teleoperation in transport is with level 0 autonomy. This means that the driver still has full control of the vehicle, but does not perform these tasks in the vehicle, but in a control room at a different location. Teleoperation is primarily interesting for the transport industry because it allows logistics services providers to increase the productivity of drivers and trucks. Teleoperated drivers can be allocated to other trucks while trucks have come to standstill because they are waiting or (un)loading. Trucks can be exploited more effectively because their deployment is not limited to the allowed driving hours of drivers that have to rest before they can continue their journey. The gain in productivity is significant in logistics operations with long waiting times, with long loading/unloading times and in long haul international transports when resting times considerably add to the complexity of planning and impact trip duration, therefore have an impact on efficiency and overall costs.

9.2 Benefits of teleoperated transport

The main benefit of teleoperation is the opportunity to deploy a driver onto another vehicle once a vehicle goes to a standstill. A group of operators can support a fleet of vehicles that is larger than the number of operators. The teleoperator/vehicle ratio (TO/V-ratio) gives insight into which percentage of the required traditional drivers would be sufficient to operate the fleet with teleoperators. The TO/V ratio depends heavily on the characteristics on the logistics operations (percentage of the time vehicles come to a standstill), the service levels that have been agreed with supply chain partner. The service level could be defined as the maximum waiting time for teleoperated vehicle waiting for a teleoperated driver to be assigned to the truck. In this study a simulation model is presented to analyze the TO/V-ratio and to explore the relationship between the TO/V ratio and the service levels. The case studies indicated that a 10-minute improvement in response time could require 10 percent more teleoperators to operate a fleet, which leads to lower operator utilization rate and higher cost.

9.3 Size of fleet matters in creating benefits

Furthermore, the simulation of a fictitious operation with 450 vehicles showed that the TO/V ratio decreases if the number of vehicles increases. Teleoperation for companies managing larger fleets will be more cost-effective than companies operating smaller fleet. This implies that the traditional owner-operator or other SMEs operating a small number of trucks contracted by larger logistics service provides could be vulnerable if large companies start exploiting these economies of scale with new business models that focus on teleoperated driving, even if they adopt the teleoperator as a service business model.

9.4 Operational and organizational changes required in the supply chain

Not all activities currently performed by drivers can be executed by a teleoperator. Examples are fueling, opening and closing of doors and hatches, connecting trailers, loading and unloading goods, securing and inspection of the cargo and managing paperwork and official documentation. While some activities can be automated in the near future (opening and closing of doors, connecting trailers) or digitized (e.g. waybills), in other cases local presence is required to perform physical activities or physical checks on the cargo or vehicle. The contractual arrangements required for the transfer of responsibilities for safe loading and lashing of the cargo need further investigation. According to the CMR and subsequent insurance regulations, the transport company remains responsible for safe and secure transport of goods, even if the cargo was not inspected or secured by the transport company itself. To properly arrange the quality of service provided by a local presence (shipper or service provider) and the liability, these services need to be contracted by either the transport companies themselves with the respective shippers and logistics service providers at the (un) loading facilities or the tasks and responsibilities in the supply chain should be redefined in the conditions of the CMR (the contract between shipper and logistics service provider) and in INCOTERMS (contract between the seller and buyer). In the current industrial standards (CMR, Incoterms) the logistics service provider remains responsible for undamaged and safe transport.

9.5 Role of the trucking support operator to support teleoperator

Furthermore, a driver is responsible for finding his way at a logistics facility presenting his documents, receiving instructions for loading or unloading and collecting and checking the documents for the next transport. Also, when some traditional driver activities are performed by a local presence, there is a need for communication. Following the example of Waymo for organizing the control room for autonomous taxi service, the consortium suggests shifting all the non-driving tasks from the teleoperated driver to a trucking support operator that is in close contact with the various logistics facilities and support stations (for refueling and safe parking). The trucking support operator will organize the documentation and procedures at a warehouse. The trucking support operator will probably manage the process of multiple trucks in parallel.

9.6 Business case dashboard for road transport

In this project, a business case tool was developed to analyze the business case of introducing teleoperation on a homogeneous logistics operation (e.g., same kind of logistics activities or same type of goods). The model takes into account the impact of the teleoperator to vehicle ratio, the specific characteristics of the logistics operation (length of trips, waiting and (un)loading times, required transfer of activities) and specific costs related to teleoperation. The teleoperator to vehicle ratio is an input to the model and needs to be estimated by analyzing empirical data or simulation of the operation using teleoperations. In this study we do not aim to determine the business case for specific types of logistics operations and the market size for teleoperations in a specific region or corridor. This requires more collection and analysis of empirical data in the various segments of the transport sector.

9.7 Teleoperation in barge transport

The technology for teleoperation is already commercially available for barge transportation in Belgium and the Netherlands. Currently, the main barrier for deployment of commercial services is that it is not permitted by law to sail without a captain or shipper physically present on the ship. The costs and benefits of teleoperated barging is different compared to road transport because waiting and (un)loading times are different compared to road transport and also fitting the teleoperation kit to a vessel takes more effort, partly because of the diversity in ship designs and age. As there is also other crew on the ship there is no need to transfer of tasks and responsibilities related to physical activities to other supply chain or third parties.

9.8 Teleoperation in passenger transport

Teleoperation can also be applied in passenger transport or in private cars. In this deliverable we explored the opportunities and requirements of teleoperation in taxi and bus services. The business case for taxi services is promising since waiting for a new ride has a significant share in the taxi driver's daily activities. In literature, an example from Porto indicates that the teleoperator to vehicle ratio could be .39. Interaction with passengers can be arranged with either cellphones or a communication system built into the vehicle. Besides the costs of management and execution of the teleoperations system, major concerns are cleaning of the vehicle and measures to avoid other undesired behavior by passengers. On the other hand, taxi operators indicate that a large group of passengers need the support of a driver for entering or leaving the taxi or to get from door-to-door.

Furthermore, taxi companies may also provide special transport service to school children or other groups of passenger that cannot use public transport independently. Teleoperation does not seem to be an option in these markets. Apart from the guidance that these groups need, the disadvantage is that these services take place at the same time, creating peak hours. That does hardly provide any opportunities to reallocate teleoperators from one vehicle to another.

The introduction of teleoperated taxis and eventually autonomous vehicles blurs the differences between the services of private cars, rental services, private driver services and taxis services. The opportunity to reposition vehicles between the rides of different passengers or users increases productivity of the vehicles and brings both the operational concepts and the costs of these services closer to each other.

There are no significant operational barriers for applying teleoperation to bus services in public transport. All activities performed by drivers can be taken over by a teleoperator. However, teleoperation does not have direct operational benefits. Waiting times and times needed for entry and exit of passenger are generally much shorter than for road transport and taxi services. Public transport operators can only gain utilization of driver-hours because virtualization of the driver allows the company to use 100% of the available shift (especially when a bus take over can take place during the trip). This may improve the utilization of available driving hours with only 1 o 2% (from 98% tot 100%), but it may have a considerable impact on profitability of public transport operators. In general the profit margins are very thin.

For both bus and taxi transport a significant improvement of the business case could be realized if teleoperators can be shared across mobility markets, i.e. taxi and bus drivers required in the morning and evening peaks may be used in for instance container transports for trips that do not have strict time constraints and can be planned in a flexible way (e.g. inter terminal transports). This may require that teleoperators are trained or certified for operation in multiple markets. Furthermore, unions might not be in favor of more flexibility in the deployment of teleoperators because it will have an impact on the number of jobs in the taxi, bus or logistics industry.

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APPENDIX A. INTERVIEW SUMMARY: SEAFAR

Use case 1 - Teleoperated barge transport

Organization: Seafar
Date: 5 November 2020

Use case description in the light of teleoperated transport

Development of a control center that will facilitate teleoperated barge transport. At the control center a captain will be able to guide one or multiple ships by the use of 5G connectivity. The controlcenter will receive alert when manual take-over is required.

Required investment for deployment of teleoperated barge transport

1) Primary product: Existing ships can be equipped with a control kit that is linked to existing systems and collects available data on engines, thrusters, generators, rudder, etc. This kit will transmit the data to the control center via 5G. The surroundings of the ship will be mapped by an additional HD camera, radar, lidar, sound detection systems that are placedby Seafar. Combination of these tools should be sufficient to control a barge ship from ashore. Depending on the age of the ship and amount of technology already available, thecost and effort will be higher or lower.
2) Secondary product: AI to be used to reduce the need for manual (teleoperated) control image recognition and collusion detection/ avoidance New ships can already be built withthe control and automation kit included.

Effects of teleoperated barge transport:

1) Decrease of idle time
   a. When a barge ship is waiting to moor or to be (un)loaded, currently the captain willstill be bound to that ship for hours or even up to 2/3 days, while with tele-operation the captain can switch to a different barge ship that requires guidance.
   b. Autopilot on straight stretches of the canal will enable captain to switch to a different barge ship. Curves, locks, passing ships, bridges or overtaking wouldrequire support.
2) Decrease resource cost
   Working hours change from 10-16 hours on board of work to 8 hour shift will lead to costdecrease. Captains will no longer need to leave their homes for multiple days
3) Change in the content of the job.
   Captain’s job will turn into onshore job while sailors will get more responsibilities as they will need to become hands, ears and eyes for the captain
4) Decrease fuel cost.
   ETA calculation, lock timeslots and other smart shipping tools can advise on the ideal speedand decrease the need of station keeping.
5) Increase of capacity of new barge ships
   As a captain will no longer be required to stay on board, the facilities and cabin should no longer be fabricated and therefore could be used for additional storage. For now however, a sailor will need to stay on board for maintenance and communication with the controlcenter so some form of human facilities will need to remain.

6) Contribution to sustainability
   Decrease of cost will create financial room for investment in new sustainable barge ships.
7) Safety increase
   Radar, Lidar, sensors will be able to see farther/more than the human eye and hence will beable to respond more pro-actively.
8) Barge-sector in Flanders is decreasing rapidly. It is hard to attract young people that are willing to work long hours on board. Teleoperated transport with 8 hour shifts should turnthis around.

Stakeholders of teleoperated barge transport

1) Shipowners of barges with a length of 38 metres or bigger that are willing to invest in thecontrol and automation kit.
2) New investors willing to buy a new barge ship that would be teleoperated by the Seafar control center.
3) Logistic service providers or shippers situated at inland waterway that are not using bargetransport yet, but are willing to switch/invest
4) Shippers that are interested in modal shift to barge transport.
5) Captains/sailors

Business models teleoperated barge transport

Captain as a service:

1) Niche projects: Smaller barges (38m) fare without a crew on fixed routes, coordinated fromthe control center and with on shore support. Seafar responsible for complete execution.
2) Shore supported navigation: Captain remains on board but during rest hours, Seafar couldtake over control.
3) Crew reduced navigation: captain and crew activities are partially moved from onboard crewto control center.

Added value of 5G for teleoperated barge transport

Improved network coverage expected to improve stability of bandwidth. Connection with the shipneeds to be kept at all times which means that network connection needs to be stable. Large amount of data needs to be transmitted which leads to high network service costs (9 data streamsby 9 camera's per ship)

Required changes for deployment of teleoperated barge transport

1) Training for sailors who take on extra responsibilities on board and captains who will startworking at a control center and need to learn the system and tools at hand.
2) Legal framework requires update. At the moment teleoperated barge shipping is only allowed by means of a permit on ship level. One ship can handle multiple routes if this isindicated in the permit request.

Teleoperated and autonomous barge transport

Teleoperation is considered the control and support of a ship from a distance with specific attentionduring navigation and maneuvering scenario's. Adding autonomy will increase the efficiency, comfort and safety by supporting the captain and crew. However, bargetransport will alwaysrequire a person in the loop.

Risks teleoperated barge transport

1) Increase of layers in the communication
2) Connectivity loss
3) Hacking/Spoofing
4) Technical errors on board or at control center

Benefits of teleoperated barge transport

1) Contribution to sustainability by decrease in fuel consumption
2) Safety increase by shortening working day to 8 hours and support of smart shipping toolslike image recognition and collusion avoidance.

Prerequisites of teleoperated barge transport

1) Define requirements in relation to insurance, certification, safety.
2) Ability for a teleoperated barge ship to execute station keeping in case of emergency.

Key- elements of the business case for teleoperated barge transport

1. Idle time. Captain will no longer have to be paid during idle time as he/she will be able tomove to another barge ship that requires control.
2. Resource cost. Move to 8 hour shifts is expected to lead to a decrease in cost. (See below)
3. Manufacturing cost. If humans are no longer required to remain on board, facilities such asdormitories, kitchens, restrooms and garbage disposal can be disregarded which could decrease the cost and increase the storage capacity.
4. Investment cost. Depending on the age of a ship retrofit could potentially be cheaper thanhaving to invest in a new barge ship.

Feedback resource cost Seafar:

We offer the skippers in the control center the opportunity to work in a shift of 8 hours. This allows them to go home in time and build a social life, which is not possible when they live on board. Because we offer this benefit, skippers are willing to work at a lower wage (we take away the disadvantages of the job).

We offer a continuous service to the ship owner. We work in shifts: early (8), late (8) and night (8) and the skippers alternate. This has the advantage for a ship owner that he is not bound by the sailing hours of personnel on board. Personnel on board may work no more than the number of hours prescribed by law:

Minimum Crew levels on motorships and push barges								
Ship Length	Crew members	Number of crew members by mode of exploitation and standard staffing						
		Trip length max10h	**Trip length max 14h**		**Trip length max 18h**		**Trip Length 24h**	
		Solo operation	A1		A2		B	
		S2	S1	S2	S1	S2	S1	S2
				bow thruster		bow thruster		bow thruster
L<=70m	Skipper *Schipper*	1	**1**		**2**		**2**	**2**
	Helmsman *Stuurman*							
	Able sailor *Volmatroos*							
	Sailor *Matroos*		**1**				**1**	
	Ordinary sailor *Lichtmatroos*						**1**	**2**
70m<L<=86m	Skipper Schipper		**1 of 1**	**1**	**2**		**2**	**2**
	Helmsman Stuurman							
	Able sailor Volmatroos		**1**					
	Sailor Matroos		**1**	**1**			**2**	**1**
	Ordinary sailor Lichtmatroos			**1**	**1**			**1**
L>86m	Skipper Schipper		**1 of 1**	**1**	**2**	**2**	**2 of 2**	**2**
	Helmsman Stuurman		**1**	**1**			**1**	**1**
	Able sailor Volmatroos							
	Sailor Matroos		**1**		**1**		**2**	**1**
	Ordinary sailor Lichtmatroos			**2**	**1**	**2**		**1**

(S1 and S2 indicate technical regulation that may or may not be present on a ship, such as a bow thruster). See: https://wetten.overheid.nl/BWBR0030215/2019-07-01#HoofdstukII_Titeldeel3_Paragraaf3

APPENDIX B. INTERVIEW SUMMARY: HAN

Use case 3 – Automated Docking (driver in the loop)

Organisation: HAN

Date: 6 November 2020

Use case description in the light of teleoperated road transport

The automated docking functionality will support the teleoperator to dock a truck in a safe and efficient manner, where the forward movement of parking is executed by the teleoperator and the back-up maneuver is handled automatically. The functionality can be used on legacy vehicles as there is no need to adjust the truck, rather the infrastructure of the loading site.

Required investment for deployment of Automated Docking

Infrastructure adjustment by placing localization system: placing camera's and RQS GPS antenna.

Effects of Automated Docking

Efficiency increase. Tests have shown that automated docking is faster than manual docking.

Safety increase. Docking based on truck coordinates rather than driver experience and sight.

Capacity increase. Currently traffic flows for docking are always one-way as driver dock from the left where they can check the back of the trailer. With automated docking this requirement would disappear and trucks could dock from the right angle as well. This could increase site capacity.

Driving comfort. After a long drive, truck drivers can be tired, less concentrated, so it could be hard for them to dock safely. Automated docking could take this pressure and additional risk away.

Stakeholders of Automated Docking 1. Distribution centers

1. Distribution centers
2. Driver / carrier
3. Manufacturer (Terberg)
4. RDW (permit for testing)

Business models Automated Docking

As a research facility, this is not part of scope for HAN.

Added value of 5G for Automated Docking

1. low latency
2. closer real time like solution
3. More robust, more stable connection
4. No need for network redundancy

Prerequisites for deployment of Automated Docking

1. Training of teleoperators
2. Training of operators on site
3. Drive by wire product
4. Presence of 5G router/hardware
5. Deployment of teleoperation center

Teleoperated and autonomous road transport

Teleoperation to be initiated on private territories like distribution centers before it can gradually move to public roads where the entire route is 100% teleoperated. One truck will require one teleoperator to be in control at all times.

Risks teleoperated road transport

1. Job environment will become more demanding. Monitoring screens will require moreconcentration than being physically present in the vehicle.
2. Chance of job environment from truck to office with screens will be a big adjustment fortruck drivers. It might lead to their discontent.
3. 5G connectivity might not be able to deliver what was promised. Perhaps at small scalewith individual tests, but the question remains if it will be able to support large scale deployment.

Benefits of teleoperated road transport

1. Safety increase due to increased visibility on and around vehicle (e.g. truck leavingwithout closing door)
2. Efficiency increase (see point 3)
3. Work-life balance & job market variety (project objective)
4. Decrease idle time

Prerequisites of teleoperated road transport

1. Basic safety guarantees need to be provided by automated braking and distance keeping
2. Development of legal framework for testing and further deployment (permit, insurance, certification, safety, etc.)
3. Ensure compatibility of semi-trailer with teleoperated truck/terminal tractor
4. Roadmap that provides insight into expected innovations.

Key - elements of the business case for teleoperated road transport

1. Resource cost. Driver v teleoperator
2. Investment cost for enabling drive by wire on legacy trucks
3. Investment cost for new truck with built-in drive by wire functionality
4. CO_2-emission
    - Manufacturing new models will increase CO_2 level
    - Change in propulsion (electric/hydrogen) will decrease CO_2 level

APPENDIX C. INTERVIEW SUMMARY: VTRON

Use case 2 – CACC based platooning

Organisation: Vtron

Date: 2 November 2020

Use case description in the light of teleoperated road transport

Cooperative Adaptive Cruise Control (CACC) for Truck Platooning: Operational Concept Alternatives

2015 | **Author(s):** Nowakowski, Christopher; Shladover, Steven E; Lu, Xiao-Yun; Thompson, Deborah; Kailas, Aravind

Main Content | Metrics | Author & Article Info

– Abstract

Cooperative Adaptive Cruise Control (CACC) provides an intermediate step toward a longer-term vision of trucks operating in closely-coupled automated platoons. There are important distinctions between CACC and automated truck platooning. First, with CACC, only truck speed control will be automated, using vehicle to vehicle (V2V) communication to supplement forward sensors. The drivers will still be responsible for actively steering the vehicle, lane keeping, and monitoring roadway and traffic conditions. Second, while truck platooning systems have relied on a Constant Distance Gap (CDG) control strategy, CACC has relied on a Constant-Time Gap (CTG) control strategy, where the distance between vehicles is proportional to the speed. For these reasons, a series of trucks using CACC is referred to as a string, rather than a platoon. This report mainly focuses on describing the various CACC operational concept alternatives at the level of individual vehicles, local groups of vehicles and their drivers, and which alternatives should be employed in this research project. These operational concepts can be broken into four categories: string formation, steady-state cruising, string split maneuvers, and faults or abnormal operating conditions.

https://escholarship.org/uc/item/7jf9n5wm

CACC based platooning could be facilitated in two ways by teleoperation:

1) Teleoperator is guiding the first vehicle and the others are following without an active driver. A teleoperator takes over control when a truck is required to leave the platoon.
2) The first vehicle is driven by a regular driver and the others by teleoperator(s).

Required investment for deployment of CACC based platooning

One time hardware investment and monthly cost for software & service that will allow continuous updates.

Trucks need be able to be teleoperated (steer&drive by wire)

Effects of CACC based platooning

The business case for platooning has already been developed. It has a positive impact on fuel consumption due to optimal use of aerodynamics, vehicles can drive closer together which has a positive effect on traffic flow and can lead to safety increase as the vehicles are connected and could better anticipate traffic incidents, and lastly, it adds to the driving comfort of the drivers in the queued vehicles.

