Identifying Suitable Environments for Autonomous Truck Development

A Study on Controlled Outdoor Environments and Their Characteristics

Master's thesis in Management and Economics of Innovation, and
Quality and Operations Management

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Abstract

As the transportation industry is struggling with several structural problems, autonomous trucks have emerged as one potential solution to the issues such as driver shortage, shrinking margins and climate change. As of today, there is low technical maturity in autonomous solutions, and due to this the developers are struggling to find well-suited locations for the technology's primary implementation. In light of this issue, several authors have turned attention to controlled outdoor environments as a potential arena for deployment of autonomous trucks, suggesting that these sites may be easier to operate than public environments. Despite this interest, there exists no comprehensive compilation of which types sites these potential controlled outdoor environments would consist of, when placing them in the context of autonomous trucks. Moreover, there is a lack of knowledge about which characteristics these controlled outdoor environments exhibit that make them suitable for autonomous trucks. In light of this, this report investigates both which characteristics of controlled outdoor environments that predisposes suitability, as well as identifying which of these controlled outdoor environments exhibit the characteristics that supports the operations of autonomous trucks. During the research, it was found that there were both site specific characteristics and general characteristics. The first category of characteristics were divided into the categories vehicle requirements, size of automation opportunity, traffic environment, operational conditions and site actor attitudes. Subsequently, the general characteristics were divided into weather conditions, regulatory conditions, economic conditions and autonomous loading and unloading. Moreover, the site types assessed by the study were dry ports, manufacturing plants, ports, intermodal terminals, transshipment centers, freight village/logistics clusters and airports. Both the impact of characteristics and the sites were discussed from several dimensions, namely use case, profitability, safety and regulatory conditions. Key characteristics from a deployment perspective was the internal transport volume on a site, its physical size, cargo type and form factor requirement, weather conditions as well as if the site was fenced-off. As for the evaluation of site types, ports stand out from the other sites due to their suitability on all dimensions, although they have specific requirements for vehicle capacity and performance. Next in line in terms of suitability are manufacturing plants, freight villages and airports. Finally, the report concluded that there is large internal variation between individual sites of the same type, and therefore it is important to study each site individually prior to a deployment decision.

Key words: controlled outdoor environments, autonomous trucks, deployment factor, technology adoption, site characteristic.

Acknowledgements

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Terminology

AGV: Automated Guided Vehicle. A robot that is designed to perform transport operations without human intervention in a controlled setting. It follows a predetermined and guided path independently, to fulfill the purpose to which it is dedicated.

Autonomous truck: An autonomous truck is a self-driving truck, operating without any human intervention, using advanced technologies such as Lidar, Radar and GNSS to navigate.

Controlled outdoor environment: Outdoor private area with clearly defined boundaries. The site owner can sometimes decide who is granted access to the premises, therefore this environment tends to have a low amount of public traffic.

Fenced-off: The denotation of a physical area which is enclosed from the surrounding environment by a barrier, more particularly a fence.

Form factor: Referring to the physical specification of any type of hardware, including size, shape and arrangement of parts. In the context of autonomous trucks, this can refer to the chassis of the truck.

Intermodal: This term refers to the transportation of cargo and goods by transferring it between several modes of transport, commonly used for long-distance transportation.

Logistic center: A strategically located area or facility that is part of a supply chain, where all types of transport activities can be conducted, including storage, distribution and processing.

ODD: Operational Design Domain. A description of the environment surrounding a vehicle, including but not limited to physical limits, traffic, road dimensions, environmental conditions, as well as functional constraints of the vehicle.

Rigid truck: Or box truck, is a vehicle with a cargo compartment that is fixed to the chassis, without standardized dimensions. Mainly used for short-haul regional delivery.

Site: A particular location or physical area for individuals or organizations that requires a space to conduct some type of activity. In this report, a site is considered a space where internal transportation occurs.

Swap body: A cargo unit of specified dimensions that is designed specifically for transfer between shipping modes. The swap body is light and stackable, with a reinforced steel frame but collapsible sides. The design may differ between regions and transport networks.

Trailer: A load-carrier without a motor, that is designed to be towed behind another vehicle, carrying different types of cargo.

Tractor truck: A powerful heavy-duty motorized vehicle, primarily used for towing of large load units over long distances.

Trailer-agnostic: A term used to describe that different types of trailer units can be towed interchangeably by a vehicle.

VAS: Value-Added-Services. Activities in a supply chain that to some extent enhances the state of the goods transported, e.g. labeling, maintenance, repair, and consolidation of goods.

VRU: Vulnerable Road-User. Individuals in traffic that are at risk of being harmed by a motor vehicle, e.g. cyclists, pedestrians, or motorcyclists.

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1. Introduction

In this first chapter, the background to the following research study will be outlined, to contextualize the research in a purposeful way. Moreover, the research aim and questions will be introduced, together with the scope of the study.

1.1 Background

As of today, the transportation industry is struggling with several structural problems. To start with, there is a substantial threat due to driver shortage, as the bulk of professional truck-drivers are retiring and recruitment is hampered by poor remuneration, lack of possibilities of advancement, and large problems connected to physical- and psychological health (Ji-Hyland & Allen, 2022). Moreover, the pressure on CO_2 emission-intensive industries to reduce climate impact is extensive (Berggren & Magnusson, 2012). Lastly, the road transportation industry is struggling with profitability, for instance the road haulers in the UK had profit margins ranging from 1% to 4% from 2008 to 2018 (Statista, 2022). The low margins mean that the industry does not have much room for a higher cost base, since a small increase in costs can push the bottom line down in red territory.

Lately, attention has been drawn to autonomous transport, which holds potential to address climate targets, driver shortages and profitability issues simultaneously. Ercan et al. (2022), state that autonomous transport is estimated to give a reduction of approximately 34% on overall transportation industry emissions globally, due to more efficiently planned transport, accelerated adoption of alternative fuels and intelligent charging decisions (Jones & Leibowicz, 2019). Additionally, Short & Murray (2016) proposes that autonomy creates an opportunity to increase the attractiveness of trucking by introducing remote driving stations, which entails improved flexibility and proximity to home. Naturally, this will lead to a decrease in the number of drivers needed, relieving long-term driver shortage (Short & Murray, 2016). Autonomous trucking is also expected to bring increased operational efficiency and reduce labor costs, hence providing relief to the shrinking margins of the industry (Slowik & Sharpe, 2018).

Despite these promising prospects, there are several road-blocks for a wide implementation of autonomous trucks. First, Engström et al. (2019) describe six key deployment factors that need to be considered on the road towards large-scale adoption of autonomous trucks. These factors range to include use cases and business models, safety assurance, human factors, regulation, public acceptance and trust as well as the impact on labor. By assessing these key deployment factors in different applications for autonomous trucks, the challenge in finding a suitable implementation opportunity can be addressed in a structured way. Examples of applications provided by Engström et al. (2019) are both long-haul transport on motorways, as well as short-haul implementations off-road. Furthermore, van Meldert & De Boeck (2016) suggest that implementation should first take place in the short-haul, claiming operation in controlled outdoor environments to be especially interesting. So far, very little attention from the research community has been turned towards controlled outdoor environments in the context of autonomous trucks.

Up until now, actors in the autonomous truck industry struggle to find deployment opportunities that are available at the developing state of technical maturity, and due to economical constraints these should preferably already exist within current infrastructure (Metz, 2022). van Meldert & de Boeck (2016) as the stepping stone to large-scale deployment, without further elaborating on what characteristics outdoor controlled environments should exhibit in order for them to be suitable for autonomous truck implementations or on which controlled sites they can be found.

1.2 Scope, aim and research questions

This research aims to extend the understanding of the opportunity to deploy autonomous trucks in the context of controlled outdoor environments. The scope of the study has been designed for this purpose, meaning that the study disregards all focus on long-haul public road transport of autonomous trucks, along with short-haul transport outside of controlled sites. Additionally, the study is delimited to research on freight transportation, meaning that the study does not address private or public transport. Within the broad concept of controlled outdoor environments, this study has focused on different logistics centers along with manufacturing plants, deemed as the most relevant and feasible technological starting points.

Moreover, the controlled outdoor environments are studied in collaboration with a single case company, which has chosen to remain anonymous.With this context as background, the suitability of controlled outdoor environments is examined through the lens of the key deployment factors provided by Engström et al. (2019). In this study a focus is on a subset of these factors, namely use case and business models, safety assurance and regulations. These are chosen based on the interview material, as they are discovered to be of highest relevance to cases of controlled outdoor environments, throughout the interview study.

The aim of this study is to fill the previously mentioned research gap on controlled outdoor environments in relation to autonomous trucks. For this thesis, this will include investigating what types of controlled outdoor environments that autonomous trucks could be implemented, at their current level of technological capability. In addition to this, this means to provide an understanding of which characteristics, attributed to a controlled outdoor environment, have an impact on a specific site's suitability for deployment of autonomous trucks. In order to fulfill this purpose, two questions have been formulated to guide the research:

- What are the characteristics of controlled outdoor environments that are connected to the suitability of autonomous trucks?
- Which outdoor controlled environments exhibit characteristics that can support operations of autonomous trucks?

2. Theoretical background

This section will provide the theoretical background as well as the framework that the study is based upon. The first section describes different aspects of transport automation, starting out with the official definitions of automation levels, and concepts central to the technology. Consecutively, the challenges to development of autonomous trucks are described along with its projected benefits, and finally an overview of the current applications of autonomous transport in logistics is presented. The second part describes the different types of controlled outdoor environments investigated by this study, including a wide range of logistics centers as well as manufacturing plants. Finally, the key deployment factors are described in detail, to create a foundation for the following interview study and discussion.

2.1 Transport automation

2.1.1 SAE - Levels of automation

The most foundational concept within autonomy, is the different levels of automation that SAE International (2021) has defined. In order to understand the levels of automation there are a few concepts defined by SAE International (2021) that need to be understood. The dynamic driving task (DDT), is the task of driving the vehicle, the difference between the levels are to which extent the autonomous driving system carries out the DDT. Moreover, the operational design domain (ODD) is of importance, since it describes the operating conditions where the automated driving system is supposed to work. This ranges to include restrictions on weather conditions, time of day, road- or other characteristics that must be present to ensure that the autonomous vehicle can function. The final important concept is the object and event detection and response (OEDR), that is the capability to monitor the environment and respond appropriately to the situations encountered by the vehicle. This can be performed both by a human driver or by an autonomous driving system.

Moving into the levels, there are six levels of automation, starting from Level 0 and ending at Level 5. The Level 0 is no driving automation, which means that the entire DDT is handled by a human. At Level 1, driving assistance, the autonomous driving system performs an ODD-specific part of the DDT. This means either lateral or longitudinal, meaning either to turn or accelerate/decelerate, but not the two together simultaneously. Level 2, partial driving automation, is similar, but with the extension that the autonomous driving system can perform both lateral and longitudinal driving.

Level 3, conditional driving automation, is a further extension, the autonomous driving system can now perform a wider ODD-specific part of the DDT with the expectation that the driver is ready to engage in driving when the system notifies it to do so. In Level 3, the autonomous driving system also performs the OEDR, meaning that the system recognizes the environment and acts accordingly to its requirements. At Level 4, high driving automation, the autonomous driving system now performs the entire DDT in a specific ODD, and also performs DDT fallback. This means that the human in the driver seat is more of a passenger within the specific ODD. However, the human takes over the DDT if the autonomous vehicle exits the ODD. An example of this is an autonomous vehicle that has the capability to perform the DDT on a highway, but can not enter or exit the highway by itself, instead it needs to have a human driver able to perform those tasks. The last is Level 5, full automation, this means non-ODD-specific performance by an autonomous driving system of the entire DDT and DDT-fallback. This means that the autonomous vehicle can operate wherever a typically skilled human driver could drive the vehicle.

2.1.3 Challenges related to autonomous trucks

In this section challenges of autonomous trucks will be described to understand the issue at hand. Firstly, there are technical challenges to autonomous trucks. The whole technical system needs to run smoothly to enable good operations of autonomous vehicles. Milford et al. (2019) mention sensors and interaction with vulnerable road users (VRUs) as major challenges that need to be solved. Sensors are used to identify data on the driving environment and are used by the vehicle to take appropriate action (Kocić et al. (2018). Milford et al. (2019) show that different sensors experience different challenges, an example of this is lidar technology that can provide information about the position of objects far from the vehicle, but whose effectiveness is limited when the weather conditions are adverse. Therefore, a combination of sensors is preferred, but even then challenges such as path planning persist (Kocić et al., 2018). The challenges with VRUs are different, and instead evolves around detecting, recognizing and predicting the actions of VRUs. Milford et al. (2019) describes that machine-learning could help in recognizing the VRUs. Moreover, the autonomous system has to communicate its intent with VRUs (Milford et al., 2019). The authors mention the prediction VRU action to be the most important of these challenges, as well as one of the most complex tasks (Amini et al, 2021). Humans base their prediction of VRUs actions on a guess of the goal of a specific VRUs in traffic, and autonomous systems should try to mimic this ability (Milford et al., 2019). Moreover, there are technical challenges at higher levels of autonomy. Anderson et al. (2018) write that Level 3- systems that require the human to be in-the-loop and be ready to handle the DDT-fallback are dangerous. This is due to the fact that the human needs to be awake and aware to take appropriate action at any time. Furthermore, Slowik and Sharpe (2018) write that a higher level of automation, Level 4 or more, is at risk of being hacked, meaning that there would be a safety concern rather than a safety benefit.

Moreover, there are other challenges to autonomous vehicles, which are mainly social challenges and business model challenges. Slowik & Sharpe (2018) present two of the social challenges linked to the adoption of autonomous vehicles. That is that social acceptance may be a problem and that truckers may be losing their jobs. The social acceptance mainly regards safety and system reliability concerns, there is a need for a proof of concept of autonomous driving to make it widely accepted. The loss of jobs of truckers is quite substantial. According to Slowik & Sharpe (2018) there are 3.5 million truck drivers in the US only and the potential loss of these jobs are a high barrier to adoption of autonomous trucks. Talebian & Mishra (2022) further speak about this challenge. The potential job loss of truckers can incite labor unions to act against the legislation of autonomous trucks, putting up a potential regulatory barrier.

Engström et al. (2019) write that there are business model challenges to autonomous trucks. The authors note that in general the trucking industry has low margins, meaning that there is a need for fast economic return on investment for the industry as a whole. However, this could also mean that profitable and safe autonomous trucks would pave the way for a fast and wide adoption of the technology.

2.1.4 Benefits of autonomous trucks

Autonomous trucks have several benefits, as described by Engström et al. (2018), and these benefits vary based on where autonomous trucks are adopted. The main categories of benefits seen in the literature are cost benefits, safety benefits and productivity benefits (Slowik & Sharpe, 2018; Andersson & Ivehammar, 2013; Hoque et al., 2021; Khan et al., 2022).

The cost benefits in autonomous trucks are based on two main levers. The first being the decreased costs stemming from saving on eliminating driver salary. Slowik & Sharpe (2018) describe that 35% of the marginal cost per driven mile are driver costs and Andersson & Ivehammar (2013) also conclude that driver costs are a significant part of the total cost for trucks. This means that a decrease or an elimination of these costs would therefore be quite beneficial for the trucking companies. The second lever are the cost savings stemming from increased fuel efficiency (Slowik & Sharpe, 2018). The fuel costs are also a large part of the total costs of long-haul trucking, according to Sharpe (2017) the fuel costs can be between 25% and 40% of operational trucking costs. Thus reducing the fuel cost would be very beneficial. The fuel efficiency gains can either be realized through truck platooning (Hoque et al. (2021) or by being electric (Litman, 2017).

The next category are the safety benefits. The benefit or risk of these systems vary with the level of automation. Slowik & Sharpe (2018) describe that already on low levels of automation, Level 0 or 1, the collision mitigation systems reduce accidents by 87%. Moreover, Anderson et al. (2018) write that systems up to Level 3 have many safety benefits such as lane assist and safety braking which help prevent fatal accidents.

The final category is productivity benefits. Litman (2017) describes one form of productivity benefits, increased driver productivity, that is that the driver can perform other tasks while driving. This means that the driver will be able to work on other tasks relevant to the trucking company whilst driving. Moreover, Engström et al. (2019) tells us that there are productivity gains from increased hours of truck operation. Moreover, the authors mean that increased productivity by autonomous truck operations can stem from more flexible working hours for long-haul trucking. Furthermore, Slowik & Sharpe (2018) mean that autonomous trucks and specifically truck platooning give less road congestion. This means that less time will be spent stuck in traffic for the traffic system as a whole, which Harriet et al. (2013) view as a productivity gain.