Teleoperated platooning, depending on the scenario (see point 1.), could lead to a resource cost decrease. Due to teleoperation in combination with automation the hours spent by the human driver/teleoperator is lower as compared to the current system. If scenario 1 is used the business case is clear as there won't be an active driver at all times, in the second scenario, it is still valid although the expense on the human driver in the first vehicle is to be taken into account, but the second or more following vehicles can be automated reducing the cost from the current system. However scenario 2 would be more expensive than the first scenario due to the presence of a driver on board, but this would be more easier on the implementation side and regulation aspect by having at least having one human driver leading the platoon.

It adds to additional safety as the human response time is eliminated by vehicle to vehicle communication and we expect teleoperated trucks to be able to brake themselves as there is no time for communication from vehicle to control center and back.

Stakeholders of CACC based platooning

1) Shippers
2) Carriers
3) Truck manufacturers
4) Truck (tele)operators
5) Road authorities

Business models CACC based platooning

Offer as a part of the teleoperated package deal, or can be offered as a individual technology as well, however teleoperation would have a higher added value when sold together in terms of revenue for customers.

Added value of 5G for CACC based platooning

5G supposedly will enable teleoperation and with that the business case for platooning can be improved due to decrease of resource cost (see point 3) .

Prerequisites for deployment of CACC based platooning

1) OEM needs to be on board.
    a. Truck's built-in systems need to be compatible with CACC software.
    b. Truck already has CACC software built-in.
2) Basic level of safety
3) Legal framework that defines the requirements regarding CACC based platooning and teleoperation. E.g. Regulation of technology, certification, inspection and maintenance.
4) Availability of 5G during the complete trip including cross border connectivity throughout EU

Teleoperated and autonomous road transport

Teleoperation and automation should go hand-in-hand. Teleoperation is the bridge between traditional transport and fully autonomous transport. Teleoperation will be a business to business set-up rather than business to consumer, unless e.g. Uber/taxi services.

Risks teleoperated road transport

1) Amount of 5g points that are needed to maintain connection at all times
2) Connectivity long range and crossborder throughout the EU
3) Additional role for Rijkswaterstaat to ensure maintenance of 5g point

Benefits of teleoperated road transport

1) Cost reduction in terms of man hours provided that part of the system is automated.
2) Safety increase provided that teleoperation is combined with automation and human errors could be reduced or damages limited
3) Bridge to autonomy in terms of technology where can further automate the driving process step by step.

4) Enhance confidence of the public into semi-automated vehicles where the driver is not physically in the cabin.
5) Additional possibilities like teleoperated cranes where you could benefit from 1 teleoperator being in control of two cranes.

Prerequisites of teleoperated road transport

1) Stable 5G connectivity at all times which is able to transmit at least 4GB/sec (This could be dependent on the amount of vehicles on the same network)
2) Ensure that different tools & technology are able to be integrated.
3) Defined legal framework across Europe. Multiple countries should allow teleoperated transport otherwise OEMs will not be triggered to start manufacturing
4) Define required maintenance by Rijkswaterstaat for 5G connectivity

Key - elements of the business case for teleoperated road transport

1) Required investment for end-user
2) Cost of 5G network connectivity albeit by service cost or infrastructure.
3) Idle time will determine the cost saving by not having a driver at stand-by and enabling a teleoperator to switch to a different vehicle in need of monitoring/assistance.

APPENDIX D. INTERVIEW SUMMARY: ROBOAUTO

Use case 4 – Remote take over operations (road)

Organisation: RoboAuto

Date: 4 November 2020

Use case description in the light of teleoperated road transport

Facilitating teleoperated transport. Control unit with sensors/camera's/add on software can be placed on an existing vehicle allowing it to be controlled from a distance. Several scenarios are possible: 1 driver steering 1 vehicle; 1 driver monitoring several vehicles, 1 driver who is taking overfrom other driver for example during shift change.

Application within the project:

1. Teleoperation of a passenger car in cooperation with Toyota,
2. Teleoperation of a logistics vehicle (Auto-tug?) in cooperation with Terberg
3. Teleoperation of a crane in cooperation with (Kloosterboer?)
4. Set-up of a teleoperation control center in the Netherlands

In a control center, a teleoperator will be assigned a vehicle to steer or he can make a selection to monitor or drive. Assumption is that a vehicle will be standing still if it was not selected by a teleoperator so a teleoperator would always be starting teleoperation from a stand still. However, theuse case on CACC platooning will allow testing of take-over of a running vehicle. This would mean that an operator would get a signal in advance that his assistance is required.

Interaction with other operators could be handled via voice communication or a tablet display togive instructions. Assumption at hand is that we will have paperless document flow and identification of vehicle and driver.

Teleoperation could be a well thought investment in agriculture, mining, city facility services andnon - public sector operations like terminals or distribution centers.

Map of the vehicle operating area (e.g. terminal, city)) would contribute to safety as it will support the teleoperator to navigate on terminals/plants/shipping locations. In addition, GPS position couldbe used to keep the lane. Sensors will be creating their own short range map. All teleoperated vehicles will share the collected data to cloud to which all of them will have access.

All shared data, including video will be encrypted to guarantee maximum security.

Required investment for deployment of Remote take over operations

1. Vehicle control unit with required hardware and software
2. Control center with teleoperators

Effects of Remote take over operations

1. Decrease in resource cost by shared resources
2. Decrease idle time as a driver can easily switch vehicle.
3. Efficiency increase as driver can manage different vehicles at the same time.
4. Job market optimization because it is remote work.

5. Job of operator/driver is growing with current generation. It is a logical change to get younger and new employees to apply for the job as they are used to sitting behind screen.
6. Increased safety for the driver (e.g. mining, chemical industry, explosive materials)

Stakeholders of Remote take over operations

1. Vehicle owner like carrier, terminal or distribution center
2. OEM
3. Local road-authority/regulator

Business models Remote take over operations

1. Subscription model
2. License model
3. Full service model

Added value of 5G for Remote take over operations

1. Increased network capacity. Testing with one or two cars was successful. However, afully teleoperated terminal would require a more powerful infrastructure, let alone teleoperation across the EU.
2. Reliability of connection
3. Vehicle to vehicle communication could increase safety
4. Decrease network latency
5. Increased bandwidth to transfer higher image quality

Prerequisites for deployment of Remote take over operations

1. Network coverage
2. Electronically controllable
3. Working collision avoidance (EF 5) – vehicle stop and/or safe pullover in case connectionis lost
4. Legal framework for teleoperation on public roads

Teleoperated and autonomous road transport

Teleoperation is the ability to drive any vehicle from any place in the world based on sensor data that is transmitted through internet. It provides the most real experience for the teleoperator who is driving the vehicle. A certain amount of autonomy of a teleoperated vehicle is required to guarantee safe operations on the road. This by allowing the vehicle to brake and/or pull over of its own accord in case the teleoperator is not fast enough to respond, an emergency situation or in caseconnection is lost.

Semi-autonomous transport increases the ratio of vehicles to control centers and as such decreaseshuman resource cost. Machines are less prone to error than humans which increases safety.

Risks teleoperated road transport

1. No market on public roads because of legislation.
2. Protest by unions
3. Limited signal coverage

4. Assistance at remote locations

Benefits of teleoperated road transport

1. Lower manufacturing cost as OEM can remove cabin
2. Decrease human resource cost
3. Increased mobility of employees --> connect remote workers
4. Acceleration development of autonomous system
5. Increased safety of the driver due to working remotely

Prerequisites of teleoperated road transport

1. 5g coverage
2. legal framework how to test and validate technology
3. legal framework to operte on public roads
4. OEM support → ability for vehicle to be electronically controlled by external systems (open source software)

Key - elements of the business case for teleoperated road transport

1. Ratio vehicle to driver.
2. Effectivity remote operator compared to operator in the vehicle.
3. Efficiency gain in chain of operations.

APPENDIX E. INTERVIEW SUMMARY: BE-MOBILE

Enabling functions 1 - 8

EF	Functionality	Organisation
1	Enhanced Awareness dashboard (HMI)	Be-Mobile
2	Vulnerable road user interaction	Locatienet
3	Timeslot reservations at intersections	Sweco
4	Distributed perception	IMEC
5	Active collision avoidance	RoboAuto
6	Container ID recognition	Sentors
7	ETA sharing	Be-Mobile
8	Logistics Chain Optimization	Room 40

Interview date: 2-5 November 2020

Introduction

The purpose of the enabling functions is to support and facilitate teleoperated road transport by communication of on-site data to the remote operator by use of a dashboard (EF1). As all enabling functions are expected to provide input through the dashboard and they are all very much intertwined and complementary to one another, the input collected during the interviews was grouped together.

Description of the integrated HMI dashboard in the light of teleoperated road transport The integrated HMI dashboard will enable the teleoperator to see all required traffic and vehicle information in one single view. Comparable to screens currently installed with board computers.

Functionalities of the dashboard:

1) Speed advice based on traffic data & route and taking into account booked intersection timeslots (EF 3).
2) Dynamic map of surroundings that is created based on data collected by one or more operated vehicles by sensors, radar, lidar, camera's (EF 4)
3) Warnings of technical errors, collision avoidance (EF 5), approaching vulnerable road user (EF 2) and other anomalies detected in the transmitted data (EF8)
4) Navigation and routing including ETA (EF7)
5) Container information (EF 6)
6) Place reservation at parking

Required investment for deployment of Integrated HMI dashboard

1. HMI dashboard to be connected to control tower. Investment by teleoperation service provider in the form of a yearly service fee. Discussion would be required how to fit the enabling function cost into this service fee.
2. Traffic light software update (EF 3)

3. Placement of sensor/camera/radar equipment on (legacy) truck (UC 2/3/4 + EF 4/5 potentially EF6)
4. Placing camera's on (public) site(s) (EF 6/8)

Effects of Integrated HMI dashboard

1. Partial transfer of responsibilities to system instead of human operator
2. Create extra safety by additional functionalities apart from camera images on screen
3. Driving comfort for teleoperator by a one-view summary of the situation
4. Monitoring four screens can be quite intensive, with the dashboard the teleoperator has an extra safeguard that it will give a notification if he missed something
5. The dashboard provides a long range view
6. The dashboard provides a safety net in case of image quality loss
7. The dashboard compensates some of the sensory perception loss due to remote driving
8. The dashboard will make the route more predictive and will eliminate unforeseen circumstances. This will allow the teleoperator to plan better and allow an increase ofthe ratio vehicle to human.
9. Decrease of fuel consumption
10. Decrease of CO2 emission
11. Minimize delays
12. Less wear and tear of vehicles
13. Integration of existing business processes such as signing-off the CRM (?)

Stakeholders of Integrated HMI dashboard

1. Teleoperator
2. Control center
3. Teleoperation service provider
4. Road authorities
5. National traffic information provides like NDW (NL) and AWV (BE)
6. Vulnerable road users
7. Non teleoperated traffic participants
8. Terminals
9. Distribution centers
10. OEMs
11. Carrier/end- user

Business models Integrated HMI dashboard

- License model – fixed fee which includes updates and maintenance.

Added value of 5G for Integrated HMI dashboard

1. Low latency
2. Augmented reality
3. Increased connection stability
4. Increased bandwidth

Prerequisites for deployment of Integrated HMI dashboard

1. Quasi real time connectivity

2. Integration other enabling functions (data input)
3. Data prioritization & processing (which information to be shown when.
4. Integration with control center (data output)

Teleoperated and autonomous road transport

Teleoperation is considered to be the next step towards fully automated driving. Although automation would not be necessary for teleoperation, it will make a big contribution to the business case as it will increase safety and vehicle-drive ratio. Overall expectation is that teleoperated transport will gradually move to autonomous transport. It will be a first encounter with driverless vehicles and will support community acceptance. In addition it can be used to test and prove basic safety measures like collision avoidance (EF 5) and test first autonomous functionalitieslike platooning (UC 2) and docking (UC 4).

Risks teleoperated road transport

1. Acceptance by community
2. Safety of other road users
3. Teleoperation will require more concentration of operator
4. Outsourcing teleoperation to non EU drivers
5. Sensory deprivation could lead to more and/or different incidents .
6. Building layers in the communication chain increases risk of error
7. Diagnostics of car infrastructure
8. Human decision-making
9. Theft of data/ control take over/ terrorism by hacking
10. Limited deployment options
11. Union protest
12. Change of job requirements
13. Lack of OEM support

Benefits of teleoperated road transport

1. Cost decrease as resting time and waiting hours will disappear
2. Decrease of manufacturing cost
3. Remote take-over possible in case of hijacking
4. Including machine in the process should lead to decreased risk of error
5. Spread of traffic over 24 hours
6. Possibility to work from different time zones and use that for 24h service
7. Possibility to swap resources within logistics chain (crane/forklift/terminal tractor)
8. Less disputes on waiting times
9. Enabling teleoperator as a freelance job
10. Enabling time for machine learning
11. Change of job requirements
12. Work- life balance (future) drivers

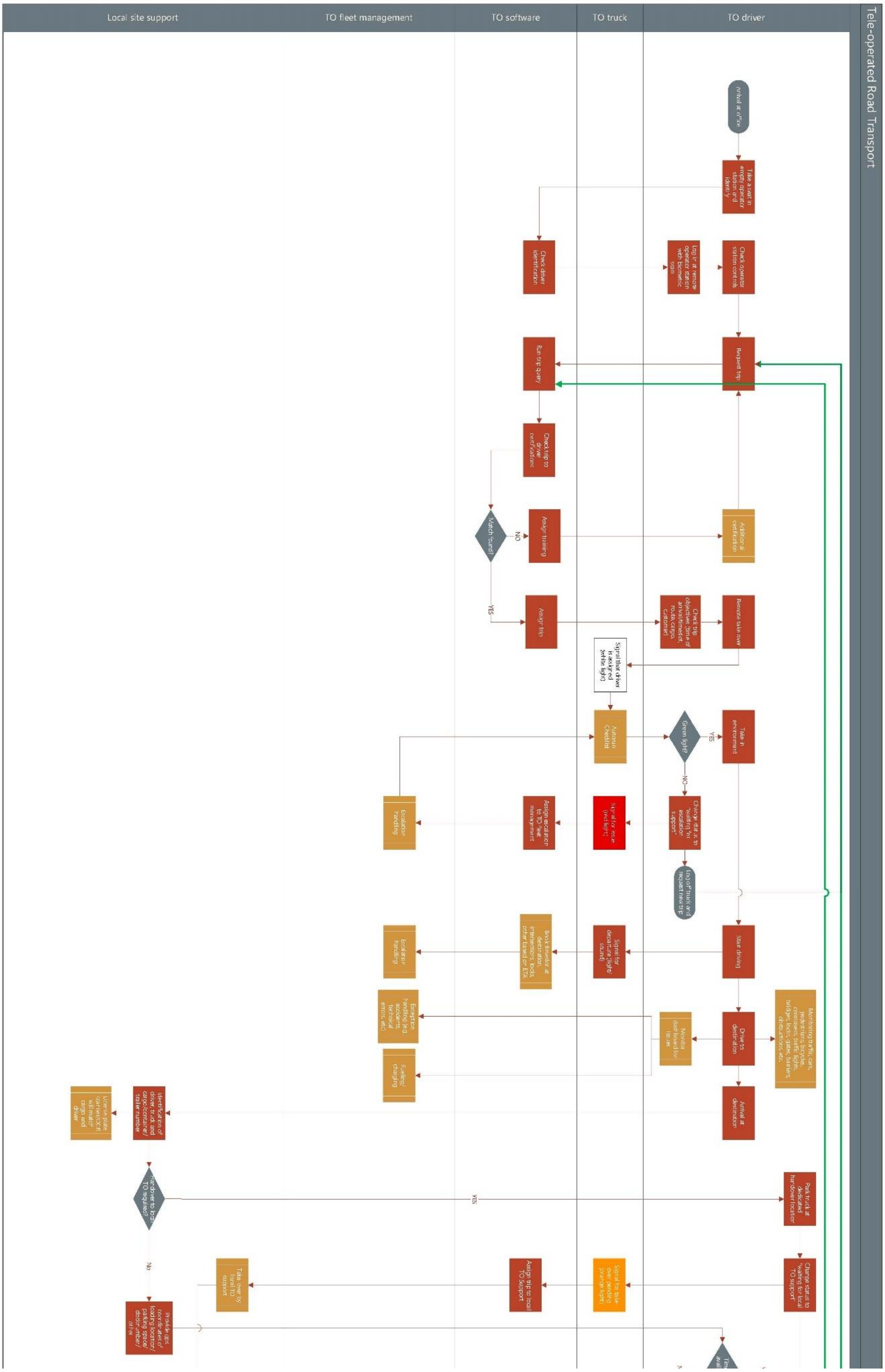
Prerequisites of teleoperated road transport

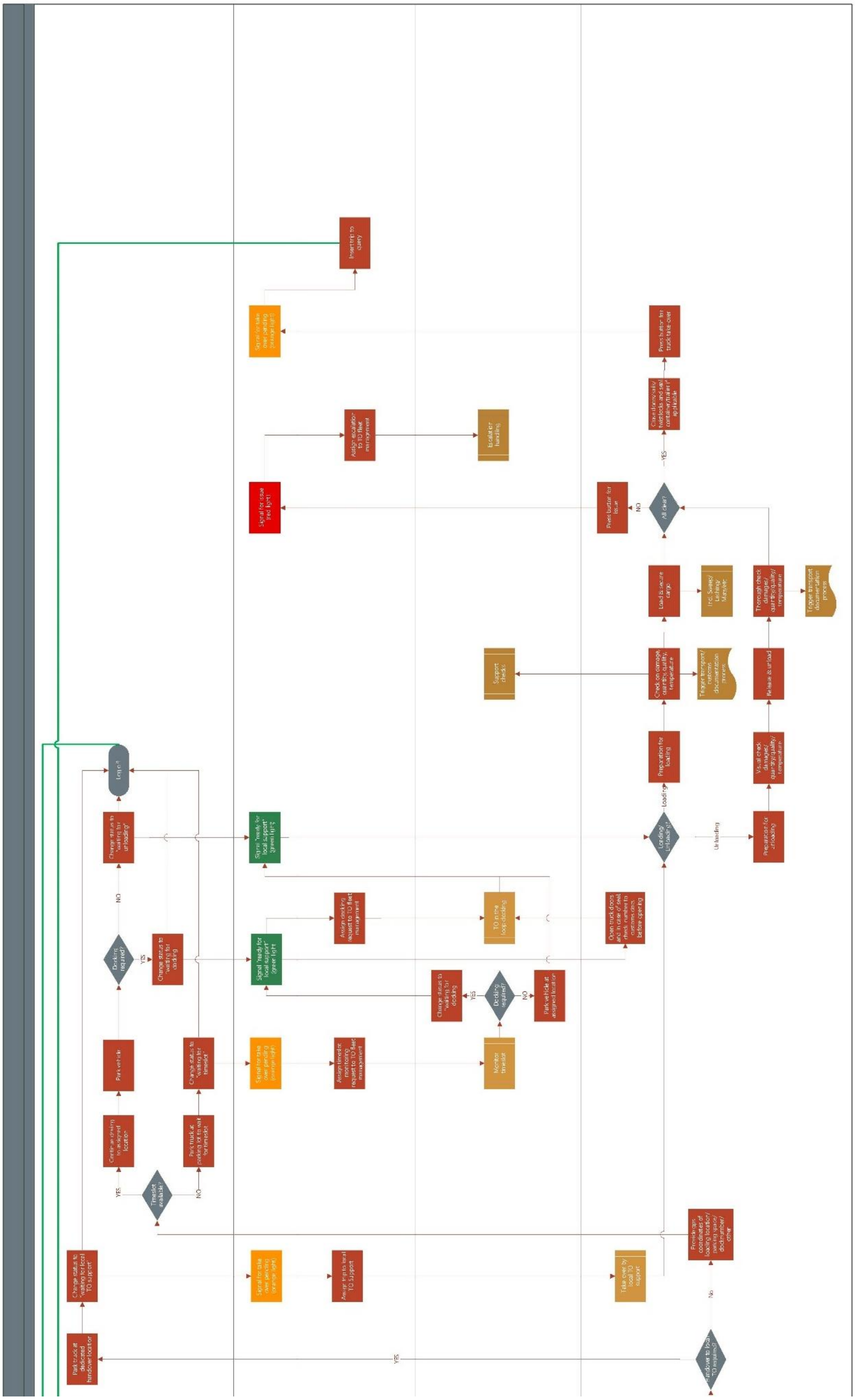
1. Minimum safety guarantee (safe degrade function (EF 5)
2. Standardization of data exchange within EU
3. Piloting to validate that data exchange works properly
4. Governance & regulatory framework regarding insurance, certification, liability, etc.
5. Integration of teleoperation in current business processes in the supply chain, without demanding major changes
6. 5G network to provide what was envisioned
7. 5G connectivity cross border, throughout EU including remote locations, valleys, forest, etc
8. Good representation of reality (including sound, vibrations, etc)
9. Error mitigation plan
10. Good training required/ Good documentation on HMI
11. Good diagnostics of car infrastructure
12. Software should detect connectivity loss and instruct vehicle to a stop (EF5)
13. OEM support

Key - elements of the business case for teleoperated road transport

1. Idle time
2. Distance of routes
3. Cost human capital (driver v teleoperator)
4. Driver – vehicle ratio
5. Manufacturing cost
6. Service cost dashboard
7. Cost infrastructure/organizational changes

APPENDIX F. BUSINESS PROCESS MAP FOR TELEOPERATED ROAD TRANSPORT





Appendix G. Initial Value Network Analysis: Value Network Identification

Introduction And Purpose

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

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

Since a value network describes a more complex economic environment than the 'value chain' concept (Peppard & Rylander, 2006), we choose to use the value network approach to analyze the specific economic environment of cross-border, teleoperated transport. With the adoption of digital technologies and services within the automotive and logistics industries, supply chains have become more complex, requiring a broader perspective.