2.1.2 State-of-the-art and use cases of autonomous transport in indoor logistics operations

Having defined the levels of autonomy, the challenges and benefits of autonomous vehicles, the next step is to delve into what the state-of-the-art of autonomous vehicles in logistics operations is today. There are several potential use-cases for these. In logistics, there are two main applications of autonomous- or automated vehicles, namely indoor- and outdoor logistics operations (DHL, 2014). This section will cover the case of indoor logistics operations.

According to van Meldert & De Boeck (2016), mainly split into production plants, cross-docking stations, warehouses and distribution centers. In this setting typically automated guided vehicles (AGVs) are used. AGVs are essentially automated robots that transport goods of some kind from one location to the other (De Ryck et al. (2020). van Meldert & De Boeck (2016) outline that AGVs can both be used for horizontal and vertical transportation of goods, and coupled with autonomous loading and unloading the whole logistics operation can be automated. The authors describe autonomous forklifts as a common use-case for vertical goods transportation. Ullrich (2015) further provides examples of horizontal transportation of goods where AGVs can be used as an alternative to fixed assembly lines, automating warehouse operations or handling specific equipment.

2.1.2 State-of-the-art and use cases of autonomous transport in outdoor logistics operations

The next use-case for autonomous vehicles are in outdoor environment operations. The use-cases here are long-haul autonomous vehicle operation, last mile delivery and operation in outdoor controlled environments (DHL, 2014).

The long-haul autonomous vehicles in logistics operations are divided into truck platooning and exit-to-exit automation. Truck platooning is a use case mentioned in the literature for adoption of autonomous trucks (Engström et al., 2019). The definition of this is according to Janssen et al. (2015) two or more trucks following each other at a close distance, since they are digitally connected to each other there is no need for a driver in the trucks that are following the first one. Autonomous truck platoons are thought to save energy due to the lower drag experienced by the following trucks (Tsugawa et al, 2011) and be more stable (Kim et al., 2022). However, truck platooning has been researched for several decades (Heikoop et al. (2017), and is still in testing phase (Yang et al., 2022). Slowik & Sharpe (2018) describe that more research needs to be done in order to understand which trucks to use for platooning, how much they should weigh and how many trucks should be in a platoon. Slowik & Sharpe (2018) further conclude that the subject needs to be further investigated in order to understand what impact platooning could have on truck fleets, in order for a business case to exist for the use of the technology.

Another use case for autonomous trucks is operations in exit-to-exit highway automation (Engström et al., 2019). According to the authors, this is a use-case where autonomous trucks operate on highways, which could be done with a range of different autonomous systems. Firstly, Slowik & Sharpe (2018) describe Level 1-systems in use and Level 2-systems approaching commercial readiness that have collision avoidance and driver warning systems. Furthermore, Engström et al. (2019) describe systems with Level 1 and Level 2 capabilities such as lane assisting capabilities and adaptive cruise control are in use today. Moreover, Slowik & Sharpe (2018) describe that Level 3 trucks by Uber ATG and Otto are being developed and tested in long-haul trucks, however they are not in a commercialization stage.

Another use-case for autonomous vehicles in logistics is described by van Meldert & De Boeck (2016) as last-mile delivery systems. Last mile delivery is defined by Boysen et al. (2021) as encompassing all parts of the logistics system relating to urban private customer delivery. According to DHL (2014) this is the area that is most unpredictable for autonomous vehicles due to the vast amount of actors in the ODD, e.g. cyclists, pedestrians, trucks. Moreover, van Meldert & De Boeck (2016) point out that the automated driving system needs to be at Level 4, meaning more advanced than any system in current use. Examples of hypothetical use-cases described range from autonomous grocery shopping and autonomous parcels (van Meldert & De Boeck, 2016) to even autonomous drones (Brunner et al., 2019).

The final use-case for autonomous trucks is described by Engström et al. (2019) as off-road trucking, and by van Meldert & De Boeck (2016) referred to as operations in controlled outdoor environments, which is also the main focus of this research report. According to Engström et al. (2019) and Meldert & De Boeck (2016) these enclosed areas are appropriate for the primary implementation of autonomous trucking, in advance to large-scale on-the-road adoption. Shah & Piragine (2018) describe that the first step in taking autonomous vehicles from *"the security of controlled settings into the uncertain world of everyday traffic"* is to implement them in controlled outdoor environments and then to implement them in long-haul transport and last-mile delivery. van Meldert & De Boeck, (2016) describes the reason for this being that these sites exhibit fewer regulations, less uncertainty and have a less complex liability issue. The authors also emphasize the improved security of the controlled environment as a strong argument for the fenced-off use case, where autonomous vehicles can be operated in a low-speed and simple route environment where disturbing elements are minimized.

Engström et al. (2019) describe mine hauling, ports, yards and terminals as such potential areas for autonomous trucks. The area of operation is under investigation by several companies, both with and without driver cab. An area where this is already in use is the mine hauling (Brundrett, 2014). Moreover, Brundrett (2014) writes that the operation of autonomous trucks started back in 2008 when Rio Tinto and Komatsu collaborated to create a mining haulage truck operation, and that the commercialization of autonomous trucks is happening faster than autonomous public automobiles.

In the segment of controlled outdoor environments there is also a variety of AGV:s (van Meldert & De Boeck, 2016; Ullrich, 2015). AGV in port operations are described in many cases, such as Kim & Bae (2004), Vis et al. (2001) and Ioannou et al. (2000). Ioannou et al. (2000) describes that AGV:s are used in different container operations, mostly in the terminal operations. Vis et al. (2001) further describe that usage could be that the AGV is implemented between quay crane and the straddle carrier. That is, the goods are unloaded from the boat, lifted onto an AGV and then transported to the straddle carrier that then stacks the container. Moreover, Ullrich (2015) describes outdoor warehouse areas as a use-case for outdoor AGV:s, where they instead of handling containers handle palletized goods as the AGV:s are automated forklifts. The author further describes automated heavy load transporters in outdoor manufacturing plants as a use-case.

As seen in this section there is a wide variety of potential applications for autonomous trucks and AGV:s in outdoor controlled environments. Engström et a. (2019), van Meldert & De Boeck, (2016) and Shah & Piragine (2018) describe examples of outdoor controlled environments, but the authors do not investigate the specific characteristics of different types of individual sites in any further depth. The next section will describe the general knowledge of the facility types that is the subject of this report.

2.2 Controlled outdoor environments

As previously described by Engström et al. (2019), van Meldert & De Boeck (2016) and Shah & Piragine (2018), controlled outdoor environments constitute a promising use case for autonomous trucks. When talking about enclosed environments where the technology can be initially implemented, van Meldert & de Boeck (2016) exemplifies the concept with ports, manufacturing plants, airports and other different types of logistics centers and courtyards. However, the concept of logistics centers is broad, and classifications of different logistics centers are concerned with a high degree of confusion and conceptual ambiguity (Notteboom et al., 2016). Despite how a vast amount of typologies has been suggested to bring clarity to the field, no consensus has been reached (Meiduté, 2005). The two following sections aim to provide basic knowledge and contextualize different controlled outdoor environments in a structured way. Due to the broad ranging concept of logistics centers (Notteboom et al., 2016), most sites of interest in a transportation context can be accommodated under its roof, and in addition to this, manufacturing plants will be outlined as a separate section.

2.2.1 Logistics centers

According to the UN connected logistics association Europlatforms EEIG (2004), a logistic center can be defined as a *" a clearly defined area within which all activities relating to transport, logistics and the distribution of goods - both for national and international transit - are carried out by various operators on a commercial basis".* As previously mentioned, this include a wide range of facilities, and this section will be organized according to a typology created by Higgins et al. (2012), where the authors have combined the considerations of several authors in the research field to form a novel typology based on size, influence, function in freight- and logistics processes as well as value adding activities. The main types of logistics centers have then been placed in a hierarchy accordingly, see Figure 2.1 (Higgins et al., 2012). The typology was selected since it distinguishes itself from other work by being based on a comprehensive theoretical framework of existing typologies, and also sheds light on the incoherences of the research field, for instance how different authors define facilities differently and views them as having different positions in the logistics hierarchy.

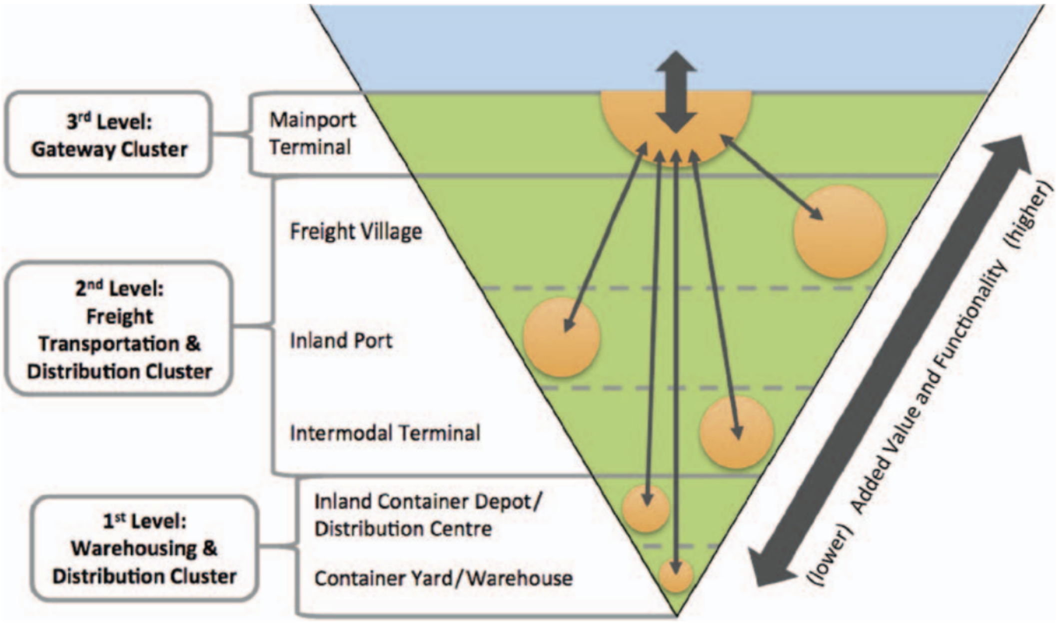
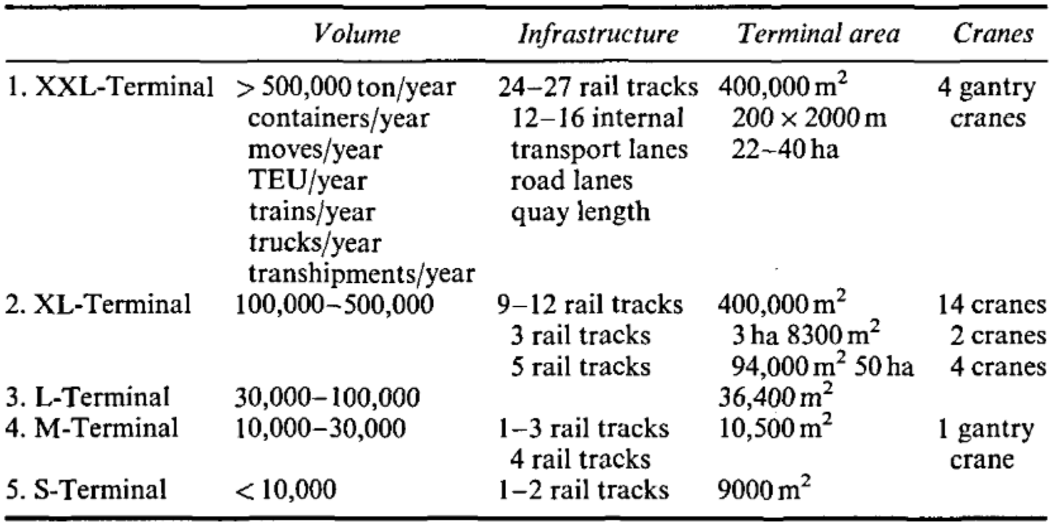


FIGURE 3 Standardized logistics center hierarchy.

Figure 2.1: Standardized logistics center hierarchy (Higgins et al., 2012).



	Volume	*Infrastructure*	*Terminal area*	*Cranes*
1. XXL-Terminal	> 500,000 ton/year containers/year moves/year TEU/year trains/year trucks/year transhipments/year	24–27 rail tracks 12–16 internal transport lanes road lanes quay length	400,000 m^2 200 × 2000 m 22–40 ha	4 gantry cranes
2. XL-Terminal	100,000–500,000	9–12 rail tracks 3 rail tracks 5 rail tracks	400,000 m^2 3 ha 8300 m^2 94,000 m^2 50 ha	14 cranes 2 cranes 4 cranes
3. L-Terminal	30,000–100,000		36,400 m^2	
4. M-Terminal	10,000–30,000	1–3 rail tracks 4 rail tracks	10,500 m^2	1 gantry crane
5. S-Terminal	< 10,000	1–2 rail tracks	9000 m^2	

Figure 2.2: Freight terminal types (Wiegmans et al., 1999)

This typology is based on the five facility classes as presented by Wiegmans et al. (1999) in Figure 2.2, where the characteristics of geographical coverage, volume and capacity distinguishes them into five orders of magnitude. The focus on facility size is pervading the literature as a distinguishing feature when trying to structure the dispersed area of logistics facilities, which for instance is present in later work by Onstein et al. (2021). This paper is based on logistics facilities literature and a large dataset on logistics facilities in the Netherlands, and it is in the same way investigating the relationship between size and site characteristics, such as activity type, product type, network structure, and market service area (Onstein, 2021).

A similar approach and division criteria is used by Notteboom et al. (2016), who also classifies based on size, position in transport and commodity chains, and geographic market coverage etc. However, instead of concluding a hierarchy Notteboom et al. (2016) divides facilities into three primary functions; i) storage, deposit & warehousing, ii) cargo transloading & rapid transit, iii) value added services & light manufacturing. Comparing this typology is interesting since it sheds light on the functionalities of the modern logistics systems, while strengthening the criteria on which the Higgins et al. (2012) and Onstein et al. (2021) models are based.

In the following section, an extended review of the Higgins et al. (2012) categorisation will be made, to outline the activities and attributes the most frequently occurring logistics facilities are referred to in a relatively unified way.

The first level facilities, with the size classification S (Wiegmans et al., 1999), are completing the most simple tasks in the transport network. It serves as a logistic backbone due to fulfillment of basic logistic functions such as storage and serving as a general support in goods movement and transloading. The main facility types are 1) *warehouses,* generally being single facilities acting as a buffer in the supplier - customer relations, providing space for temporary storage and inventory. 2) *distribution centers* are one or several facilities with the main purpose of smoothening and bridging the flow of goods, combining warehousing, shipping, goods consolidation, cross-docking and transloading. 3) *containers yards* & *inland container depots* also counts as first level facilities, and they are dedicated to container storage and maintenance, and container movement and container goods modification respectively.

The second level facilities, with size classifications ranging from M-L (Wiegman et al., 1999), encompasses a plethora of activities including extensive intermodal goods transfer, a large geographical market service area and a complete offering of value-added services. Higgins et al. (2012) elevates three types of second level facilities, firstly the 1) *intermodal terminal,* an important construct, which varies in size and range of activities. The general purpose is to handle extensive freight flows, and manage the transshipment of goods between transportation modes, e.g. rail, road and maritime. The intermodal terminal can act as a consolidating connection point between regions and continents, and also provide value-adding services to the passing goods. The 2) *inland port* is an extension of a port, often with a close infrastructural link to the mentioned that enables it to improve the mainport capacity in storing, storage and logistics management. Through this extension, the maritime freight flows can be consolidated and transshipped, and incoming goods can also be deconsolidated for local market distribution. Additionally, inland ports generally contain the extensive container handling of container yards and depots, and manage all customs-related activities. According to the typology by Higgins et al. (2012) the 3) *freight village* is the largest inland logistics facility in terms of both physical size and transport network impact. Typically, the freight village is characterized by its provision of shared logistics supporting functions, including administrative- and commercial support, maintenance areas, and worker amenities. Moreover, the freight village has strong intermodal connections with road, rail, air and barge infrastructure. Overall, the site is dedicated to the support of efficient goods flows and facilitated supply change management.

The third level facilities address the *mainport terminals* of the logistics system, generally classified as XL and XXL logistics centers. Mainport terminals connect continental inland transport networks, acting as an interface between national and international supply chains. The terminals are generally handling large maritime freight flows, hence creating a lot of economic and logistic activity in its surrounding hinterland, by inducing large good transport flows to the inland distribution chain. The mainport exchanges immense volumes of goods and passengers deconsolidate the flows onto intermodal transportation modes, and consolidates outgoing freight flows for shipping. In order to do this, the mainports contain all previously mentioned logistic activities, being transshipment, storage, maintenance, value-added services, customs, administration and workforce amenities. Due to their transport network impact, the mainport terminal has been described with many names with common examples being gateways (Notteboom & Rodrigue, 2009) and logistics nodes (Rimienè and Grundey, 2007), however Notteboom & Rodrigue (2009) include both airports and ports in this category. According to Weigmans et al. (1999), logistics facilities of this size are characterized by high volumes, high-capacity utilization, and large international companies on site.