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

Value networks also help study connections of economic nature between different roles. This usually involves illustrating the flows of revenue, value and other streams (e.g., data or knowledge). The objective is to show how value is co-created by a combination of independent stakeholders that perform the different, mutually-influenced roles (Peppard and Rylander, 2006).

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

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

Methodology

First, we plotted a draft of the value network based on desk research. We identified a list of layers, which in turn include the specific roles and responsibilities. We started by identifying all the key roles involved in creating and delivering value in the studied teleoperated setting;

then, for clarity, we grouped these more granular elements into a common function (the layers).

This role identification also suggested an allocation of certain roles to actors who are potentially willing and able to fulfil them, for the clearest cases. For most roles, these potential actors are still unknown, even though in several cases multiple logical stakeholders could be hypothesized to be the relevant ones, relying on the status quo and promises in terms of their publicized strategies and objectives. However, relying on feedback from our industrial project partners in a later stage will help deliver a more appropriate and confident assessment.

This draft was circulated within the project consortium, and later updated with the feedback we received. The importance of validation is paramount, as no single project partner has an in-depth understanding of the entire ecosystem, due to its scope and complexity.

In the present iteration, we identify six different layers and a total of 42 roles. This results in a comprehensive -albeit not exhaustive- picture of the value network. For simplicity, some elements are simplified; some roles could be broken down into more granular ones, for instance the provision of other network equipment or vehicle components, including the orchestration of edge cloud applications or chipsets for computation in vehicles.

This analysis will be extended and complemented in Task 3.2 of the project. Moreover, this initial value network will be used as an input and groundwork to define the business models, as well as for the techno-economic analysis of T3.3.

In Task 3.2, we will look at the value network in more depth, in order to assess the impact of future remote operation use cases on the current situation. We will, through individual feedback and workshops with project partners, identify which actors have the capabilities to perform each role, and what they would require from others in order to do so, in terms of goods, data, etc. Next, we will also map interactions amongst roles.

Value network mapping & description of roles

The architecture in the figure below identifies six different layers of roles involved in the overall teleoperation use cases ecosystem, together with an incipient allocation of each role to the actors potentially willing and able to fulfil it. This initial role allocation shows the potential able and willing actors that could fulfil each role. Most roles remain unallocated, either because it is unclear who could perform them, or because the existence of the role in question will depend on a particular business model. If key roles are not taken up by any entity, even at the project's 'pre-market' stage, the chances of the project's innovations being adopted will be threatened, since the different stakeholders will need certainty that other actors will take up the complementary actions and responsibilities. Therefore, our analysis in T3.2 will discuss options and provide recommendations regarding these roles.

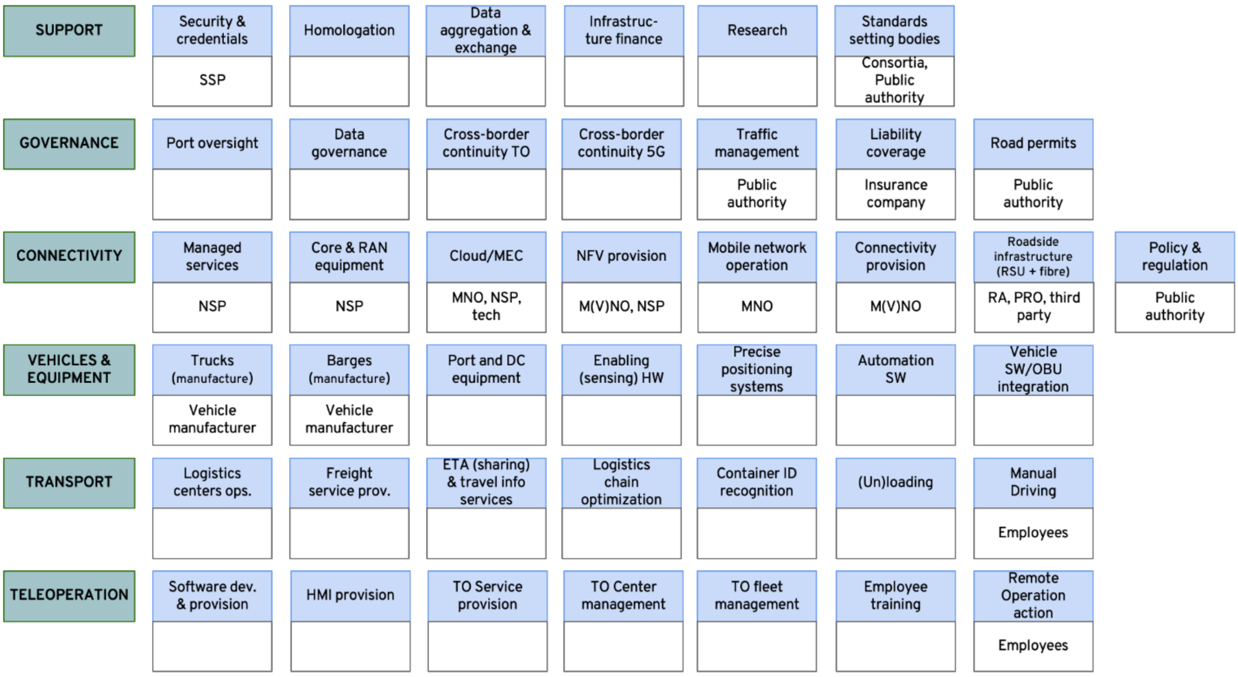


Figure 25 Initial value network for teleoperation services. Role identification and allocation[3]

We start the discussion of individual roles from the bottom layer, as it has the most direct contact with the provision of the ultimate teleoperation service and represents the most novel part of this analysis.

Teleoperation layer

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

Provision of technology (software and HMI). Technology providers provide the technology for the vehicle and for the control room from which a teleoperation driver can control the vehicle, vessel, crane, etc. On the one hand, this consists of the technology aimed at creating and increasing the situational awareness and on the other hand creating the optimal human machine interface (HMI) to allow the teleoperated driver to function optimally. The HMI includes a dashboard where messages on speed advice, warnings, navigation and routing features are shown to the remote operator employee. These messages represent important functions to enable teleoperation. Regarding the uptake of these roles, the provider of the dashboard software may be a different one than who provides the teleoperation software, as it may be a company that specialises in the processing and visualization of the information. Because a wide range of different technologies is used in teleoperation, integrators may offer complete solutions and relieve logistics users.

Remote operation (TO) service provision. The introduction of teleoperation also makes new roles possible, for example providers of teleoperation services, i.e. those services where a transport company requests, on-demand, a driver from a service operator to drive a vehicle from a certain point to another. This service can be expected to be provided from a teleoperation (TO) center by a service provider. Despite the high pressure on the labor market for drivers, a positive business case is necessary to convince companies to invest in

[3] **Legend**. RA: road authority (incl. traffic agency); NSP: network solutions and equipment provider; M(V)NO: mobile (virtual) network operator; PRO: private road operator; SSP: security services provider.

teleoperated transport. The main advantages and disadvantages of teleoperated transport from a cost-benefit perspective will be discussed in a different section of D3.1.

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

Teleoperated fleet management is a new role responsible for activities that require interaction with local operations, road users and fueling/charging stations. It is assumed that these interactions will be provided via a mix of manual and audiovisual signals. For instance, for the current driver responsibilities of docking and fueling, these activities include, among others:

Communicating, digitally, to the TO driver when a vehicle is ready for docking, after receiving such request for docking. And when being notified by the TO driver that docking has been executed, communicating that all is clear for loading.

Communicating with an employee of a gas/charging station that the truck is requesting fuel via an audio or visual sign (e.g, via a screen in the truck), or providing payment in a similar way. When the task is done, the fleet manager can notify the TO driver that the vehicle is ready for departure.

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

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

Remote operation action. This refers to the actual task of teleoperating a vehicle or equipment, as well as the responsibilities with respect to safety and cargo handover that are now performed by a driver. These tasks will be taken over by employees at a logistics center, which will lead to new responsibilities for said center. As a central stakeholder, logistics employees are the ones who will ultimately perform the remote operation actions. The introduction of teleoperated driving and barging will change the work of drivers and skippers and reduce the need for the traditional role of driver. While other workers will still need to be present on-site for certain tasks, here we focus on remote operators. In addition, the new position of a teleoperation driver, skipper or crane operator is created with different job requirements and employment conditions. Even though we group them into one single role for simplicity, operators who are responsible for different types of vehicles or equipment may require different skills, training, workplace settings, locations, dashboard information, etc. Moreover, safely performing the teleoperation task in the open road instead of in more controlled environments will require different permits as well.

Transport layer

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

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

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

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

From the point where cargo arrives at a port by ship until it reaches the motorway with a truck, multiple logistics-related roles are involved at the different stages of the trip. Some straightforward roles entail **loading and unloading** the cargo, **identifying and assigning containers** in real-time, and **providing navigation, localization and estimated time of arrival** (ETA).

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

(Non-remote) Manual driving. Skippers and truck drivers will be aided by teleoperation, but (at least during the short- and mid-term) teleoperation technology will not make them redundant. Therefore, they will still hold, to some extent, responsibility for the well-being of the vehicle and the cargo. They are an important stakeholder, since they are subject to be affected as their job changes as a consequence of remotely operating certain tasks or parts of the trip. In certain deployment scenarios, an entire route or 'milk run' may be remotely operated, removing the need for a human driver or supervisor physically on board.

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

Lastly, the **operation of logistics centers**. Logistics centers are locations (warehouses and terminals) where teleoperated vehicles and barges load and unload goods. These locations must be adapted to receive and handle teleoperated vehicles. This requires adjustments in communication with the teleoperation driver and solutions for the tasks that are currently still being performed by drivers.

Vehicles and equipment

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

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

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

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

Provision of precise positioning systems. This role implies the provision of high-accuracy vehicle positioning and is likely to be played by an equipment manufacturer or integrated into other roles of this layer. Precise positioning may be enabled by GNSS receivers in vehicles and roadside infrastructure. This role could be merged with, or likened to, the role of providing HD maps via streaming in 5G CroCo (Vilajosana et al., 2019).

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

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

Connectivity

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

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

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

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

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

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

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

Policy and regulation. This role covers the definition and enforcement of regulations and policies relating to network aspects, such as allowing (active) network sharing or assigning spectrum licenses. It may be played by national and/or supranational bodies.

Deployment of roadside infrastructure. Lastly, deploying small cells and fibre networks by the side of the road will enable vehicle-to-infrastructure communications. It is unclear who will be responsible for deploying these elements, as they can be used for traffic management purposes, C-ITS services and road user-oriented entertainment services. It may be done by a road operator-public or private- or a third party. In similar European projects it has been argued that road authorities, as owners and/or managers of road infrastructure, must play a critical role in aligning with the automotive and telecom industries to deploy the technology (see, e.g., Vilajosana et al., 2019).

Governance

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

Port and road authorities can expect to keep playing their traditional **management and oversight** roles. In addition, besides managing traffic, road authorities may be responsible to hand out **permits** for teleoperation in public roads. To that end, authorities would need to define the system requirements and operational limits for vehicles and TO services (e.g., in terms of vehicle speed, road characteristics, telco network KPIs and amount of supervised vehicles per remote operator). Having a framework for regulatory permits may also require prior changes in national traffic codes.

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

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

Cross-border continuity of service: connectivity. The coverage of a given telecommunications network will not reach the entire teleoperated trip for some of the scenarios discussed in WP3, or at least the network will not be able to cover the entire area while meeting the defined performance KPIs. Therefore, continuity of service will require a handover between 5G networks of different national MNOs or between public and private networks. It is unclear who will perform this role or the exact responsibilities that it carries; for instance, it may entail guaranteeing that the necessary service-level agreements are in place or defining and enforcing roaming obligations. This role may rely on market agreements between MNOs (e.g., SLAs) and/or supervision and action by public entities (e.g., supranational regulatory bodies). To enable end-to-end seamless connectivity in cross-border situations, and thus seamless roaming, MNOs may also need to adapt their networks.

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

Support

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

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

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

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

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

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APPENDIX H. SIMULATION STATISTICS

Simulation validation

LSP_1

Table 29 LSP_1 Activity frequencies: real data

	Moving	Load/Unload	Resting	Paperwork
Average frequency per vehicle per day	7.02	4.55	3.08	1.93

Table 30 LSP_1 Activity frequencies: simulation

	Moving	Load/Unload	Resting	Paperwork
Average frequency per vehicle per day	7	4	3	2

Table 31 LSP_1 activity durations: real data

Activity	Duration		
	mean	**std**	**median**
Load/Unload	37.90	29.24	31
Moving	55.17	57.86	34
Paperwork	15.07	10.87	12
Resting	25.92	12.47	32

Table 32 LSP_1 activity durations: simulation

Activity	Duration		
	mean	**std**	**median**
Load/Unload	37.48	28.90	30
Moving	52.16	48.58	34
Paperwork	14.59	11.33	11
Resting	31.14	37.98	17

LSP_2

Table 33 LSP_2 Activity frequencies: real data

	Moving	Load/Unload	Resting
Average frequency per vehicle per day	8.83	8.04	1.70

Table 34 LSP_2 Activity frequencies: simulation

	Moving	Load/Unload	Resting
Average frequency per vehicle per day	9	8	2

Table 35 LSP_2 activity durations: real data

Activity	Duration		
	mean	std	median
Load/Unload	45.77	38.59	34.00
Moving	40.14	42.85	21.00
Resting	30.51	15.75	41.64

Table 36 LSP_2 activity durations: simulation

Activity	Duration		
	mean	std	median
Load/Unload	45.33	38.77	32.47
Moving	46.98	43.69	30.77
Resting	26.83	37.21	13.20

LSP_3

Table 37 LSP_3 (bulk) Activity frequencies: real data

	Moving	Load/Unload	Resting
Average frequency per vehicle per day	2.79	3.62	2.34

Table 38 LSP_3 (bulk) Activity frequencies: simulation

	Moving	Load/Unload	Resting
Average frequency per vehicle per day	3	3	2

Table 39 LSP_3 (bulk) activity durations: real data

Activity	Duration		
	mean	std	median
Load/Unload	77.55	52.60	87.13
Moving	65.10	54.58	49.50
Resting	21.06	14.22	19.00

Table 40 LSP_3 (bulk) activity durations: simulation

Activity	**Duration**		
	mean	**std**	**median**
Load/Unload	77.47	52.32	66.95
Moving	75.76	59.10	54.98
Resting	23.88	34.73	11.55

Table 41 LSP_3 (tank) Activity frequencies: real data

	Moving	**Load/Unload**	**Resting**
Average frequency per vehicle per day	3.11	1.81	2.36

Table 42 LSP_3 (tank) Activity frequencies: simulation

	Moving	**Load/Unload**	**Resting**
Average frequency per vehicle per day	3	2	2

Table 43 LSP_3 (tank) activity durations: real data

Activity	**Duration**		
	mean	**std**	**median**
Load/Unload	91.64	47.60	102.00
Moving	68.75	63.70	50.00
Resting	20.12	13.51	18.50

Table 44 LSP_3 (tank) activity durations: simulation

Activity	**Duration**		
	mean	**std**	**median**
Load/Unload	94.94	45.08	92.17
Moving	72.03	54.60	56.00
Resting	23.55	33.44	11.23

KPI and simulation summaries

LSP_1

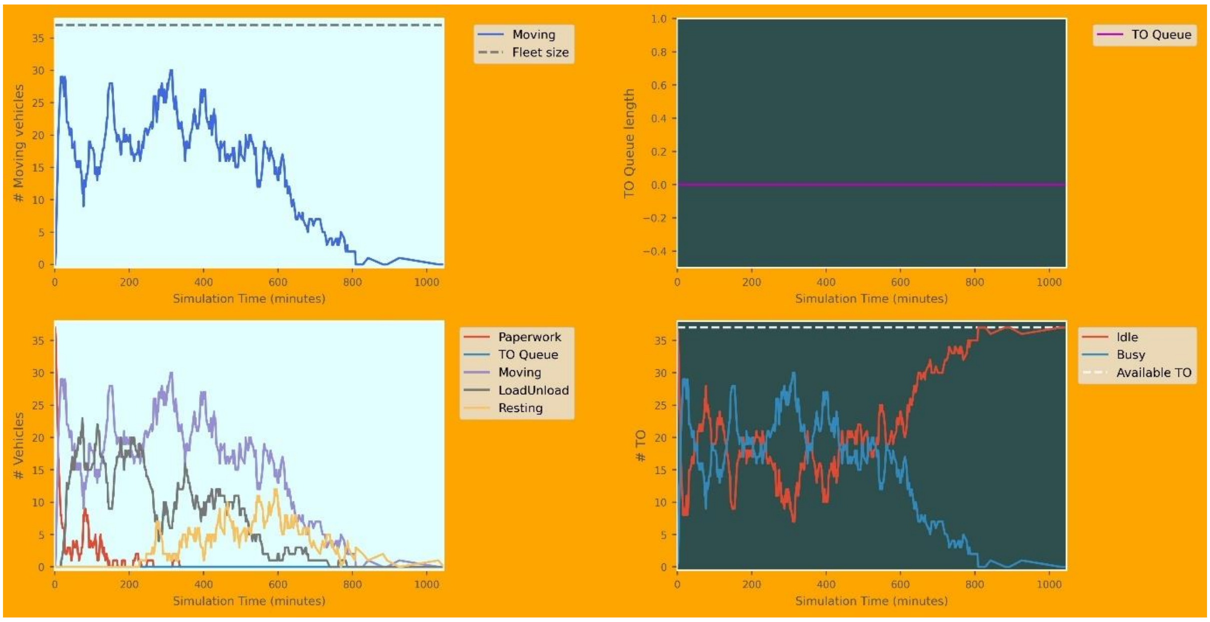


Figure 26 Simulation summary for LSP_1 with TO/V ratio of 1 and TO setup time of 0

Table 45 KPI summary for LSP_1 with TO/V ratio of 1 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.34	0.02	0.31	0.33	0.34	0.35	0.37
AVG TO utilization	30	0.34	0.02	0.31	0.33	0.34	0.35	0.37
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