2.2.2 Manufacturing plants

While logistics facilities can be difficult to classify due to conceptual ambiguity and lack of consistency in nomenclature (Notteboom & Rodrigue, 2016), manufacturing plants are an even more varied group of controlled outdoor environments, with individual sets of manufacturing facilities and strategic goals (Vokurka & Davis, 2004). A general characteristic of manufacturing plants is their complex organization, where coordination and planning of all operations must be efficient to reach the plant overarching performance objectives (Sule, 2008). The author mentions several activities of the plants that are in need of coordination both during design and production, these ranges to include the utilized manufacturing processes, plant layout, material-handling, storage systems, and the unified operational cost estimate of the plant. According to Vokurka & Davis (2004), manufacturing plants are often classified based on the product they produce, which entail describing attributes such as volume, variety, complexity. They can also be classified based on production process, with attributes such as complexity and flow, or the market that they serve, which can differ regarding scope, need, diversity (Vokurka & Davis, 2004). Moreover, the authors emphasize the need for specificity in the configuration of manufacturing facilities and the assignment of facility functions, based on the production goals and the market service area.

2.3 Deployment factors

As discussed in section 2.1, there exist several potential applications of automated trucking technology both on- and off-road, and they share challenges that in the first case may be easier to surmount in controlled environments. As stated by Engström et al. (2019), the target scenario for the development of autonomous trucks is to be deployed on large-scale on public roads while inducing revenue streams to the solution developers and the customers. Engström et al. (2019) present six deployment factors that can be used to assess the potential for large-scale deployment of autonomous trucking technology in a specific arena, namely; use cases, business models, safety assurance, human factors, regulation, impact on labor, public acceptance and trust. In this paper, the different sites and their characteristics will be viewed from these deployment perspectives, when assessing the suitability of sites and the importance of certain characterizing elements in a controlled environment. The primary focus will be on the factors discussing use cases, business models, safety assurance and regulations, as the emphasis on human interaction as well as the attitude of the general public is less important in enclosed and private environments. Subsequently, the deployment factors of focus for the study will be reviewed.

2.3.1 Use cases

Engström et al. (2019) write that *"the potential benefits of automated trucking depend strongly on the specific use case considered"*, meaning that the primary precondition for successfully implementing autonomous trucks is that the transport operation being automated are well-suited for the new technology. The authors place emphasis on the heterogeneity of trucking operations, and explain that the initial use cases of autonomous vehicles will be in environments of low complexity (Engström et al., 2019). van Meldert and de Boeck (2016) claim that the likely development is that autonomous vehicles will be allowed under extremely specific conditions; at one particular speed, specified weather conditions and certain routes. Fagnant & Kockelman (2015) states that the benefits in most use cases depend on the improvement of automated driving capabilities, and agrees with Canis (2019) who mention the potential of infrastructure adaptation as a way to construct a more favorable public landscape that could contribute to increase the number use cases for autonomous vehicles that are within reach in the near future. Engström et al. (2019) claims that the type of use cases that will be considered for the current autonomous technology could be operating large private fleets on fixed and predictable routes. Moreover, the same authors conclude that deployment of autonomous technology in its current state relies on developers to identify highly suitable venues with low-complexity use cases where autonomous solutions can be customized to solve individual carrier needs.

2.3.2 Profitability

Automated trucking differs from automated private vehicles in terms of the motives for the investment, due to the fact that trucking companies are driven by the promise of expanded profit margins, in contrast to private vehicle owners who also prioritize comfort, status and safety (Engström et al., 2019). According to Fagnant & Kockelman (2015), widespread technology adoption is lagging behind to a large degree due to the extremely high investment barriers for both the trucking industry and private customers, even basic autonomous solutions being excessively expensive. The typical small margins of the trucking industry places a demand for rapid, and guaranteed, return on investment (Engström et al., 2019). Predictions are that when sufficient technological progress is accomplished, the operational efficiency improvement and cost reductions in freight will disrupt the trucking industry and adoption will accelerate (Sing Muddhar et al., 2016). According to the authors, the potential economic benefits consist of efficiency improvements in around-the-clock operations, efficient fuel-consumption, as well as cost reductions when no driver is paid. Engström et al. (2019) state that it is essential to present a convincingly strong business case to customers, where sufficient value can be translated to the bottom-line, to incentivize commercial deployment of autonomous trucking in the long-term.

In the proposed list of deployment factors proposed by Engström et al. (2019), this factor is denoted as "business models", however the authors of this study har chosen to replace this with the word "profitability", as this suits the scope of the research better.

2.3.3 Safety assurance

In their paper, Engström et al. (2019) explains this deployment factor as the issue of how one can ever be able to completely ensure that an autonomous system can respond appropriately to all edge cases it will come across in a public traffic environment. According to Wang et al. (2020), the safety of autonomous vehicles is fragile as it depends on technical and social parameters, including automation level, traffic conditions, weather conditions, regulations, and vehicle capabilities. Sing Muddhar et al., (2016) adds to this by lifting the problem of vehicle-human and vehicle-vehicle interaction when the driver is removed from the system, which creates additional complexities when trying to make autonomous vehicles become a natural part of the public traffic environment. Similarly to the case of profitability, the expectations in terms of traffic safety when considering a fully functionable autonomous system are high-leveled, with examples such as reduction of car-crashes, speeding, in-attention, and decreased risk-taking (Sing Muddhar et al., 2016; van Meldert & De Boeck, 2016). Fagnant & Kockelman (2015) brings forward the complexity related to the mix of public traffic environments, where the requirements on object recognition and adequate responses in unpredictable traffic situations or "edge cases", comprise a major safety challenge. As of today, safety is among the most critical issues, and for the future of autonomous trucking, and vehicle manufacturers, tech companies and suppliers need to collaborate in this matter to accumulate a sufficient amount of safety evidence through simulation, test tracks and eventually on-road field tests (Engström et al., 2019). Sing Muddhar et al. (2016) agrees with this, by stating that 100 millions of miles need to be driven in order to demonstrate rigorous road safety.

2.3.4 Human factors

This deployment factor is mainly concerned with how the interaction between humans and autonomous vehicles can be handled, together with the changes the technology brings about in the organizations and lives of humans (Engström et al., 2019). At the core of this, Sing Muddhar (2016) points out the problem that machines are inherently different from the human brain, and therefore this creates problems in the interaction between humans and autonomous vehicles (van Meldert & de Boeck, 2016). Both Engström et al. (2019) and van Meldert & de Boeck (2016) describe research on the operator-vehicle interaction in pre-Level 5 automation, where current challenges are related to negative behaviors when humans become acclimated to the autonomous system. Examples brought forward by the authors range to include overreliance on the autonomous system, technological misunderstandings, and excessive distraction from the driving tasks, and also problems in the vehicle-operator driving handover. Education and training in autonomous technology can to some extent be used to mitigate these issues (Engström et al., 2019). From a more positive point of view, Sing Muddhar et al., (2016) state that autonomous technology at its mature state can actually be used to remove and mitigate human "error" from public traffic.

2.3.5 Regulations

In order to deploy autonomous vehicles over time on both a short and a long perspective, the legislative structure must be compliant with technological evolution (Carp, 2018). At the core of the current inertia in legislative change lies the fact that regulations presuppose a driver in the vehicle, which in itself constitute a large legal barrier when creating new vehicle designs and solutions (Engström et al., 2019). In the meantime, Carp (2018) points out, autonomous vehicles must comply with existing traffic- and vehicle regulations for manual vehicles. According to Canis (2019), autonomous vehicles will at some point require completely new legal standards, and Carp (2018) states that the development is handled by offering specific exemptions, meaning that current R&D is run on a case-by-case basis. Collingwood (2017) raises two other regulatory issues that have incurred attention in this field of innovation, namely, the liability and the privacy questions. In short, the liability is concerned with responsibility assignment in autonomous incidents, and privacy revolves around the use and control over all private data processed in the vehicle (Collingwood, 2017). Engström et al. (2019) places a demand for a data-driven approach among policy makers, Carp (2018) requests legislative efficiency for the autonomous vehicle question, and Collingwood (2017) concludes that legal issues may hamper technology development and delay commercialization.

2.3.6 Impact on labor

According to Engström et al. (2019), the trucking industry is aware of the risks associated with autonomous disruption. A majority of long-haul transports might be carried out without a driver, and loading- and unloading carried out by operators in the origin- and destination points (Fagnant & Kockelman, 2015). There are also speculations of further spill-over effects in connected branches, such as driver licensing, traffic policing and insurance sales (Faisal et al., 2019). Due to this potential for immense unemployment throughout the industry, the same authors claim that this could infer conflicts between labor groups in the freight railroad industry and the autonomous car manufacturers. However, in light of the present problems of escalating driver shortage, and remaining technical barriers to on-road public automation, the worries of large-scale unemployment have been dampened (Engström et al., 2019). There may also be positive effects of autonomous trucks in the industry, as these have potential to improve the driver working conditions, improve attrition rates, and create new driving tasks (Engström et al., 2019).

2.3.7 Public acceptance and trust

A central challenge to large-scale deployment of autonomous vehicles, which is particularly critical for large trucks operating in a conventional traffic environment, is public acceptance (Engström et al., 2019). According to Hőgye-Nagy et al. (2023), the attitudes towards autonomous vehicles plays a greater role in technology acceptance than concrete experiences. Therefore, the introduction of autonomous vehicles in the society should be accompanied by education and public communication in the benefit and safety question around the phenomena (Engström et al., 2019). Perceived value and trust lies at the heart of bringing about technology acceptance on a broader scale, and adoption is fully reliant upon the value creation (Yuen et al., 2020). Finally, Collingwood (2017) specifically points out the issue of the user privacy issue, which as of today is central to establishing trust.

3. Methodology

In this chapter, the methodology of the research study is described. First, the research approach will be discussed, followed by the data collection, data analysis and finally, the research quality.

3.1 Research strategy

The research strategy can, according to Bell et al. (2019) follow two very different paths, either being qualitative or quantitative. In this study the chosen method is the qualitative one. The reason for conducting the study in a qualitative way, is due to how qualitative study is able to convey vivid descriptions of complex issues (Sofaer, 1999). There are a multitude of ways of doing qualitative research, examples include but are not limited to longitudinal design, cross-sectional design, comparative design and case study design (Bell et al. (2019).

In this research the study will be done by performing a case study. Performing research designed as a case study, means to extensively analyze a single object of analysis in a particular case. In this research the case study will be of a single organization. The chosen organization is well-suited to the purpose of the study, due to the high availability of data in the company and the fact that the company is a pioneer in the segment of study. However, this case company has chosen to remain anonymous, and for this reason the interview data is anonymized. The case study will provide insight into the industry of autonomous trucks as a whole, but through the lens of this single object of study. The research will be conducted in an inductive manner, that is letting theory emerge from the research. The rationale behind doing the research inductively, is simply due to the fact that the specific business area of autonomous trucks in controlled outdoor environments is quite complex.

3.2 Data collection

In the following section the collected data will be described. The data collected will be of both primary and secondary nature, where the primary data collected will be interview data from relevant employees at the case company.

The interview data, that is primary in its nature, was sampled using three concepts. First, the data was sampled in a purposive way using purposive sampling, that is, according to Bell et. al (2019) that the sample is selected carefully and that the research questions guide which participants that are chosen for the study. Second, a subgenre of purposive sampling was used, that is theoretical sampling. According (Glaser & Strauss, 2017) this entails gathering data to form categories and concepts that together form a theory. The study follows this inductive theory-emerging approach as mentioned above in order to create a wider understanding of this new market and the specific requirements that the new technology has to adhere to in the current state-of-the-art. Third, participants were sampled through snowball sampling which according to Bell et al (2019) is when a small group of people are initially approached and interviewed and the next round of interviewees are sampled by asking the first group.

The interviewed subjects were from several categories, both from the case company and other interesting parties. The non-case company specific sampled participants were academics from different backgrounds, including research institutes, university researchers and research consultants, as well as freight transport experts and logistics facility leads. Moreover, the case company interviewees had different roles within the company. The interviewed participants had product responsibilities, e.g. product strategy and product managers, team leader or director roles, e.g. team leader of technical operations, director of regulatory affairs, senior technical director or more business roles, e.g. business developer, and finally a company executive, senior vice president autonomous freight. Initially, a pre-interview round was done internally at the company to understand the problem at hand and what information was in need of gathering. After this round, the interviews were conducted both internally at the company to get a wider view of the case, as well as externally to get a better understanding of the industry as a whole.

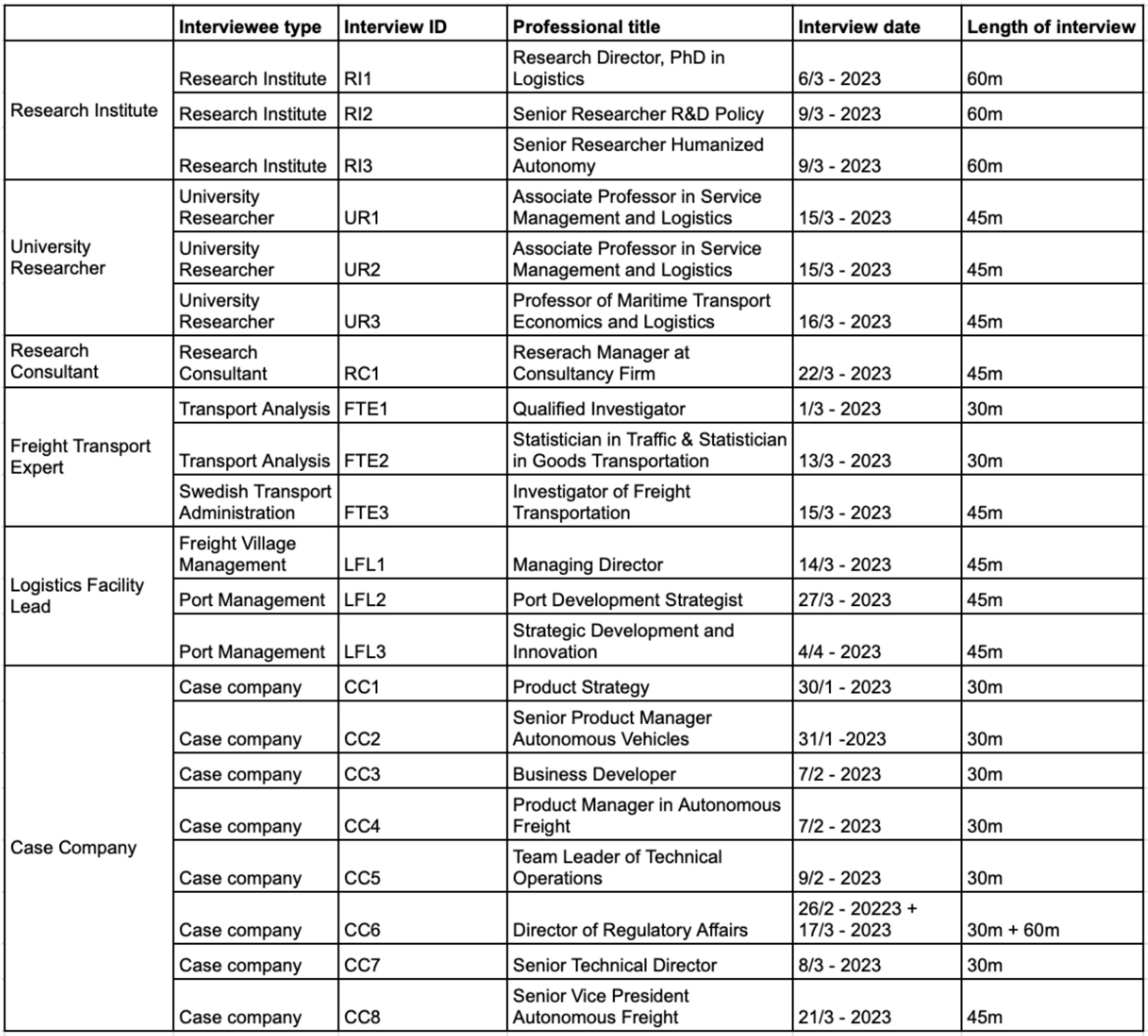
The sampled participants were interviewed in a qualitative manner in semi-structured interviews. The semi-structured interviews are according to Bell et al. (2019) interviews where the interviewer has prepared questions but has some freedom to ask follow-up questions or ask them in a different order. These were conducted using an interview guide, recorded whenever possible and the recording was supported by taking notes during the interview. In total, 21 interviews were conducted during the study. The interviewed participants are presented in the table below.