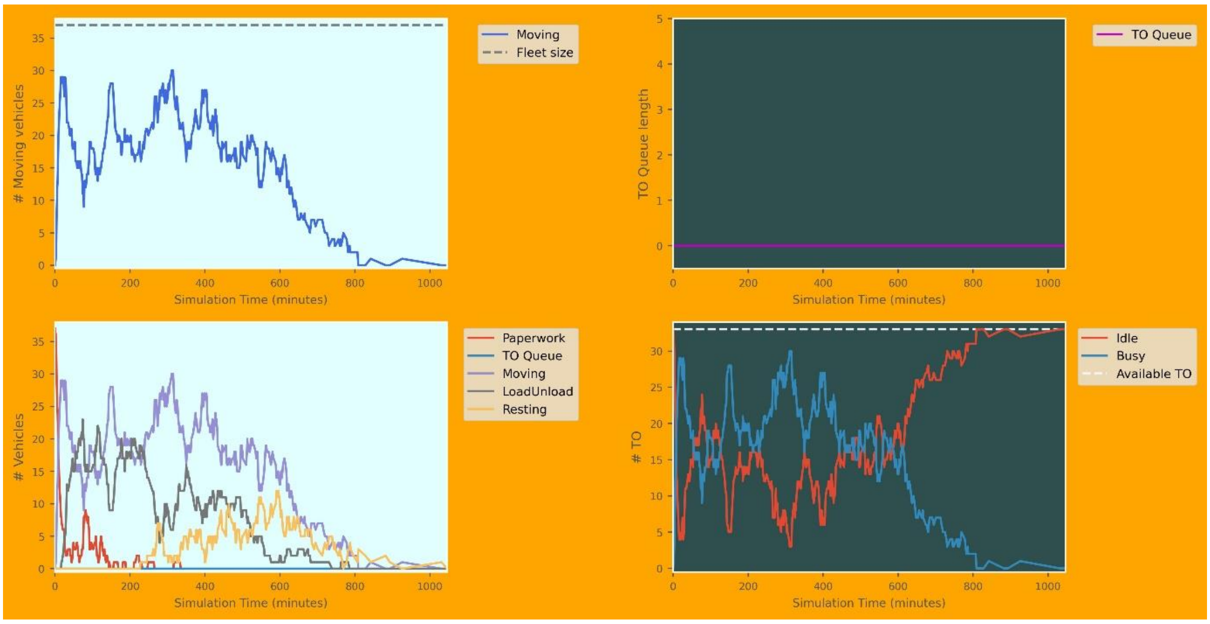


Figure 27 Simulation summary for LSP_1 with TO/V ratio of 0.75 and TO setup time of 0

Table 46 KPI summary for LSP_1 with TO/V ratio of 0.75 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.34	0.02	0.29	0.33	0.34	0.34	0.37
AVG TO utilization	30	0.45	0.02	0.39	0.44	0.45	0.46	0.49
AVG wait time/vehicle	30	0.96	0.75	0.05	0.36	0.80	1.29	2.62
AVG queue duration	30	4.51	2.28	1.40	3.00	3.96	5.84	10.78
MAX queue duration	30	7.37	3.55	2.00	5.00	7.50	9.00	15.00
AVG queue length	30	0.03	0.03	0.00	0.01	0.03	0.04	0.09
MAX queue length	30	3.43	1.77	1.00	2.00	3.00	5.00	7.00

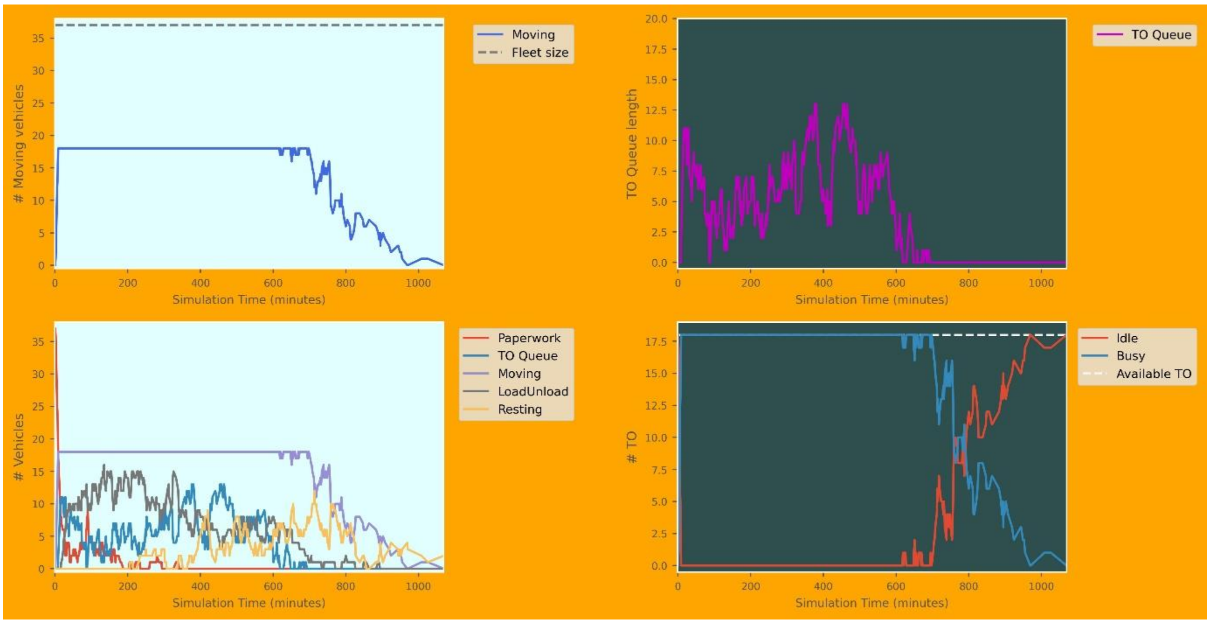


Figure 28 Simulation summary for LSP_1 with TO/V ratio of 0.5 and TO setup time of 0

Table 47 KPI summary for LSP_1 with TO/V ratio of 0.5 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.34	0.02	0.30	0.33	0.34	0.36	0.38
AVG TO utilization	30	0.70	0.04	0.62	0.68	0.70	0.73	0.77
AVG wait time/vehicle	30	99.31	24.22	52.84	79.50	102.60	110.90	156.89
AVG queue duration	30	18.84	3.97	10.86	15.13	19.69	21.11	27.25
MAX queue duration	30	47.60	8.76	31.00	41.25	47.00	52.75	70.00
AVG queue length	30	3.40	0.83	1.81	2.73	3.52	3.80	5.38
MAX queue length	30	14.33	1.52	11.00	13.25	14.50	15.00	17.00

LSP_2

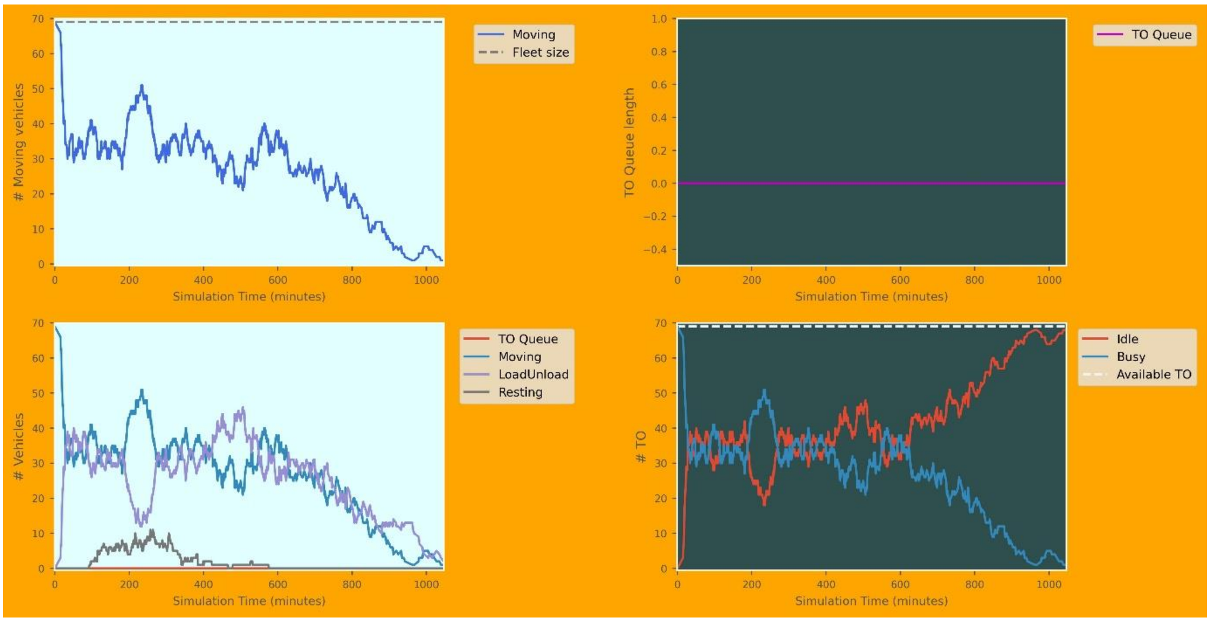


Figure 29 Simulation summary for LSP_2 with TO/V ratio of 1 and TO setup time of 0

Table 48 KPI summary for LSP_2 with TO/V ratio of 1 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.39	0.02	0.35	0.38	0.39	0.40	0.42
AVG TO utilization	30	0.39	0.02	0.35	0.38	0.39	0.40	0.42
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

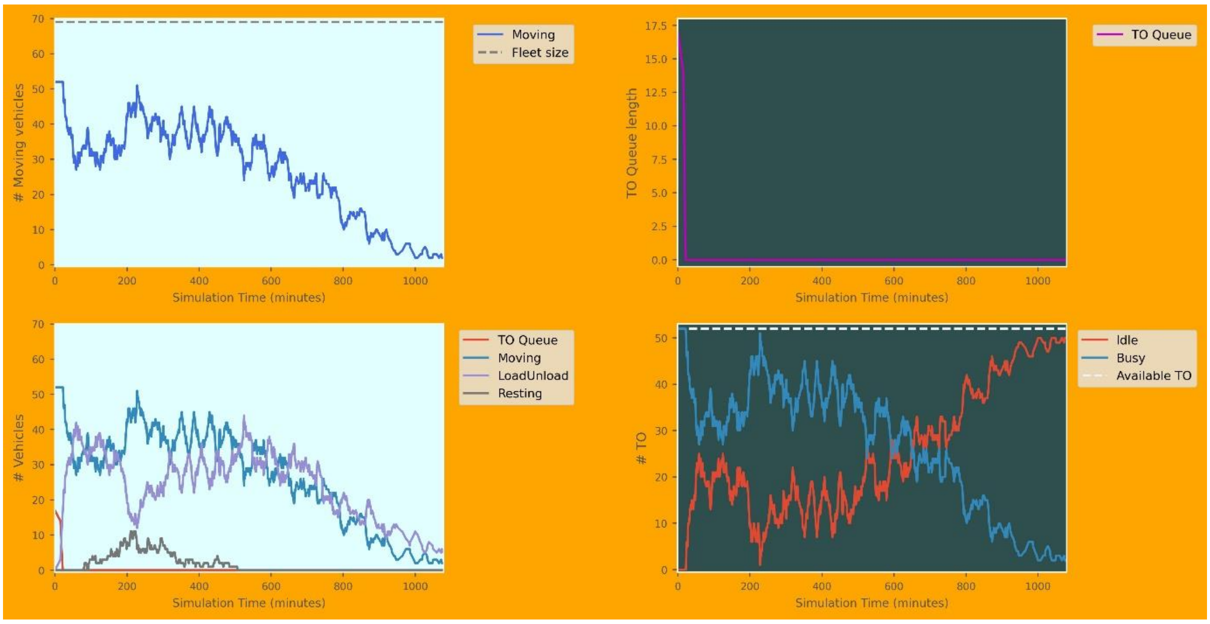


Figure 30 Simulation summary for LSP_2 with TO/V ratio of 0.75 and TO setup time of 0

Table 49 KPI summary for LSP_2 with TO/V ratio of 0.75 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.39	0.02	0.35	0.38	0.39	0.40	0.41
AVG TO utilization	30	0.52	0.02	0.46	0.50	0.52	0.53	0.54
AVG wait time/vehicle	30	4.87	0.34	4.41	4.60	4.83	5.09	5.80
AVG queue duration	30	18.99	1.45	16.05	17.93	18.69	20.03	22.22
MAX queue duration	30	23.97	2.01	21.00	23.00	23.00	25.75	28.00
AVG queue length	30	0.31	0.02	0.28	0.29	0.31	0.33	0.37
MAX queue length	30	17.00	0.00	17.00	17.00	17.00	17.00	17.00

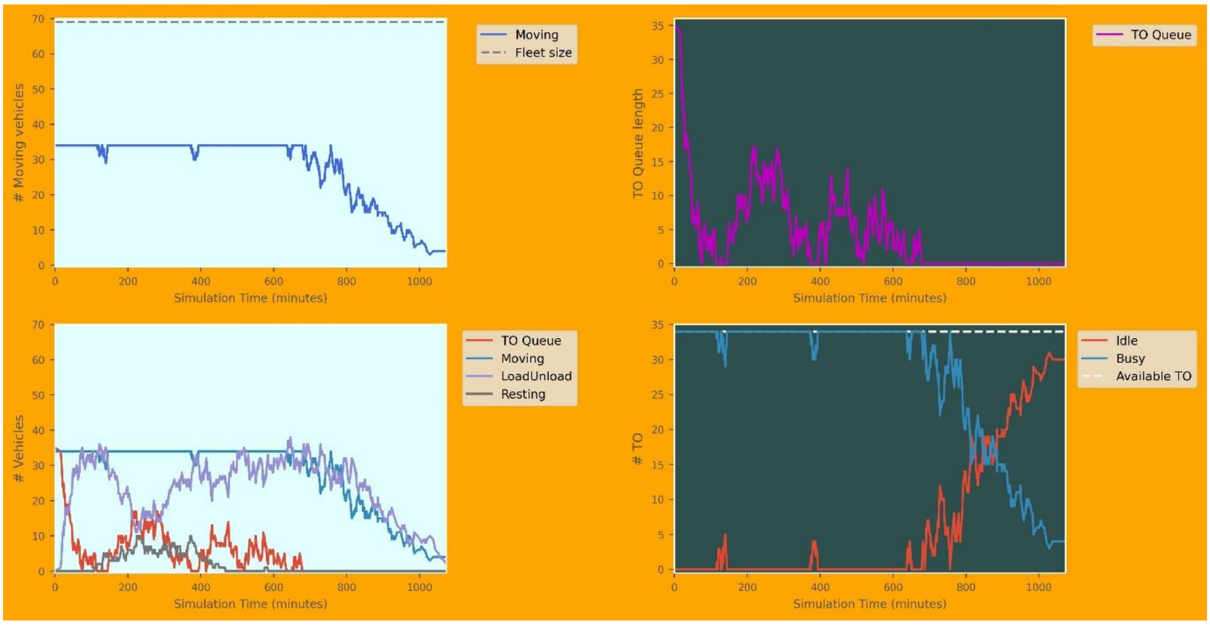


Figure 31 Simulation summary for LSP_2 with TO/V ratio of 0.5 and TO setup time of 0

Table 50 KPI summary for LSP_2 with TO/V ratio of 0.5 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.39	0.01	0.36	0.38	0.39	0.40	0.40
AVG TO utilization	30	0.78	0.03	0.73	0.76	0.79	0.81	0.82
AVG wait time/vehicle	30	67.84	12.86	39.28	59.19	67.88	76.60	91.19
AVG queue duration	30	11.87	1.43	8.45	11.21	12.21	12.75	14.05
MAX queue duration	30	52.83	5.26	44.00	50.00	51.50	57.50	63.00
AVG queue length	30	4.33	0.82	2.51	3.79	4.34	4.89	5.83
MAX queue length	30	35.00	0.00	35.00	35.00	35.00	35.00	35.00

LSP_3

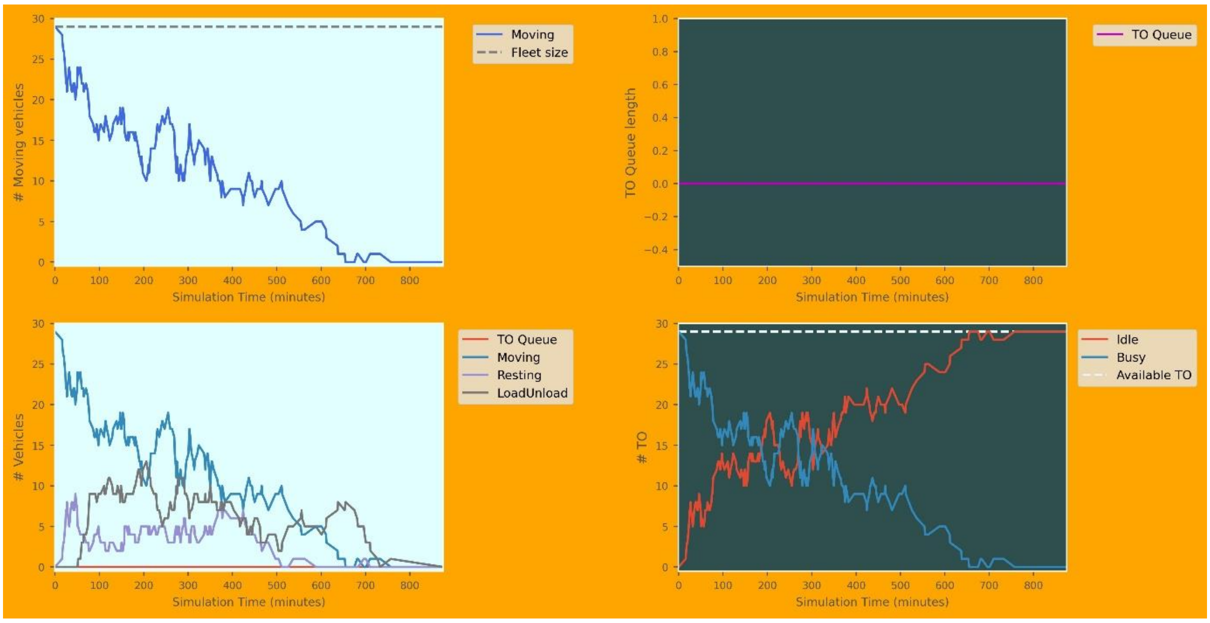


Figure 32 Simulation summary for LSP_3 (bulk) with TO/V ratio of 1 and TO setup time of 0

Table 51 KPI summary for LSP_3 (bulk) with TO/V ratio of 1 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.28	0.02	0.25	0.27	0.28	0.29	0.32
AVG TO utilization	30	0.28	0.02	0.25	0.27	0.28	0.29	0.32
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

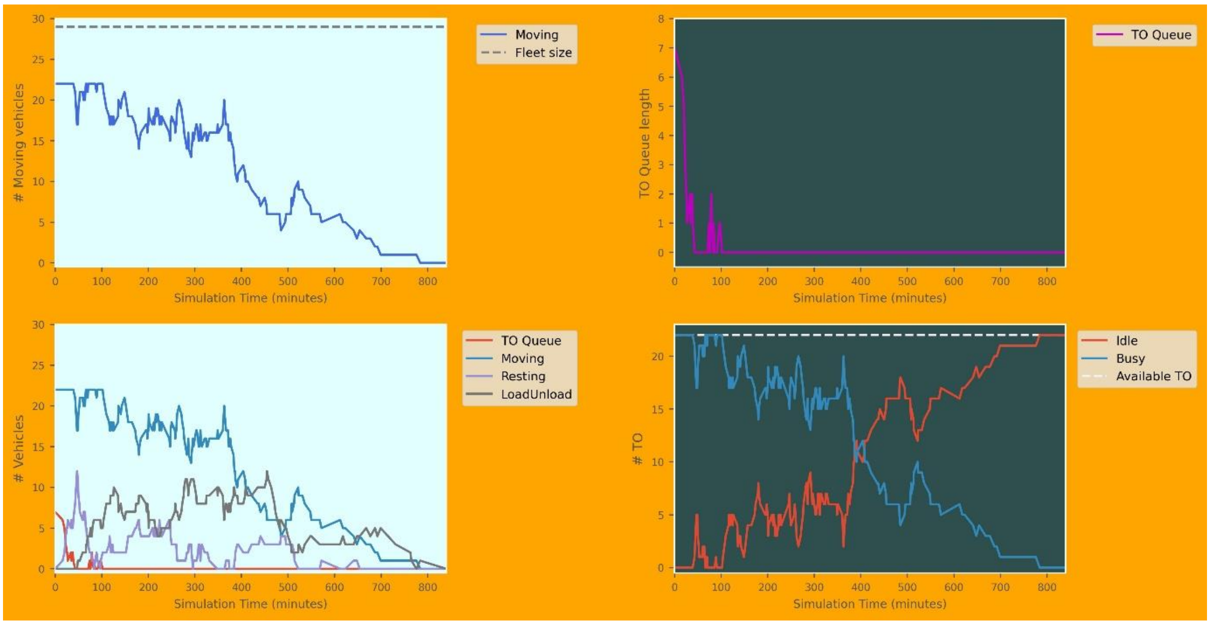


Figure 33 Simulation summary for LSP_3 (bulk) with TO/V ratio of 0.75 and TO setup time of 0