	Interviewee type	**Interview ID**	**Professional title**	**Interview date**	**Length of interview**
Research Institute	Research Institute	RI1	Research Director, PhD in Logistics	6/3 - 2023	60m
	Research Institute	RI2	Senior Researcher R&D Policy	9/3 - 2023	60m
	Research Institute	RI3	Senior Researcher Humanized Autonomy	9/3 - 2023	60m
University Researcher	University Researcher	UR1	Associate Professor in Service Management and Logistics	15/3 - 2023	45m

	University Researcher	UR2	Associate Professor in Service Management and Logistics	15/3 - 2023	45m
	University Researcher	UR3	Professor of Maritime Transport Economics and Logistics	16/3 - 2023	45m
Research Consultant	Research Consultant	RC1	Research Manager at Consultancy Firm	22/3 - 2023	45m
Freight Transport Expert	Transport Analysis	FTE1	Qualified Investigator	1/3 - 2023	30m
	Transport Analysis	FTE2	Statistician in Traffic & Statistician in Goods Transportation	13/3 - 2023	30m
	Swedish Transport Administration	FTE3	Investigator of Freight Transportation	15/3 - 2023	45m
Logistics Facility Lead	Freight Village Management	LFL1	Managing Director	14/3 - 2023	45m
	Port Management	LFL2	Port Development Strategist	27/3 - 2023	45m
	Port Management	LFL3	Strategic Development and Innovation	4/4 - 2023	45m
Case Company	Case company	CC1	Product Strategy	30/1 - 2023	30m
	Case company	CC2	Senior Product Manager Autonomous Vehicles	31/1 -2023	30m
	Case company	CC3	Business Developer	7/2 - 2023	30m
	Case company	CC4	Product Manager in Autonomous Freight	7/2 - 2023	30m
	Case company	CC5	Team Leader of Technical Operations	9/2 - 2023	30m

	Case company	CC6	Director of Regulatory Affairs	26/2 - 20223 + 17/3 - 2023	30m + 60m
	Case company	CC7	Senior Technical Director	8/3 - 2023	30m
	Case company	CC8	Senior Vice President Autonomous Freight	21/3 - 2023	45m

Table 3.1: Overview of the conducted interviews during the thesis



	Interviewee type	**Interview ID**	**Professional title**	**Interview date**	**Length of interview**
Research Institute	Research Institute	RI1	Research Director, PhD in Logistics	6/3 - 2023	60m
	Research Institute	RI2	Senior Researcher R&D Policy	9/3 - 2023	60m
	Research Institute	RI3	Senior Researcher Humanized Autonomy	9/3 - 2023	60m
University Researcher	University Researcher	UR1	Associate Professor in Service Management and Logistics	15/3 - 2023	45m
	University Researcher	UR2	Associate Professor in Service Management and Logistics	15/3 - 2023	45m
	University Researcher	UR3	Professor of Maritime Transport Economics and Logistics	16/3 - 2023	45m
Research Consultant	Research Consultant	RC1	Reserach Manager at Consultancy Firm	22/3 - 2023	45m
Freight Transport Expert	Transport Analysis	FTE1	Qualified Investigator	1/3 - 2023	30m
	Transport Analysis	FTE2	Statistician in Traffic & Statistician in Goods Transportation	13/3 - 2023	30m
	Swedish Transport Administration	FTE3	Investigator of Freight Transportation	15/3 - 2023	45m
Logistics Facility Lead	Freight Village Management	LFL1	Managing Director	14/3 - 2023	45m
	Port Management	LFL2	Port Development Strategist	27/3 - 2023	45m
	Port Management	LFL3	Strategic Development and Innovation	4/4 - 2023	45m
Case Company	Case company	CC1	Product Strategy	30/1 - 2023	30m
	Case company	CC2	Senior Product Manager Autonomous Vehicles	31/1 -2023	30m
	Case company	CC3	Business Developer	7/2 - 2023	30m
	Case company	CC4	Product Manager in Autonomous Freight	7/2 - 2023	30m
	Case company	CC5	Team Leader of Technical Operations	9/2 - 2023	30m
	Case company	CC6	Director of Regulatory Affairs	26/2 - 20223 + 17/3 - 2023	30m + 60m
	Case company	CC7	Senior Technical Director	8/3 - 2023	30m
	Case company	CC8	Senior Vice President Autonomous Freight	21/3 - 2023	45m

3.3 Data analysis

The case study is analyzed through a qualitative data analysis method. The chosen method for the study is thematic analysis (Bell et al., 2019). Thematic analysis is according to Maguire & Delahunt (2017) the *"process of identifying patterns or themes in the qualitative data"* and is described more thoroughly by Braun & Clarke (2006). They describe a six-step process delineating all the important steps in doing this type of data analysis. The six-step process is described in this section and in each step of the process there will be a description of how the process is implemented in this research.

Braun & Clarke (2006) describe the first step in the process is the familiarization of oneself with the data. Thesis means that the interviews that have been conducted are read through in several iterations to understand the data in a deeper way. In this study, the interviews were recorded whenever possible, therefore in the first step the recordings were watched and the notes from the interview were further developed. Braun & Clarke (2006) further describe the second step in the process, that is to generate the initial codes, this is done through noting interesting snippets of data and collecting them in a systematic fashion. In this report, this was done by making comments in the google docs document that was used for each interview. In the third step Braun & Clarke (2006) describe that codes are being gathered to form themes together. This was done by collecting all comments in the google docs document in an excel sheet and were sorted according to the initial theme they were thought to belong to. A weakness of thematic analysis is pointed out by Bryman & Burgess (1994), this is that it is difficult to assess the exact reason for themes being created. Moreover, the authors suggest using frequency of mentions as a criteria for forming the categories to assess this weakness. This is why in this study, frequency tables were used to create the themes.

Braun & Clarke (2006) describe that the fourth step is to review the themes, meaning to refine the generated themes. In this report, this was done by iterating all the themes once more. The fifth step is according to the author to define and name the themes. In this report, themes are the overarching characteristics of outdoor controlled environments, that is vehicle requirements, size of automation opportunity, operational conditions and site actors. The sixth step is to produce the report, and the result of this will be found in the empirical findings of this report.

3.4 Research quality

In this section, the considerations regarding the research quality will be described. Bell et al. (2019) suggest that reliability and validity are important quality criteria for the qualitative researcher to analyze. Since the study is of a qualitative nature, these two criteria will be the ones that are described.

Firstly, the validity concerns according to Bell et al. (2019) the integrity of the conclusions from research. Golafshani (2003) explains validity as both the accuracy of measurement and whether the measurement does evaluate what is intended. Bell et al (2019) further describe that there are four types of validity; measurement validity, internal validity, external validity and ecological validity. Furthermore, the authors describe that measurement validity is not relevant for qualitative research and that internal and external validity are the most relevant ones in this research context. Therefore this paper will only discuss internal and external validity. Bell et al (2019 writes that internal validity is concerned with the match between the observations made in the study and the results from it. This means, if the study has a causal relationship between the observations and the following results. The interviews in this study have been conducted independently and many different interviews have been conducted, making sure to have a wide variety of information to base the results on. The external validity, according to Bell et al. (2019), are concerned with the generalizability of the study, in practice this means if it is possible to apply the results in other contexts than the specific research one. In order to ensure external validity in this report, the sampled participants are not only company specific ones, but are researchers on the subject and external experts, meaning that the perspective should be one from the general industry and not only from the company.

Secondly, reliability is according to Bell et al. (2019) concerned with the repeatability of the research study, however it is hard to meet this quality criteria in qualitative research due to the nature of the research. It is impossible to perform another experiment on a specific social setting in the exact same circumstances due to time passing. This is consistent with the view by Golafshani (2003). However, Bell et al. (2019 provide a suggestion internal reliability in qualitative research that is agreement between the researchers in a multi-researcher setting. Golafshani (2003) argues that a good method to establish reliability is to use triangulation, that is to confirm the research findings using several independent sources. In this study, this has been handled by conducting multiple interviews, and also by doing a theoretical framework on the subject matter.

4. Empirical findings

The following chapter is based on the interview study that included 21 interviews with both case company employees and external parties. The interview material was coded and consecutively divided into three categories. The thesis findings are synthesized into the sections *Characterics of sites* and *Site descriptions.* Hence, the first section presents the characteristics of controlled outdoor environments, deemed important from a deployment perspective. These characteristics are divided in site specific characteristics and general characteristics, depending if they are connected to a specific geographical location or not. In the second part, the data gathered on different sites are presented for each type, and the section is concluded with a table summarizing the characteristics of the site types.