Table 52 KPI summary for LSP_3 (bulk) with TO/V ratio of 0.75 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.28	0.02	0.23	0.27	0.28	0.30	0.32
AVG TO utilization	30	0.37	0.03	0.31	0.35	0.37	0.39	0.42
AVG wait time/vehicle	30	11.88	3.36	6.79	8.79	11.62	14.28	19.86
AVG queue duration	30	15.41	3.56	10.94	12.50	14.56	17.99	22.39
MAX queue duration	30	33.23	5.64	24.00	29.25	32.50	35.50	46.00
AVG queue length	30	0.32	0.09	0.18	0.24	0.32	0.39	0.53
MAX queue length	30	7.00	0.00	7.00	7.00	7.00	7.00	7.00

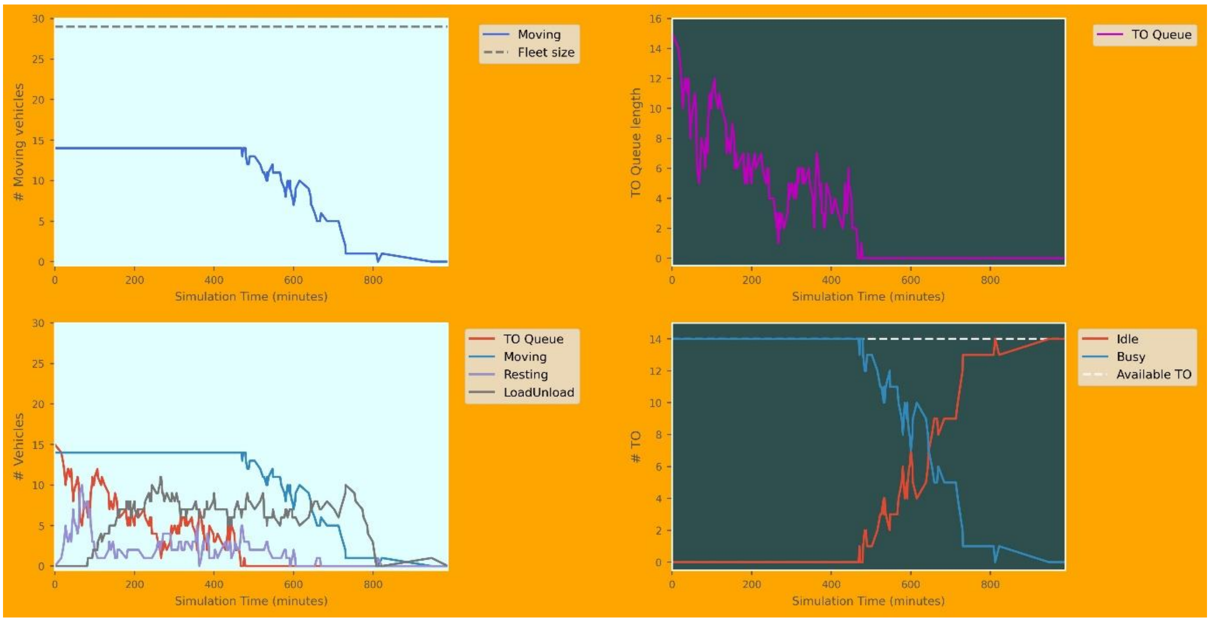


Figure 34 Simulation summary for LSP_3 (bulk) with TO/V ratio of 0.5 and TO setup time of 0

Table 53 KPI summary for LSP_3 (bulk) with TO/V ratio of 0.5 and TO setup time of 0

	replications			mean	std	min	25%	50%	75%	m
AVG vehicle utilization	30			0.28	0.02	0.24	0.27	0.28	0.29	0
AVG TO utilization	30			0.59	0.05	0.50	0.56	0.59	0.61	0
AVG wait time/vehicle	30			126.34	24.70	95.69	105.92	123.09	137.56	193
AVG queue duration	30			42.62	7.11	31.31	38.30	41.40	46.34	57
MAX queue duration	30			98.87	20.76	62.00	84.50	100.00	110.00	153
AVG queue length	30			3.39	0.66	2.57	2.85	3.31	3.69	5
MAX queue length	30			15.00	0.00	15.00	15.00	15.00	15.00	15

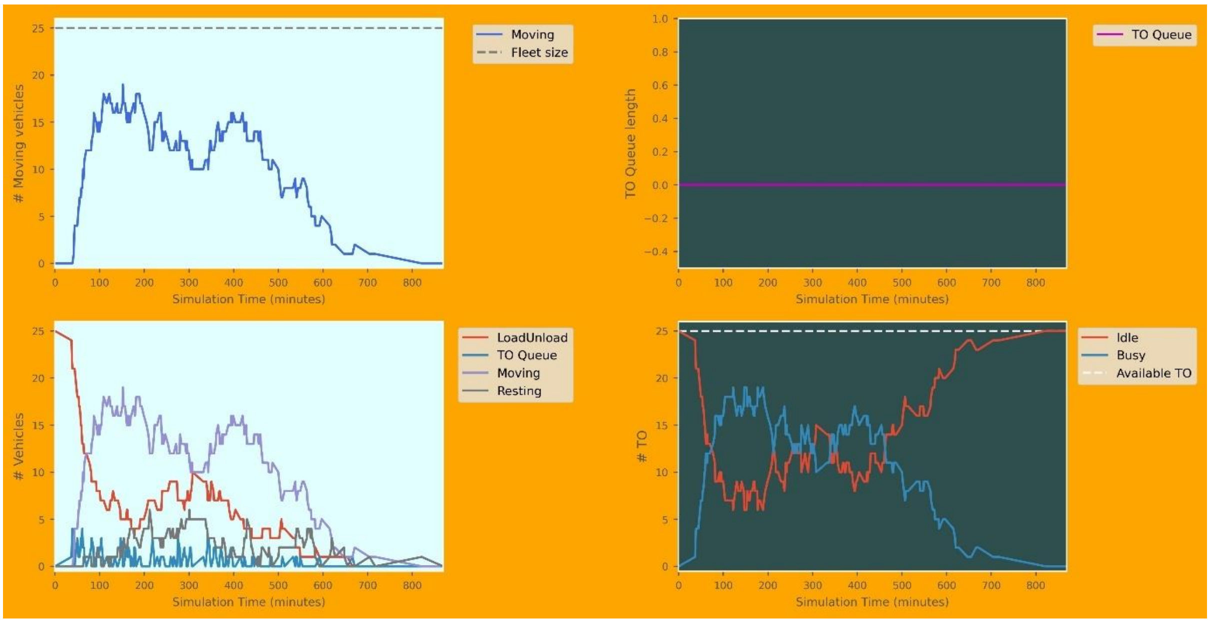


Figure 35 Simulation summary for LSP_3 (tank) with TO/V ratio of 1 and TO setup time of 0

Table 54 KPI summary for LSP_3 (tank) with TO/V ratio of 1 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.20	0.02	0.17	0.19	0.20	0.21	0.25
AVG TO utilization	30	0.20	0.02	0.17	0.19	0.20	0.21	0.25
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

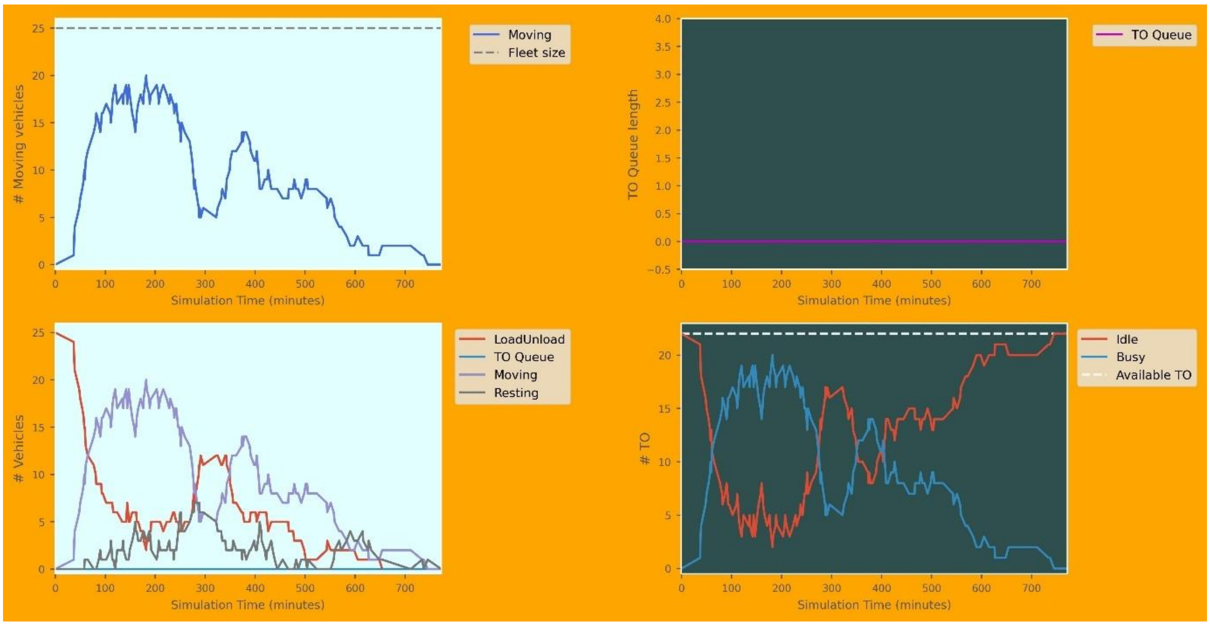


Figure 36 Simulation summary for LSP_3 (tank) with TO/V ratio of 0.75 and TO setup time of 0

Table 55 KPI summary for LSP_3 (tank) with TO/V ratio of 0.75 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.20	0.02	0.17	0.19	0.20	0.21	0.23
AVG TO utilization	30	0.26	0.02	0.23	0.25	0.27	0.27	0.30
AVG wait time/vehicle	30	0.43	0.91	0.00	0.00	0.04	0.28	4.52
AVG queue duration	30	2.73	3.70	0.00	0.00	1.00	4.04	14.12
MAX queue duration	30	3.87	5.27	0.00	0.00	1.00	6.75	21.00
AVG queue length	30	0.01	0.02	0.00	0.00	0.00	0.01	0.10
MAX queue length	30	0.90	1.03	0.00	0.00	1.00	1.00	4.00

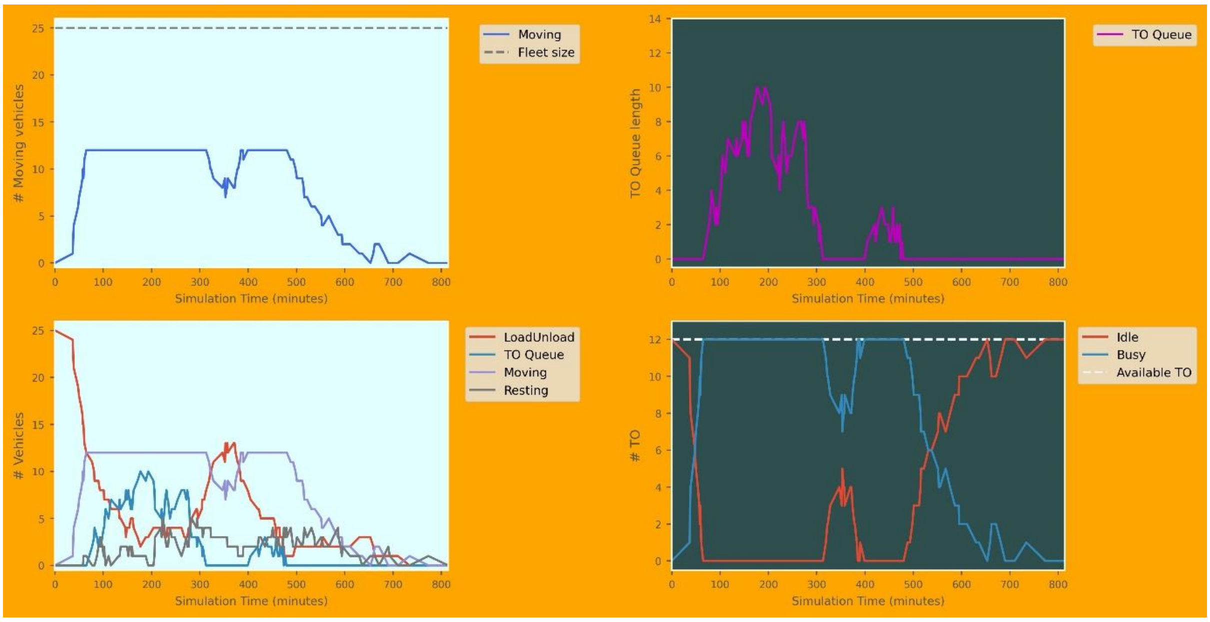


Figure 37 Simulation summary for LSP_3 (tank) with TO/V ratio of 0.5 and TO setup time of 0

Table 56 KPI summary for LSP_3 (tank) with TO/V ratio of 0.5 and TO setup time of 0

		replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization		30	0.20	0.02	0.17	0.19	0.20	0.21	0.26
AVG TO utilization		30	0.42	0.04	0.35	0.39	0.42	0.45	0.54
AVG wait time/vehicle		30	46.21	17.58	12.20	34.72	48.72	57.55	87.12
AVG queue duration		30	29.24	8.48	10.89	24.08	30.90	34.27	51.86
MAX queue duration		30	61.13	19.55	21.00	51.25	59.50	70.50	120.00
AVG queue length		30	1.07	0.41	0.28	0.80	1.13	1.33	2.02
MAX queue length		30	9.03	1.67	5.00	8.00	9.00	10.00	12.00

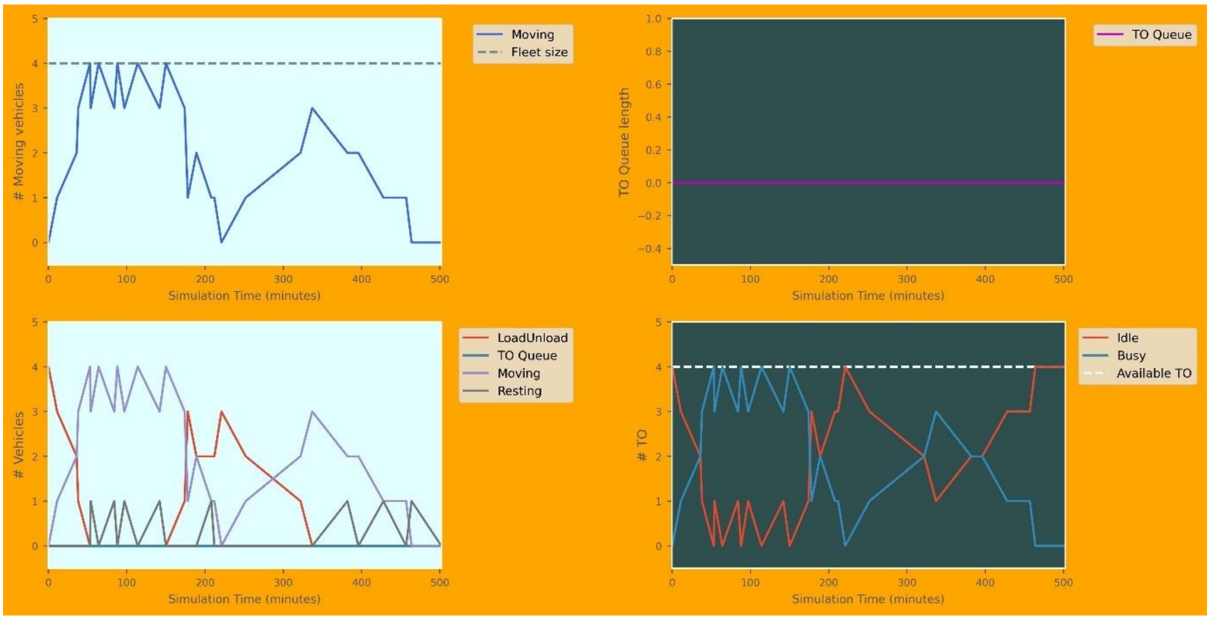


Figure 38 Simulation summary for LSP_3 (container) with TO/V ratio of 1 and TO setup time of 0

Table 57 KPI summary for LSP_3 (container) with TO/V ratio of 1 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.21	0.04	0.11	0.18	0.22	0.23	0.30
AVG TO utilization	30	0.21	0.04	0.11	0.18	0.22	0.23	0.30
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

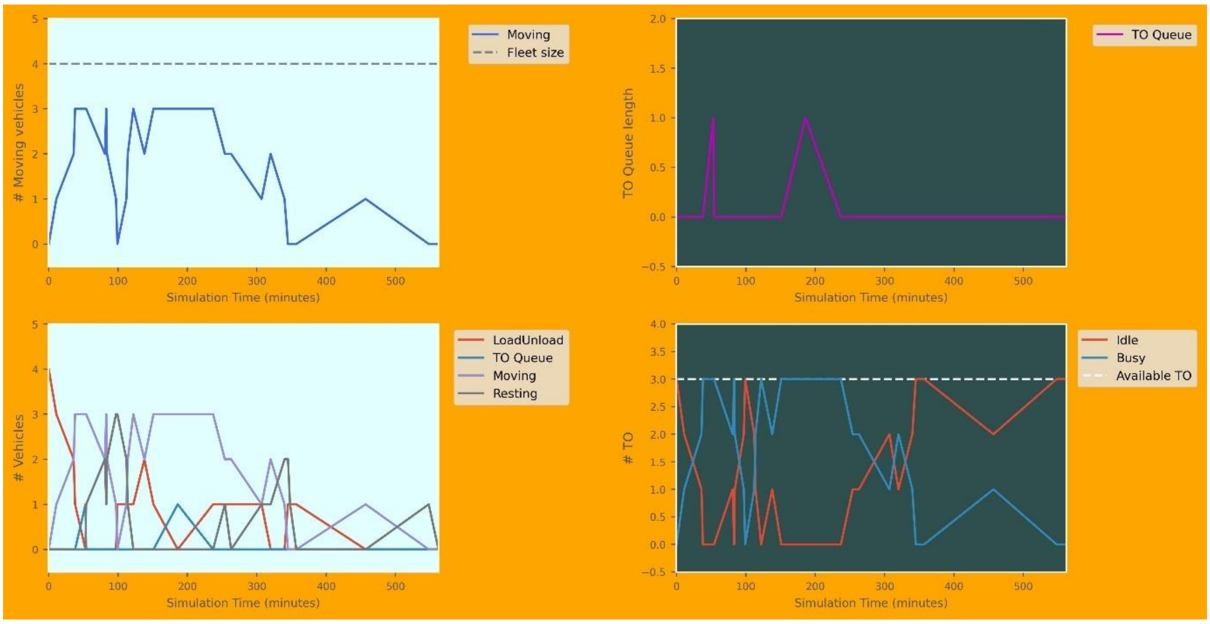


Figure 39 Simulation summary for LSP_3 (container) with TO/V ratio of 0.75 and TO setup time of 0

Table 58 KPI summary for LSP_3 (container) with TO/V ratio of 0.75 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.21	0.04	0.11	0.18	0.22	0.23	0.29
AVG TO utilization	30	0.28	0.06	0.15	0.24	0.29	0.31	0.38
AVG wait time/vehicle	30	10.03	8.35	0.00	2.25	10.88	13.44	30.50
AVG queue duration	30	19.79	19.78	0.00	5.44	16.83	22.13	85.00
MAX queue duration	30	26.80	23.45	0.00	6.50	23.00	39.00	85.00
AVG queue length	30	0.04	0.03	0.00	0.01	0.04	0.05	0.11
MAX queue length	30	0.83	0.38	0.00	1.00	1.00	1.00	1.00

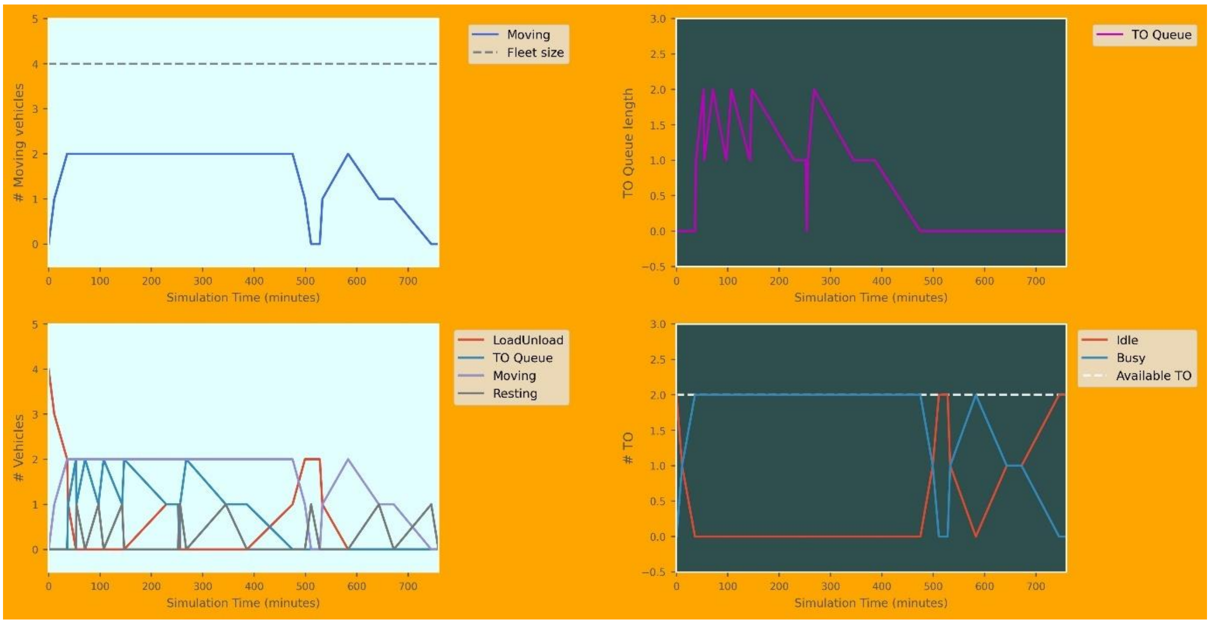


Figure 40 Simulation summary for LSP_3 (container) with TO/V ratio of 0.5 and TO setup time of 0

Table 59 KPI summary for LSP_3 (container) with TO/V ratio of 0.5 and TO setup time of 0

	replications	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.21	0.05	0.12	0.19	0.21	0.25	0.29
AVG TO utilization	30	0.42	0.09	0.24	0.38	0.42	0.50	0.57
AVG wait time/vehicle	30	77.01	43.41	9.25	46.50	75.13	94.06	164.25
AVG queue duration	30	48.07	23.53	8.12	34.18	44.23	61.88	106.33
MAX queue duration	30	92.70	45.39	18.00	56.25	101.50	126.75	207.00
AVG queue length	30	0.28	0.16	0.03	0.18	0.28	0.35	0.61
MAX queue length	30	1.97	0.18	1.00	2.00	2.00	2.00	2.00

Teleoperation center

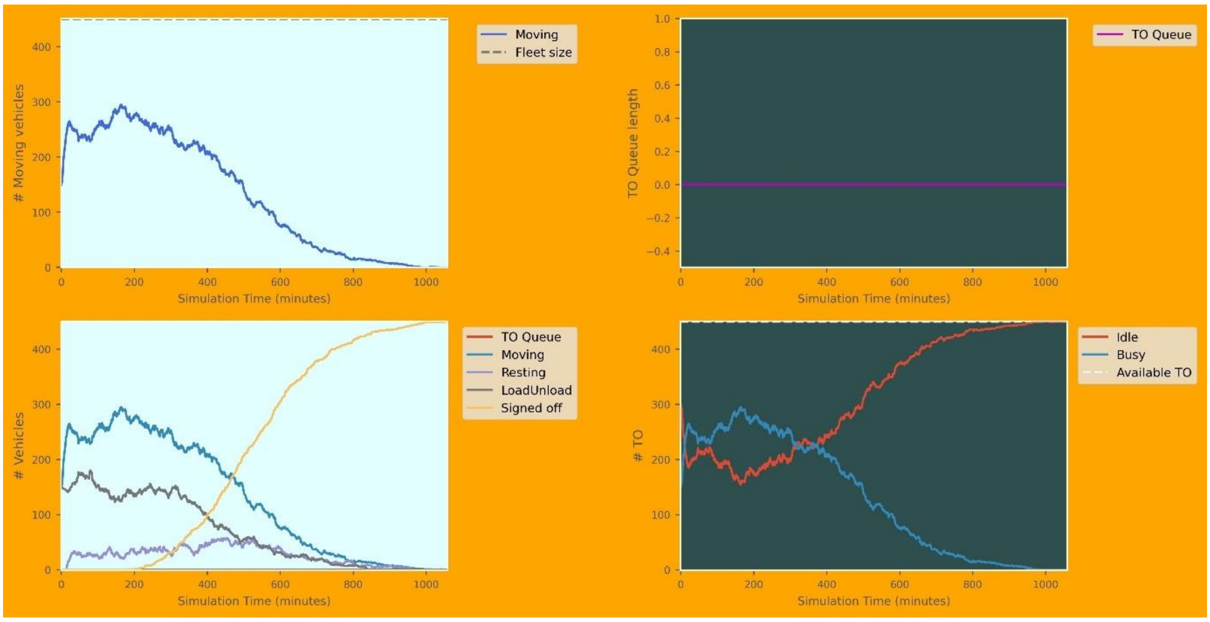


Figure 41 Simulation summary for teleoperation center with TO/V ratio of 1 and TO setup time of 0

Table 60 KPI summary for teleoperation center with TO/V ratio of 1 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.27	0.01	0.27	0.27	0.27	0.28	0.29
AVG TO utilization	30	0.27	0.01	0.27	0.27	0.27	0.28	0.29
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

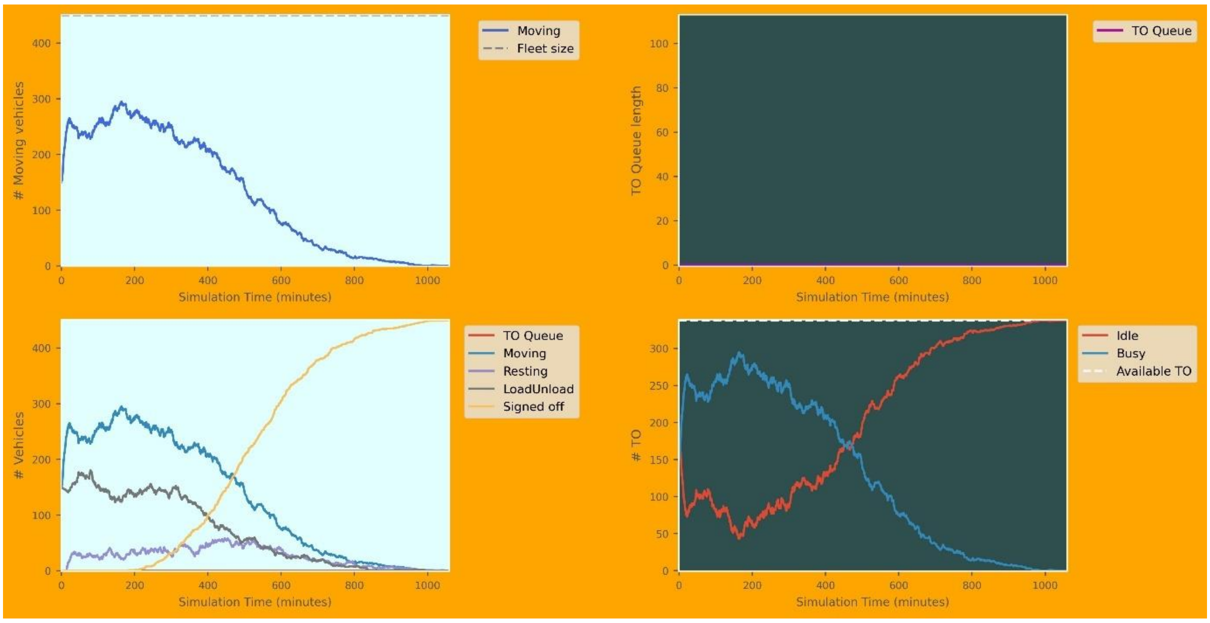


Figure 42 Simulation summary for teleoperation center with TO/V ratio of 0.75 and TO setup time of 0

Table 61 KPI summary for teleoperation center with TO/V ratio of 0.75 and TO setup time of 0

	replication	mean	std	min	25%	50%	75%	max
AVG vehicle utilization	30	0.27	0.01	0.27	0.27	0.27	0.28	0.29
AVG TO utilization	30	0.36	0.01	0.35	0.36	0.36	0.37	0.38
AVG wait time/vehicle	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue duration	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVG queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX queue length	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

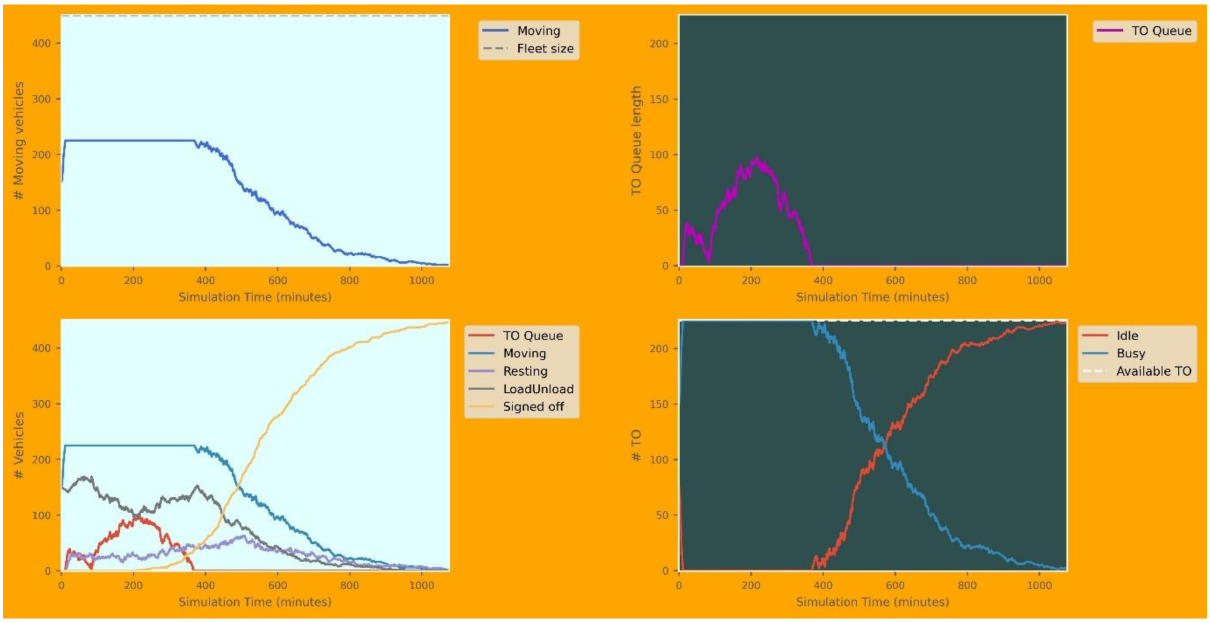


Figure 43 Simulation summary for teleoperation center with TO/V ratio of 0.5 and TO setup time of 0

Table 62 KPI summary for teleoperation center with TO/V ratio of 0.5 and TO setup time of 0

	replication	mean	std	min		25%	50%	75%	max
AVG vehicle utilization	30	0.272	0.006	0.260		0.270	0.270	0.278	0.280
AVG TO utilization	30	0.545	0.009	0.530		0.540	0.550	0.550	0.560
AVG wait time/vehicle	30	39.241	4.916	26.240		36.603	40.450	42.048	49.080
AVG queue duration	30	13.769	1.635	10.160		12.843	13.950	14.888	16.770
MAX queue duration	30	26.567	3.441	19.000		25.000	26.000	29.000	33.000
AVG queue length	30	16.351	2.050	10.930		15.255	16.855	17.523	20.450
MAX queue length	30	89.300	9.903	66.000		83.500	89.500	97.000	106.000

Teleoperator-to-vehicle ratios

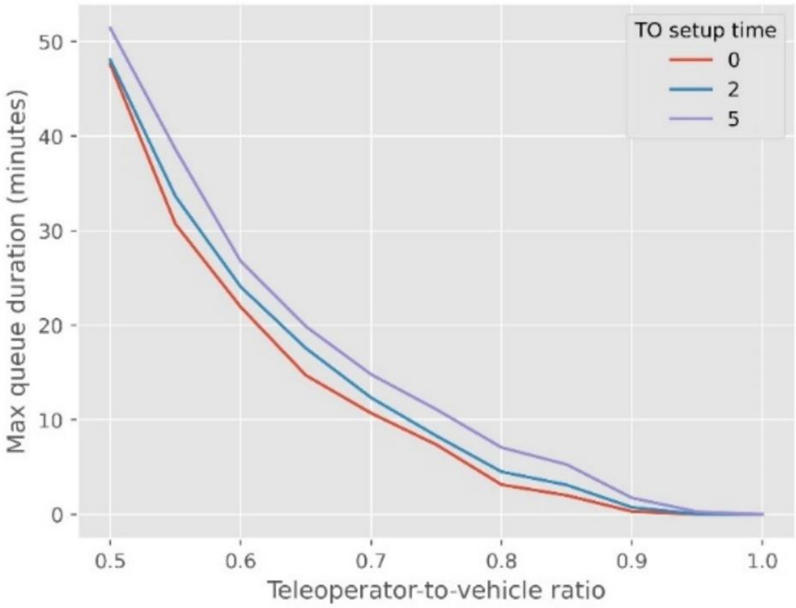


Figure 44 Maximum queue duration for LSP_1 case study

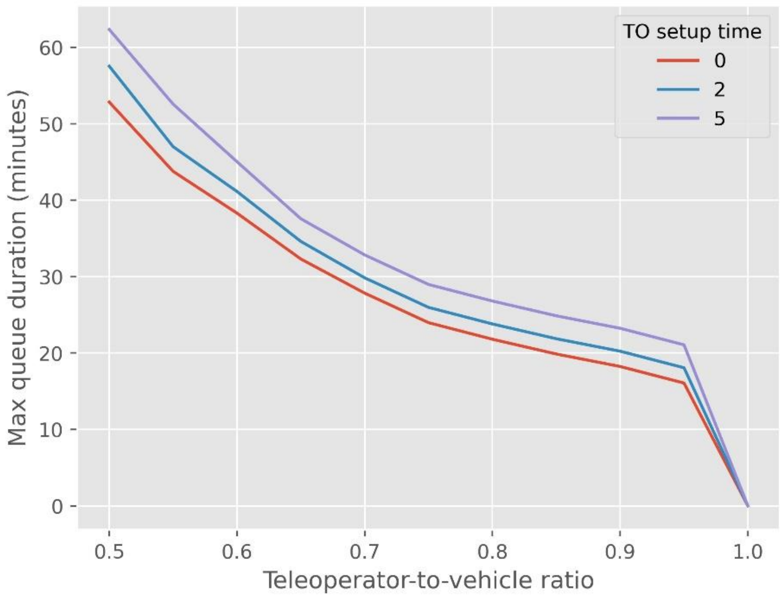


Figure 45 Maximum queue duration for LSP_2 case study

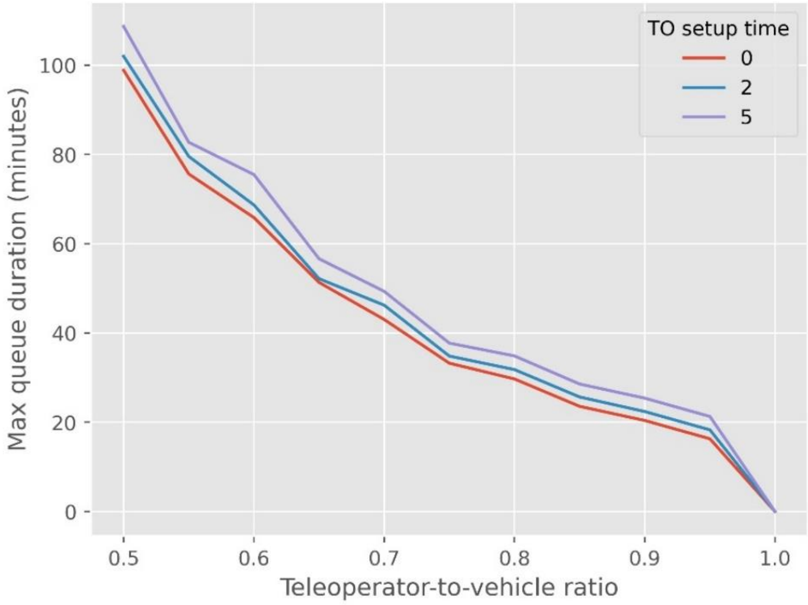


Figure 46 Maximum queue duration for LSP_3 (Bulk operation)

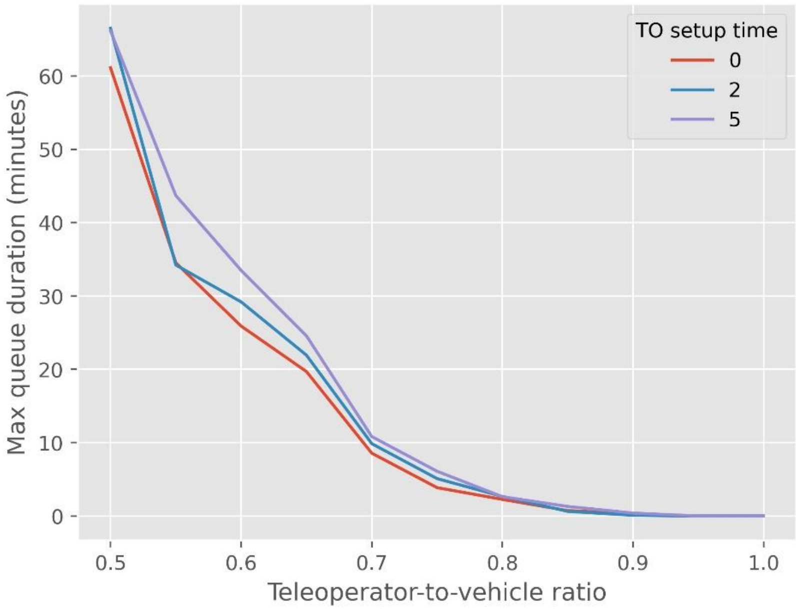


Figure 47 Maximum queue duration for LSP_3 (tank operation)

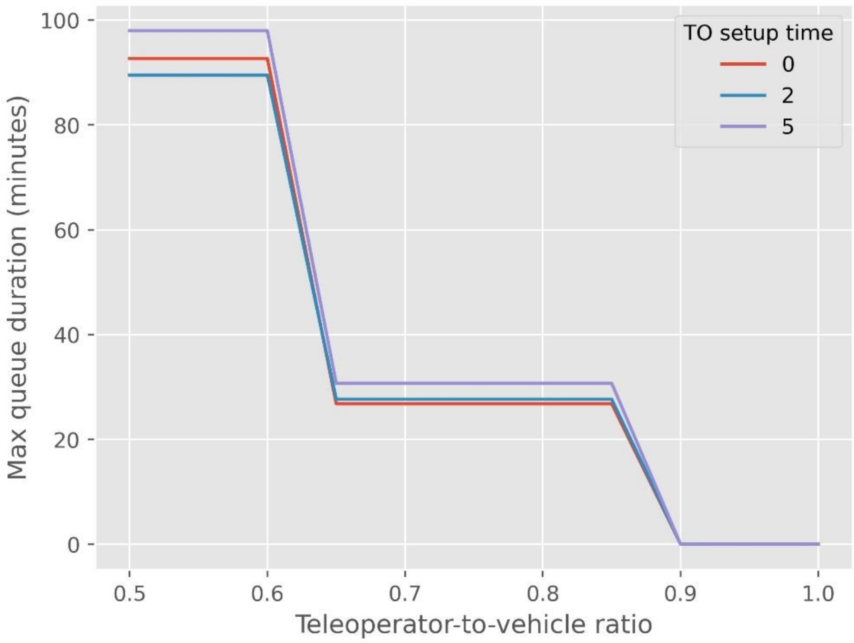


Figure 48 Maximum queue duration for LSP_3 (container operation)

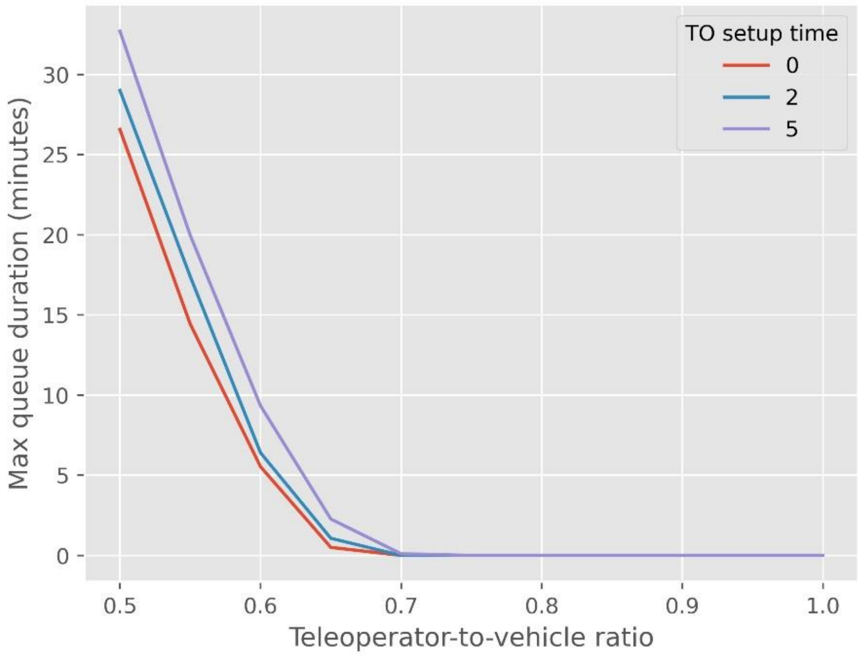


Figure 49 Maximum queue duration for teleoperation center case study

Table 63 LSP_1 TO/V v.s. level of service

Case	TO-to-v ratio	TO setup time	AVG queue time	Max queue time
LSP_1	1	0	0.00	0.00
LSP_1	1	2	0.00	0.00
LSP_1	1	5	0.00	0.00
LSP_1	0.95	0	0.00	0.00
LSP_1	0.95	2	0.03	0.03
LSP_1	0.95	5	0.27	0.27
LSP_1	0.9	0	0.24	0.30
LSP_1	0.9	2	0.63	0.73
LSP_1	0.9	5	1.46	1.73
LSP_1	0.85	0	1.37	2.00
LSP_1	0.85	2	2.27	3.10
LSP_1	0.85	5	3.81	5.27
LSP_1	0.8	0	2.29	3.13
LSP_1	0.8	2	3.33	4.50
LSP_1	0.8	5	4.74	7.07
LSP_1	0.75	0	4.51	7.37
LSP_1	0.75	2	5.27	8.30
LSP_1	0.75	5	6.71	11.10
LSP_1	0.7	0	5.72	10.70
LSP_1	0.7	2	6.30	12.33
LSP_1	0.7	5	6.67	14.80
LSP_1	0.65	0	6.21	14.70
LSP_1	0.65	2	7.00	17.57
LSP_1	0.65	5	7.63	19.87
LSP_1	0.6	0	8.07	21.93
LSP_1	0.6	2	8.55	24.07
LSP_1	0.6	5	9.18	26.77
LSP_1	0.55	0	11.20	30.70
LSP_1	0.55	2	12.33	33.63
LSP_1	0.55	5	14.03	38.60
LSP_1	0.5	0	18.84	47.60
LSP_1	0.5	2	20.38	48.07
LSP_1	0.5	5	22.42	51.43

Table 64 LSP_2 TO/V v.s. level of service

Case	TO-to-v ratio	TO setup time	AVG queue time	Max queue time
RSN	1	0	0.00	0.00
RSN	1	2	0.00	0.00
RSN	1	5	0.00	0.00
RSN	0.95	0	15.47	16.07
RSN	0.95	2	17.47	18.07
RSN	0.95	5	20.47	21.07
RSN	0.9	0	16.60	18.23
RSN	0.9	2	18.60	20.23
RSN	0.9	5	21.60	23.23
RSN	0.85	0	17.25	19.87
RSN	0.85	2	19.28	21.87
RSN	0.85	5	22.31	24.87
RSN	0.8	0	18.31	21.80
RSN	0.8	2	20.34	23.80
RSN	0.8	5	23.29	26.80
RSN	0.75	0	18.99	23.97
RSN	0.75	2	20.91	25.97
RSN	0.75	5	23.47	28.97
RSN	0.7	0	18.49	27.83
RSN	0.7	2	19.63	29.83
RSN	0.7	5	20.22	32.83
RSN	0.65	0	16.97	32.30
RSN	0.65	2	17.38	34.60
RSN	0.65	5	16.31	37.57
RSN	0.6	0	11.97	38.30
RSN	0.6	2	11.01	41.13
RSN	0.6	5	11.12	45.03
RSN	0.55	0	9.29	43.77
RSN	0.55	2	9.66	47.00
RSN	0.55	5	10.34	52.57
RSN	0.5	0	11.87	52.83
RSN	0.5	2	13.54	57.53
RSN	0.5	5	14.49	62.33

Table 65 LSP_3 (Bulk operation) TO/V v.s. level of service

Case	TO-to-v ratio	TO setup time	AVG queue time	Max queue time
VOD_B	1	0	0.00	0.00
VOD_B	1	2	0.00	0.00
VOD_B	1	5	0.00	0.00
VOD_B	0.95	0	15.64	16.30
VOD_B	0.95	2	17.53	18.30
VOD_B	0.95	5	19.95	21.30
VOD_B	0.9	0	13.84	20.40
VOD_B	0.9	2	14.59	22.40
VOD_B	0.9	5	15.87	25.40
VOD_B	0.85	0	13.59	23.57
VOD_B	0.85	2	13.60	25.67
VOD_B	0.85	5	16.34	28.57
VOD_B	0.8	0	13.32	29.70
VOD_B	0.8	2	14.84	31.80
VOD_B	0.8	5	15.32	34.87
VOD_B	0.75	0	15.41	33.23
VOD_B	0.75	2	15.41	34.83
VOD_B	0.75	5	17.05	37.73
VOD_B	0.7	0	19.07	43.03
VOD_B	0.7	2	20.43	46.23
VOD_B	0.7	5	20.42	49.33
VOD_B	0.65	0	22.14	51.33
VOD_B	0.65	2	22.59	52.17
VOD_B	0.65	5	25.20	56.63
VOD_B	0.6	0	27.40	65.87
VOD_B	0.6	2	26.98	68.70
VOD_B	0.6	5	29.98	75.50
VOD_B	0.55	0	31.42	75.63
VOD_B	0.55	2	32.31	79.57
VOD_B	0.55	5	33.58	82.73
VOD_B	0.5	0	42.62	98.87
VOD_B	0.5	2	43.38	102.00
VOD_B	0.5	5	46.19	108.70

Table 66 LSP_3 (Tank operation) TO/V v.s. level of service

Case	TO-to-v ratio	TO setup time	AVG queue time	Max queue time
VOD_T	1	0	0.00	0.00
VOD_T	1	2	0.00	0.00
VOD_T	1	5	0.00	0.00
VOD_T	0.95	0	0.00	0.00
VOD_T	0.95	2	0.00	0.00
VOD_T	0.95	5	0.00	0.00
VOD_T	0.9	0	0.30	0.30
VOD_T	0.9	2	0.10	0.10
VOD_T	0.9	5	0.40	0.40
VOD_T	0.85	0	0.51	0.73
VOD_T	0.85	2	0.40	0.63
VOD_T	0.85	5	1.07	1.30
VOD_T	0.8	0	1.71	2.27
VOD_T	0.8	2	1.53	2.67
VOD_T	0.8	5	1.95	2.63
VOD_T	0.75	0	2.73	3.87
VOD_T	0.75	2	3.14	5.10
VOD_T	0.75	5	3.65	6.10
VOD_T	0.7	0	4.59	8.57
VOD_T	0.7	2	5.34	9.87
VOD_T	0.7	5	5.74	10.83
VOD_T	0.65	0	9.19	19.70
VOD_T	0.65	2	10.63	21.93
VOD_T	0.65	5	11.89	24.57
VOD_T	0.6	0	12.22	25.90
VOD_T	0.6	2	13.10	29.20
VOD_T	0.6	5	15.62	33.50
VOD_T	0.55	0	15.72	34.53
VOD_T	0.55	2	15.88	34.23
VOD_T	0.55	5	19.58	43.70
VOD_T	0.5	0	29.24	61.13
VOD_T	0.5	2	31.27	66.50
VOD_T	0.5	5	31.99	66.17

Table 67 LSP_3 (container operation) TO/V v.s. level of service

Case	TO-to-v ratio	TO setup time	AVG queue time	Max queue time
VOD_C	1	0	0.00	0.00
VOD_C	1	2	0.00	0.00
VOD_C	1	5	0.00	0.00
VOD_C	0.95	0	0.00	0.00
VOD_C	0.95	2	0.00	0.00
VOD_C	0.95	5	0.00	0.00
VOD_C	0.9	0	0.00	0.00
VOD_C	0.9	2	0.00	0.00
VOD_C	0.9	5	0.00	0.00
VOD_C	0.85	0	19.79	26.80
VOD_C	0.85	2	20.29	27.67
VOD_C	0.85	5	21.80	30.70
VOD_C	0.8	0	19.79	26.80
VOD_C	0.8	2	20.29	27.67
VOD_C	0.8	5	21.80	30.70
VOD_C	0.75	0	19.79	26.80
VOD_C	0.75	2	20.29	27.67
VOD_C	0.75	5	21.80	30.70
VOD_C	0.7	0	19.79	26.80
VOD_C	0.7	2	20.29	27.67
VOD_C	0.7	5	21.80	30.70
VOD_C	0.65	0	19.79	26.80
VOD_C	0.65	2	20.29	27.67
VOD_C	0.65	5	21.80	30.70
VOD_C	0.6	0	48.07	92.70
VOD_C	0.6	2	48.37	89.53
VOD_C	0.6	5	51.19	98.00
VOD_C	0.55	0	48.07	92.70
VOD_C	0.55	2	48.37	89.53
VOD_C	0.55	5	51.19	98.00
VOD_C	0.5	0	48.07	92.70
VOD_C	0.5	2	48.37	89.53
VOD_C	0.5	5	51.19	98.00

Table 68 Teleoperation center TO/V v.s. level of service

Case	TO-to-v ratio	TO setup time	AVG queue time	Max queue time
TOC	1	0	0.00	0.00
TOC	1	2	0.00	0.00
TOC	1	5	0.00	0.00
TOC	0.95	0	0.00	0.00
TOC	0.95	2	0.00	0.00
TOC	0.95	5	0.00	0.00
TOC	0.9	0	0.00	0.00
TOC	0.9	2	0.00	0.00
TOC	0.9	5	0.00	0.00
TOC	0.85	0	0.00	0.00
TOC	0.85	2	0.00	0.00
TOC	0.85	5	0.00	0.00
TOC	0.8	0	0.00	0.00
TOC	0.8	2	0.00	0.00
TOC	0.8	5	0.00	0.00
TOC	0.75	0	0.00	0.00
TOC	0.75	2	0.00	0.00
TOC	0.75	5	0.00	0.00
TOC	0.7	0	0.00	0.00
TOC	0.7	2	0.00	0.00
TOC	0.7	5	0.08	0.10
TOC	0.65	0	0.34	0.50
TOC	0.65	2	0.62	1.07
TOC	0.65	5	1.15	2.27
TOC	0.6	0	2.51	5.53
TOC	0.6	2	2.82	6.40
TOC	0.6	5	4.54	9.33
TOC	0.55	0	6.75	14.43
TOC	0.55	2	8.53	17.40
TOC	0.55	5	9.66	19.97
TOC	0.5	0	13.77	26.57
TOC	0.5	2	15.03	29.00
TOC	0.5	5	17.75	32.70

APPENDIX I. BUSINESS CASE DASHBOARD

Purpose

Under the 5G Blueprint project, HZ University of Applied Sciences was anointed the task of creating a business case for teleoperated road transport and to visualize its effects on profitability. The dashboard serves as a decision making tool allowing stakeholders to check the effect for their specific operation by entering a minimum amount of data.

Users

The dashboard allows for a transportation company, governmental institution, research institution or road authority to calculate the monetary benefits of implementing teleoperated road transport for a certain region, company or type of transport.

Scope

The dashboard calculates the difference between the operational cost of the traditional road transportation company and teleoperated road transport taking into account:

- Current & future logistics processes (Business Process Model Teleoperated road transport)
- Organizational changes throughout the supply chain due to the changing role of the truck driver and the set-up of a teleoperation center (chapter 3)
- Key elements provided by other consortium partners, such as cost elements for teleoperation (Attachment - interview summaries)
- Ratio of vehicles to teleoperator based on simulation of transport flows over place and time. (Chapter 5)

Outscope

The dashboard calculates the difference between the operational cost of the traditional road transportation company and teleoperated road transport, it does not provide the actual cost of implementation and therefore does not include:

- Cost for infrastructural changes such as placing 5G network points;
- Cost for integration of IT systems such as ERP systems;
- Cost for regulatory and/or contractual adjustments;
- Cost for office buildings to facilitate a teleoperation control center;
- Cost for automation of certain processes;
- Cost for digitization of transportation documentation;
- Any other cost that may result from actual implementation of teleoperated vehicles.

Disclaimer

The dashboard was created with the information available at the time of creation (April 2020) and should not be considered binding in any way. It aims to provide a rough estimate of economic benefits. Actual implementation projects will require further research and calculations for the specific operation at hand.

Content

The dashboard consists of a front-end page where the data is entered and the business case is shown; a back-end page where the business case is calculated based on pre-entered formulas and a source page where the input for the different scenario's is pre-determined.

Front-end: Calculator

Business parameters

On the front-end page of the calculator a logistic transportation company can enter company specific data in order to determine if there is a business case for implementation of teleoperated transport.

Business parameters

Scope	< enter name/region >
Country	Netherlands
Transport type	Container
Equipment type	Retrofit w/kit
Control center	Outsource
Data period	Year

Logistic operations	Long range	Medium range	Short range
Trips (average no./day)	50	50	50
Trip duration (h)	12,0	5,0	1,0
Distance/ trip (km)	800	300	20
Waiting time/ trip (h)	1,0	1,0	1,0
Resting time/ trip (h)	2,0	1,0	0,0
Shifts (no./day)	2	2	2
shift duration (h/shift)	8	8	8
Operational days (no./year)	300	300	300

Business case

Environmental impact	Long range	Medium range	Short range	Total
Co2	-280.800	-122.850	-9.360	-413.010
Fuel consumption	-108.000	-47.250	-3.600	-158.850

Socio-economic impact	Long range	Medium range	Short range	Total
Required FTE	-123,98	-59,75	-19,57	-203,30
Required trucks	-6,24	-3,12	0,00	-9,36

Cost differentiation	Long range	Medium range	Short range	Total
Non-TO activities	€ 23.280	€ 10.185	€ 776	€ 34.241
Total truck operation	-€ 3.159.294	-€ 1.739.460	-€ 740.060	-€ 5.638.814
Total Fuel cost	-€ 118.800	-€ 51.975	-€ 3.960	-€ 174.735
Total equipment	€ 199.033	€ 104.417	€ 76.255	€ 379.705
TOTAL	-€ 3.055.781	-€ 1.676.833	-€ 666.989	-€ 5.399.603

The top box requires choice of the following operational scenario's:

1. Country: A distinction was made between Netherlands and Belgium as the hourly cost for an operator is higher in the Netherlands. The calculator works with the data on hourly cost for a truck driver from the source page.

Scope	< enter name/region >
Country	Netherlands (drop-down: <select>, Belgium, Netherlands)
Transport type	
Equipment type	
Control center	Outsource
Data period	Year

	Scenario	Regular truck driver (€/h)
Country	<select>	N/A
	Belgium	€ 25,00
	Netherlands	€ 29,00

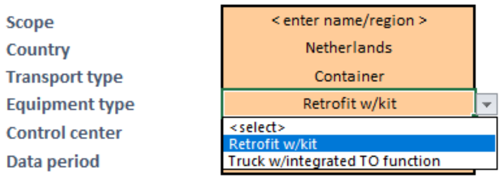
2. Transport type: The user selects a type of transport from the drop down menu.

Scope	< enter name/region >
Country	<select>
Transport type	<select> (drop-down: <select>, Container, Cargo (pallets), (ISO) Tank, Special)
Equipment	
Control center	
Data period	

This drop down is linked to the table below on the source page. The input for this table was defined with the help of several logistics parties and based on input received for Chapter 4.

	Scenario	Cost trailer (buying price)	(un)loading time (h)	local (un)loading support (h)	Fleet manager support (h)	Fleet manager activity
Transport type	<select>	N/A	N/A	N/A	N/A	N/A
	Container	€ 20.000	0,5	0	0,1	Temperature control (I/A)
	Cargo (pallets)	€ 50.000	2	2	0,25	Docking
	(ISO) Tank	€ 100.000	2	0,5	0,25	Pump
	Special	€ 200.000	4	3	0,25	General

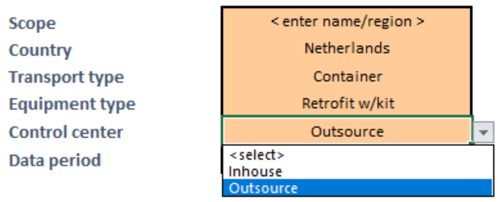
3. Equipment type: The user selects the type of equipment they would like to use. Either they retrofit existing trucks with a teleoperation kit or they buy a new truck with integrated teleoperation functionality.



The drop down menu is linked to the table below which provides the cost of a regular truck (€105.000) and adds on either the cost of a teleoperation kit of €15.000 (minimum €5.000, maximum €25.000) or engineering cost of €45.000 for an integrated teleoperation functionality. Lease was not considered to be an option for the logistics industry.

	Scenario	Cost per truck (buying price)	Insurance (€/ truck/year)	Maintenance (€/truck/year)
Business model tele-operation	<select>	N/A	N/A	N/A
	Retrofit w/kit	€ 120.000	€ 5.500	€ 15.000,00
	Truck w/integrated TO function	€ 150.000	€ 7.500	€ 15.000,00

4. Control center: The calculator provides the option to choose for inhouse teleoperation control, meaning that the company would hire their own personnel and arrange for the required equipment; or for outsourcing their activities to a centralized control center. It is expected that the latter will decrease the hourly cost with 20% as is reflected on the source page.



	Scenario	TO truck driver (€/h)	TO fleet manager (€/h)
Control Center	<select>	N/A	N/A
	Inhouse	€ 29,00	€ 43,50
	Outsource	€ 23,20	€ 34,80

For calculation of the teleoperated drives salary we assume a worst case scenario where the hourly cost will be equal to the hourly cost of a regular driver. However, as stipulated in chapter 5.1, expectation is that the hourly rate of a teleoperated truck driver could be lower due to a decreased level of complexity, overtime and expenses. The salary of trucking support operator we expect to be 50% higher than that of a regular driver, which is comparable to the contemporary salary of a planner, due to increased complexity and variety in tasks as well as the extra responsibility for escalation handling and communication with external parties.

The bottom box requires data specifics in relation to the transport type selected above, namely:

- Average number of trips per day: to calculate the total cost of the operation for the transport type selected.
- Average duration of one trip: to calculate the required amount of human resources.
- Average distance of one trip: to calculate fuel consumption and required amount of fueling stops.
- Average waiting time per trip: to calculate the required amount of teleoperators
- Average resting time per trip: To calculate the required amount of trucks

A distinction should be made between long range, medium range and short range as resting times and fuel consumption will be impacted by distance and transit time.

Logistic operations	Long range	Medium range	Short range
Trips (average no./day)	50	50	50
Trip duration (h)	12,0	5,0	1,0
Distance/ trip (km)	800	300	20
Waiting time/ trip (h)	1,0	1,0	1,0
Resting time/ trip (h)	2,0	1,0	0,0
Shifts (no./day)	2	2	2
shift duration (h/shift)	8	8	8
Operational days (no./year)	300	300	300

Lastly it will require some general company information, namely:

- The number of shifts per day: to calculate the human resource cost
- The duration of one shift: to calculate the human resource cost
- The number of operational days per year: Some transportation companies work 7/7 excluding holidays and other 5/7 including holidays so a differentiation is required.

Business case

When all data is entered, ***the right box*** wil immediately show the business case for the type of transport selected based on the data entered in the left fields.

Business case

Environmental impact	Long range	Medium range	Short range	Total
Co2	-280.800	-122.850	-9.360	-413.010
Fuel consumption	-108.000	-47.250	-3.600	-158.850

Socio-economic impact	Long range	Medium range	Short range	Total
Required FTE	-123,98	-59,75	-19,57	-203,30
Required trucks	-6,24	-3,12	0,00	-9,36

Cost differentiation	Long range	Medium range	Short range	Total
Non-TO activities	€ 23.280	€ 10.185	€ 776	€ 34.241
Total truck operation	-€ 3.159.294	-€ 1.739.460	-€ 740.060	-€ 5.638.814
Total Fuel cost	-€ 118.800	-€ 51.975	-€ 3.960	-€ 174.735
Total equipment	€ 199.033	€ 104.417	€ 76.255	€ 379.705
TOTAL	-€ 3.055.781	-€ 1.676.833	-€ 666.989	-€ 5.399.603

The elements marked green indicate a positive impact, the elements marked red indicate a negative impact.

The business case calculation provides immediate insight in the impact of a switch to teleoperated transport. It is to be noted that the tool provides the difference between traditional transport and teleoperated transport, therefore the following applies:

Traditional operation	
Teleoperation	-
Business case	**=**

The environmental impact provides the impact on fuel consumption and CO2 emission. Due to the enabling functions incorporated in the teleoperation dashboard advising on speed and timeslotbooking at intersections, a 3% decrease in fuel consumption is expected. Therefore it can be concluded that teleoperation will always have a positive environmental impact.

Environmental impact	Long range	Medium range	Short range	Total
Co2	-280.800	-122.850	-9.360	-413.010
Fuel consumption	-108.000	-47.250	-3.600	-158.850

The socio-economic impact provides insight in the resources required. Firstly, it specifies how many vehicles would be required to carry out the specified operation. As teleoperators can hand-over trips to eachother during shift changes, resting time would become obsolete. Trucks could continue driving at all times and therefore could carry out more trips. Due to this fleet capacity increase, a transportation company could either downsize their fleet or expand their services.

Socio-economic impact	Long range	Medium range	Short range	Total
Required FTE	-123,98	-59,75	-19,57	-203,30
Required trucks	-6,24	-3,12	0,00	-9,36

Secondly, it specifies how many teleoperators would be required to steer said fleet. Teleoperators will no longer be required to stay with the truck during waiting hours or loading which will therefore lead to a big efficiency increase. Consequently, the driver shortage within Europe could be decreased or even resolved with implementation of teleoperated transport.

The cost differentiation provides an overview of potential savings and/or extra costs. First, it calculates the extra cost for activities that used to be carrier out by the truck driver, but will now have to be carried out by local 'hands' such as fueling station clerks or warehouse operators. As this is a new cost element to consider, the impact on the business case will always be negative until automation solutions for said activities are found.

Cost differentiation	Long range	Medium range	Short range	Total
Non-TO activities	€ 23.280	€ 10.185	€ 776	€ 34.241
Total truck operation	-€ 3.159.294	-€ 1.739.460	-€ 740.060	-€ 5.638.814
Total Fuel cost	-€ 118.800	-€ 51.975	-€ 3.960	-€ 174.735
Total equipment	€ 199.033	€ 104.417	€ 76.255	€ 379.705
TOTAL	-€ 3.055.781	-€ 1.676.833	-€ 666.989	-€ 5.399.603

Second, it shows the cost difference for truck operation based on the cost for:

- *Teleoperation control kits for the teleoperated truck drivers and trucking support operators including yearly dashboard service fee, 5G connectivity fee and equipment.*
- *Teleoperation control center based on working hours of teleoperated truck drivers and trucking support operators.*

Third, it provides the saving on fuel cost based on the decreased fuel consumption explained previously.

Last, it determines the cost for equipment based on the cost for:

- The truck itself, being either a regular truck with a teleoperation kit installed on it later on; or a newly built truck with integrated teleoperation functionality, depending on the chosen scenario.
- Truck maintenance on yearly basis
- Truck insurance on yearly basis.

Since the cost for equipment of a teleoperated truck will always be higher than the cost for a traditional truck, it can be concluded that the required investment will always have a negative impact on the business case.

Back-end: Data input-output

The back end page ties the data entered at the frond-end page to the selected scenario's and variables determined for calculation of the business case. On the left the operational cost of traditional road transport is calculated, on the right the operational cost of teleoperated road transport is calculated. The difference between the two is reflected in the business case table on the front end page.

Traditional

Logistic operations	Long range	Medium range	Short range
trips (avg/day)	50	50	50
Distance/ trip (km)	800	300	20
trip duration (h)	12	5	1
Waiting time/ trip (h)	1	1	1
Resting time/trip (h)	2	1	1
(Un)loading time/ trip (h)	1	1	1
Fueling time/trip (h)	0,120	0,053	0,004
Shifts (no./day)	2	2	2
shift duration (h/shift)	8	8	8
Working days (no/year)	235	235	235
Operational days (no./year)	300	300	300

Operating cost	Long range	Medium range	Short range
Equipment			
Truck (buying price)	€ 105.000	€ 105.000	€ 105.000
Lifespan (y)	7	7	7
Trailer (buying price)	€ 20.000	€ 20.000	€ 20.000
Lifespan (y)	10	10	10
Driver activities			
Truck driver (€/h)	€ 29	€ 29	€ 29
Total cost driving time (€/yea	€ 5.220.000	€ 2.175.000	€ 435.000
Total costloading time (€/yea	€ 217.500	€ 217.500	€ 217.500
Total cost fueling time (€/yea	€ 52.200,00	€ 22.837,50	€ 1.740,00
Total cost waiting time (€/yea	€ 435.000	€ 435.000	€ 435.000
Total cost resting time (€/yea	€ 870.000	€ 435.000	€ 435.000
Usage (per truck)			
Insurance (€/year)	€ 5.000	€ 5.000	€ 5.000
Maintenance (€/year)	€ 8.500	€ 8.500	€ 8.500
Avg fuel consumption (l/km	0,30	0,35	0,40
Fuel consumption (l/trip)	240	105	8

Output	Long range	Medium range	Short range
Operational time (h)	4800	4800	4800
Truck usage (h)	234.300	113.288	52.560
Required trucks (no.)	48,81	23,60	10,95
Required FTE (no.)	124,63	60,26	27,96
Fuel consumption (l)	3.600.000	1.575.000	120.000
CO2 (kg)	9.360.000	4.095.000	312.000
Equipment (€)	€ 1.488.781	€ 719.848	€ 333.975
Driver activities (€)	€ 6.794.700	€ 3.285.338	€ 1.524.240
Fuel (€)	€ 3.960.000	€ 1.732.500	€ 132.000

Tele-operation

Logistic operations	Long range	Medium range	Short range
trips (avg/day)	50	50	50
Distance/ trip (km)	800	300	20
trip time (h)	12	5	1
Waiting time/ trip (h)	1	1	1
Resting time/trip (h)	0	0	0
(Un)loading time/ trip (h)	1	1	1
(Un)loading time/ trip (h) - fleet manager	0,10	0,10	0,10
(Un)loading time/ trip (h) - loading location	0,00	0,00	0,00
Fueling time/trip (h) - fleet manager	0,062	0,027	0,002
Fueling time/trip (h) - station clerk	0,062	0,027	0,002
Shifts (no./day)	2	2	2
shift duration (h/shift)	8	8	8
Working days (no/year)	235	235	235
Operational days (no./year)	300	300	300

Operating cost	Long range	Medium range	Short range
Equipment			
Retrofit w/kit	€ 120.000	€ 120.000	€ 120.000
Lifespan (y)	7	7	7
Trailer (buying price)	20.000	20.000	20.000
Lifespan (y)	10	10	10
Tele-operation control center			
Dashboard service (€/kit/ year)	€ 300	€ 300	€ 300
5G connection (€/kit/year)	€ 300	€ 300	€ 300
TO control kit (€/kit/year)	€ 5.000	€ 5.000	€ 5.000
TO truck driver (€/h)	€ 29	€ 29	€ 29
TO fleet manager (€/h)	€ 44	€ 44	€ 44
Ratio TO - vehicle	0,90	0,80	0,70
Total cost driving time TO truck driver (€/year)	€ 5.220.000	€ 2.175.000	€ 435.000
Total cost loading time fleet man. (€/year)	€ 65.250	€ 65.250	€ 65.250
Total cost fueling time fleet man. (€/year)	€ 40.507,20	€ 17.721,90	€ 1.350,24
Total cost waiting time (€/year)	N/A	N/A	N/A
Total cost resting time (€/year)	N/A	N/A	N/A
Non driving activities			
Cost local operator (€/h)	€ 25	€ 25	€ 25
Cost local (un)loading support (€/h)	0,00	0,00	0,00
Cost local fueling support (€/h)	€ 23.280	€ 10.185	€ 776
Usage (per truck)			
Insurance (€/year)	€ 5.500	€ 5.500	€ 5.500
Maintenance (€/year)	€ 15.000	€ 15.000	€ 15.000
Avg fuel consumption (l/km)	0,30	0,35	0,40
Fuel consumption (l/trip)	233	102	8

Output	Long range	Medium range	Short range
Operational time (h)	4800	4800	4800
Truck usage (h)	204.362	98.315	37.562
Required trucks (no.)	42,58	20,48	7,83
Required Fleetmanagers (no.)	0,65	0,51	0,41
Required Tele-operators (no.)	48,92	20,92	6,99
Required TO control kits (no.)	37,50	15,63	3,13
Fuel consumption (l)	3.492.000	1.527.750	116.400
CO2 (kg)	9.079.200	3.972.150	302.640
Fuel (€)	€ 3.841.200	€ 1.680.525	€ 128.040
Truck equipment (€)	€ 1.687.814	€ 824.264	€ 314.918
Tele-operation equipment (€)	€ 210.000	€ 87.500	€ 17.500
Tele-operation control center (€)	€ 5.325.757	€ 2.257.972	€ 501.600
Non-TO activities (€)	€ 23.280	€ 10.185	€ 776

The top table, labelled 'logistic operations', takes the business parameters and converts them where needed into data required for calculation of the output at the bottom.

Logistic operations	Long range	Medium range	Short range
trips (avg/day)	50	50	50
Distance/ trip (km)	800	300	20
trip duration (h)	12	5	1
Waiting time/ trip (h)	1	1	1
Resting time/trip (h)	2	1	1
(Un)loading time/ trip (h)	1	1	1
Fueling time/trip (h)	0,120	0,053	0,004
Shifts (no./day)	2	2	2
shift duration (h/shift)	8	8	8
Working days (no/year)	235	235	235
Operational days (no./year)	300	300	300

Logistic operations	Long range	Medium range	Short range
trips (avg/day)	50	50	50
Distance/ trip (km)	800	300	20
trip time (h)	12	5	1
Waiting time/ trip (h)	1	1	1
Resting time/trip (h)	0	0	0
(Un)loading time/ trip (h)	1	1	1
(Un)loading time/ trip (h) - fleet manager	0,10	0,10	0,10
(Un)loading time/ trip (h) - loading location	0,00	0,00	0,00
Fueling time/trip (h) - fleet manager	0,062	0,027	0,002
Fueling time/trip (h) - station clerk	0,062	0,027	0,002
Shifts (no./day)	2	2	2
shift duration (h/shift)	8	8	8
Working days (no/year)	235	235	235
Operational days (no./year)	300	300	300

Apart from the business parameters, the left table is updated with:

- (Un)loading time based on the selected transport type;
- Fueling time based on distance and average fuel consumption. We assume fueling takes 20 min per fueling stop and a full truck tank contains 600l.
- Working days per year per FTE, which is 235 working days based on a 40 hour workweek with 20 holidays.

The right table is updated with:

- (Un)loading time based on the selected transport type and taking into account the split in responsibilities for the local operator and the teleoperated trucking support operator in account with the table below.

	Scenario	Cost trailer (buying price)	(un)loading time (h)	local (un)loading support (h)	Fleet manager support (h)	Fleet manager activity
Transport type	<select>	N/A	N/A	N/A	N/A	N/A
	Container	€ 20.000	0,5	0	0,1	Temperature control (I/A)
	Cargo (pallets)	€ 50.000	2	2	0,25	Docking
	(ISO) Tank	€ 100.000	2	0,5	0,25	Pump
	Special	€ 200.000	4	3	0,25	General

  For example, for tank transport we assume that the local operator will need 30 min to connect and disconnect the hose and additional checks in relation the (un)loading process and that the trucking support operator will need 15 min to support the local operator where needed by for example turning on the pump on the trailer.
- Fueling time based on distance and average fuel consumption. We assume fueling takes 10 min for the teleoperated trucking support operator and 10 min for the local fueling station clerk
- Working days per year per FTE, which is 235 working days based on a 40 hour workweek with 20 holidays.

The middle table, labelled 'operating cost' provides those cost elements for a logistic operation for which a change is expected when a transition to teleoperation is made. For the purpose of this report, the costs are grouped in different categories:

'Equipment' provides the average cost for:

- Truck: investment price of €105.000 for traditional operations and €120.000 for a retrofitted truck or €150.000 for an integrated teleoperated truck. An amortization term of 7 years is included.
- Trailer: cost based on the selected transport type and amortization term of 10 years

'Driver activities' provide the cost for human resources based on the time spent by a driver and multiplied with the amount of operational days and hourly driver rate. The following formulas apply:

- Total cost driving time (€/year)= trips per day x trip duration x operational days x driver rate
- Total cost loading time (€/year)= trips per day x loading time/trip x operational days x driver rate
- Total cost fueling time (€/year)= trips per day x fueling time/trip x operational days x driver rate
- Total cost waiting time (€/year) = trips per day x waiting time/trip x operational days x driver rate
- Total cost resting time (€/year) = trips per day x resting time/trip x operational days x driver rate

For teleoperated operations the driver activities have been replaced by 'teleoperation control center' and 'non-driving activities'.

Operating cost	Long range	Medium range	Short range
Equipment			
Truck (buying price)	€105.000	€105.000	€105.000
Lifespan (y)	7	7	7
Trailer (buying price)	€20.000	€20.000	€20.000
Lifespan (y)	10	10	10
Driver activities			
Truck driver (€/h)	€29	€29	€29
Total cost driving time (€/yea	€5.220.000	€2.175.000	€435.000
Total costloading time (€/yea	€217.500	€217.500	€217.500
Total cost fueling time (€/yea	€52.200,00	€22.837,50	€1.740,00
Total cost waiting time (€/yea	€435.000	€435.000	€435.000
Total cost resting time (€/yea	€870.000	€435.000	€435.000
Usage (per truck)			
Insurance (€/year)	€5.000	€5.000	€5.000
Maintenance (€/year)	€8.500	€8.500	€8.500
Avg fuel consumption (l/km	0,30	0,35	0,40
Fuel consumption (l/trip)	240	105	8

Operating cost	Long range	Medium range	Short range
Equipment			
Retrofit w/kit	€120.000	€120.000	€120.000
Lifespan (y)	7	7	7
Trailer (buying price)	20.000	20.000	20.000
Lifespan (y)	10	10	10
Tele-operation control center			
Dashboard service (€/kit/ year)	€300	€300	€300
5G connection (€/kit/year)	€300	€300	€300
TO control kit (€/kit/year)	€5.000	€5.000	€5.000
TO truck driver (€/h)	€29	€29	€29
TO fleet manager (€/h)	€44	€44	€44
Ratio TO - vehicle	0,90	0,80	0,70
Total cost driving time TO truck driver (€/year)	€5.220.000	€2.175.000	€435.000
Total cost loading time fleet man. (€/year)	€65.250	€65.250	€65.250
Total cost fueling time fleet man. (€/year)	€40.507,20	€17.721,90	€1.350,24
Total cost waiting time (€/year)	N/A	N/A	N/A
Total cost resting time (€/year)	N/A	N/A	N/A
Non driving activities			
Cost local operator (€/h)	€25	€25	€25
Cost local (un)loading support (€/h)	0,00	0,00	0,00
Cost local fueling support (€/h)	€23.280	€10.185	€776
Usage (per truck)			
Insurance (€/year)	€5.500	€5.500	€5.500
Maintenance (€/year)	€15.000	€15.000	€15.000
Avg fuel consumption (l/km)	0,30	0,35	0,40
Fuel consumption (l/trip)	233	102	8

'Teleoperation control' consists of three main elements:

1. Teleoperation control kits including monitors, seats, audio-visual equipment, etc for a price of €5.000 per kit per year, with dashboard service connecting all enabling functions for a price of €300 per kit per year and 5G connection service for a price of €300 per kit per year.
2. The ratio of teleoperator to vehicle.
3. The cost for human resources based on the time spent by a teleoperated truck driver and trucking support operator, multiplied with the amount of operational days and hourly rates:
    - Total cost driving time TO truck driver (€/year)= trips per day x trip duration x operational days x TO driver rate
    - Total cost loading time fleet man. (€/year)= trips per day x (un)loading time/trip by TO trucking support operator x operational days x TO trucking support operator rate
    - Total cost fueling time fleet man. (€/year)= trips per day x fueling time/trip by TO trucking support operator x operational days x TO trucking support operator rate
    - Total cost waiting time (€/year) = not applicable as a teleoperator will log off from the vehicle
    - Total cost resting time (€/year) = not applicable as a teleoperator will hand over control to another operator during breaks or at the end of a shift.

'Non driving activities' assumes an hourly cost of €25 per hour for local support. With that it calculates the cost for local support during fueling and loading/unloading in accordance with the selected scenario's. The following formulas apply:

- Cost local (un)loading support (€/h) = trips per day x (un)loading time/trip by loading location x operational days x local operator rate
- Cost local fueling support (€/h) = trips per day x fueling time/trip by station clerk x operational days x local operator rate

'Usage' reflects the cost for truck usage and includes:

- A fixed insurance cost of €5.000 per truck per year for traditional operations and €5.500 for teleoperation.
- A fixed maintenance cost of €8.500 per truck per year for traditional operations and €15.000 for teleoperation which includes inspection and/or calibration of the equipment.
- The average fuel consumption (l/km) based on distance.

- Fuel consumption in liter per trip based on distance and fuel consumption. For teleoperation we assume a 3% decrease in fuel consumption due to proper use of the enabling functions such as speed advice and timeslot bookings at intersections.

The bottom table, labelled 'output' provides the essential elements for the business case calculation.

For traditional transport, the following formulas apply:

- Operational time (h)= shifts x shift duration x operational days
- Truck usage (h) = (trip duration + Waiting time/ trip + Resting time/trip + (Un)loading time/ trip + Fueling time/trip) x trips/ day x operational days
- Required trucks (no.) = truck usage ÷ operational time
- Required truck drivers (FTE) = required trucks x shifts x (operational days÷working days)
- Fuel consumption (l) = Fuel consumption/trip x trips/day x operational days
- CO_2 (kg) = Fuel consumption x 2.6kg/l TTW
- Equipment (€)= (Truck cost ÷ amortization term + Trailer cost ÷ amortization term + Insurance+ Maintenance) x required trucks
- Driver activities (€) = Total cost driving time + Total costloading time + Total cost fueling time + Total cost waiting time + Total cost resting time
- Fuel (€)= Fuel consumption x €1,10/liter

For teleoperated transport, the following formulas apply:

- Operational time (h)= shifts x shift duration x operational days
- Truck usage (h) = (trip duration + Waiting time/ trip + Resting time/trip + (Un)loading time/ trip + Fueling time trucking support operator/trip + Fueling time station clerk/trip) x trips/ day x operational days
- Required trucks (no.) = truck usage ÷ operational time
- Required Fleetmanagers (FTE) = ((Un)loading time/trip trucking support operator + Fueling time/trip trucking support operator) x trips/day x operational days)/shift duration /working days
- Required Teleoperators (FTE) = (Required trucks x ratio TO – vehicle) x operational days ÷ working days
- Required TO control kits (no.) = Required fleetmanagers + required teleoperators x working days ÷ operational days
- Fuel consumption (l) = Fuel consumption/trip x trips/day x operational days
- CO_2 (kg) = Fuel consumption x 2.6kg/l TTW
- Fuel (€)= Fuel consumption x €1,10/liter
- Truck equipment (€) = Equipment (€)= (Truck cost ÷ amortization term + Trailer cost ÷ amortization term + Insurance+ Maintenance) x required trucks
- Teleoperation equipment (€) = (Dashboard service + 5G connection + TO control kit) x required TO control kits
- Teleoperation control center (€) = Total cost driving time TO truck driver + Total cost loading time trucking support operator + Total cost fueling time trucking support operator
- Non-TO activities (€) = Cost local (un)loading support + Cost local fueling support