4.1 Site specific characteristics

All characteristics of importance to site selection will be discussed in this section, and in the review, they have been divided into five areas with regard to their degree of interrelation. The five areas of characteristics are vehicle requirements, size of automation opportunity, traffic environment, operational conditions, and site actors. Throughout the interviews, all interviewees of relevant competence were asked about their perception of suitable preconditions for implementation of autonomous vehicles, given the current state of technological capability. In the 21 interviews, several recurring themes were discovered.

4.1.1 Vehicle requirements

Vehicle requirements	
Site characteristic	**Times mentioned**
Form factor	9
Cargo type	5
Payload	3

Table 4.1: Characteristics linked to vehicle requirements

In the first category of attributes, namely *vehicle requirements,* the form factor of the autonomous vehicle was brought forward as a key consideration when assessing a site and developing a truck platform (FTE3, LFL1, LFL2, LFL3, CC2, CC3, CC7, CC8, RC1, UR3), and the discussion stems from the trend in autonomous freight to focus on rigid body trucks. The reason for the importance of the form factor, that is the hardware design of the autonomous truck, depended on the perspective of the consulted interviewee.

Inside the case company, the Product Manager at Autonomous Freight (CC4), with a bridging role between market and technology development, explains the trade-off related to developing a form factor that works in all industrial settings, while reaching a sufficient robustness in the autonomous operations. On the commercial side, technological capability to handle containers and swap body containers is heavily requested, as the need to transport these load units is much more prevalent than the need for rigid body trucks (CC3 & CC8). The Vice President at Autonomous Freight (CC8), further emphasizes the importance of developing robust trailer-agnostic vehicles to unlock the majority of business opportunities in the industrial site segment and access sites of high transport density, and CC1 & CC4 described the technical difficulties connected to developing a trailer agnostic solution. CC2, Senior Product Manager Autonomous Vehicles, comments the form factor development by stating that *"the product must be developed to target the industrial site segment without invalidating it for other applications"*. Hence, CC2 concludes that a versatile form factor is required to reduce the friction with customer operations when implementing autonomous technology at new customer sites. The Technical Director of Autonomous Freight (CC7), explains the importance of the form factor when going into an industrial site by stating that "*my first question is; how are the goods of this site packaged?"*, to see if the site is out of scope or not. According to FTE3, CC1 and CC7, it is also important to be aware of the payload requirements on a site, to ensure that it is technically feasible to handle. FTE3 explains that this can vary greatly depending on the industry, and exemplifies with the timber industry, where goods are both heavy and bulky.

Transport professionals hold a general perception that targeting the large transport volumes of the transport system will require container handling, as the sites with the highest transport density are transporting standardized units that are incompatible with rigid trucks (UR3, FTE3). Also, transport industry actors clearly state that the bulk of their transport flows will be inaccessible with a rigid truck (LFL1, LFL2, LFL3). Another factor directly connected to the form factor, is the type of cargo on a site and the payload of the cargo (CC3, CC5, CC7). Different sorts of controlled outdoor environments are to a varying degree challenging for the autonomous technology in terms of cargo packing and cargo characteristics (LFL1, CC7, UR1, RC1, UR3). For instance, the goods of the port segment are to a large degree containerized (RC1, LFL2, LFL3) and in the chemical industry goods are too sensitive to be handled autonomously (CC7). Moreover, cargo types can determine how efficiently you can operate a vehicle on site, as certain sites have operational set-ups that require detachable load units, for them to act as "warehouses-on-wheels" (CC2, CC3).

4.1.2 Size of automation opportunity

Size of automation opportunity	
Site characteristic	**Times mentioned**
Size	6
Transport volume	6
Multiple facilities	2
Distance	6
VAS	2

Table 4.2: Characteristics linked to size of automation opportunity

As touched upon in the previous section, the *size of automation opportunity* on a site is critical when looking from the commercial perspective, the characteristics linked to this can be seen in table 4.2. Essentially, the size criteria is summarized by a transport economics expert (UR3), who claims that *"the amount of internal transportation is proportional to the size of the plant"*. Throughout the interviews, there has been a compelling consensus regarding the need for sufficient on-site transportation flows in order to reap the benefits of autonomous trucks (RI1, UR2, FTE3, CC2, CC7, CC8). According to UR2 and LFL1, having sites with multiple facilities will likely drive the need for more internal transport flows, increasing the possibility of finding suitable flows. Moreover, if there are value-added-services on the site, it may also lead to suitable flows (UR2). UR1 exemplifies value-added service with the case of consolidation, meaning to package different products on a site that are going to the same destination together. Sizeable opportunities for autonomous transportation on a site is an absolute necessity from a business case perspective. This stems from the need to spread the initial investment on as many vehicles as possible (CC3, CC8), moreover, the profitability is currently directly connected to the number of vehicles on an individual site (CC1). Larger site sizes means a higher amount of internal transportation volumes targetable by the capabilities of the current autonomous trucks, which would create an opportunity to operate a larger fleet while minimizing the number of sites where implementation investment, development of site specific solutions and customer conversion is necessary (CC4). The perception that site size and voluminous transport flows are necessary to motivate investments in expensive autonomous technology is not specific to the case company but also shared by logistics experts (UR1, UR2, UR3, RI1, FTE3). For instance, a logistics researcher (UR2) claims that *"the autonomous solution must drive down the operational costs to motivate large investments",* and an experienced investigator of freight transportation (FTE3) states that *"the internal goods volume must be sufficiently large to motivate the investment cost of the autonomous solution".* Moreover, the distance of the flow is also important according to (CC7, LFL3, UR3, RI1, FTE1, FTE3). The distance should be long according to researchers of human and machine interaction in order to lengthen the fully autonomous operation. However, according to UR3 the short-haul truck operations are the most costly, in terms of driver costs.

4.1.3 Traffic environment

Traffic environment	
Site characteristic	**Times mentioned**
Fenced-off	6
Mixed traffic	5
VRUs	6

Table 4.3: Characteristics linked to the traffic environment

Moving on to the section regarding *Traffic environment*, the case company is at the current level of autonomous capabilities strictly focusing on controlled traffic environments as the primary use case and business opportunity of autonomous vehicles (CC4). The research and case company perspective agrees on the need for a fenced-off or semi-fenced off environment in driving contemporary autonomous trucks (RI1, RI2, RI3, LFL2, LFL3, CC4, CC7). This logically connects to the consistently mentioned issues of combining autonomous trucks with mixed traffic (RI1, RI3, LFL1, LFL2, CC1, CC4, CC6. CC7) and operating them in environments with vulnerable road users (RI1, RI3, LFL1, LFL2, CC1, CC4, CC6. CC7). The fenced-off characteristic can facilitate the definition of the circumstances in the surrounding environment of the vehicle, which constitutes the documentation necessary to build evidence of vehicle safety in a specific ODD (CC7). Moreover, the speed in these mixed traffic environments could be a problem, if there is a high difference in speed between the autonomous truck and the surrounding traffic it could be a safety issue (CC6). Specialists on humans in the transport system (RI1), the current capacity of autonomous vehicles requires them to be further developed in enclosed environments, which are protected or semi-protected. According to the Director of Regulatory Affairs (CC6), the regulations take the perspective of the vulnerable road user, hence the permit process becomes facilitated in fenced-off environments to which no unauthorized personnel have access. Current autonomous vehicles can not dynamically act as a part of their traffic environment, as many traffic situations and traffic signals are outside their capability scope, which turn them into a safety risk (CC6, CC7). Both RI1 and RI3 highlights how a potential mix of vehicles, both autonomous and non-autonomous, jeopardizes the security of the traffic system, and RI3 states that *"it is in the fenced-off areas I believe business opportunities currently exist"*. The perception of the case company is also clear, for instance CC1 claims the presence of vulnerable road users in autonomous operations to be highly challenging from a technical perspective, and the Senior Technical Director concludes that *"public road operations come with a lot of risk"*.

4.1.4 Operational conditions

Operational conditions	
Site characteristic	**Times mentioned**
Predictable operations	5
Repetitive route	7
SLA/uptime	6

Table 4.4: Characteristics linked to the operational conditions

The next category of characteristics is concerned with the *Operational conditions* of different sites, meaning the operational set-up and the site performance requirements, as well as physical attributes. The Team Leader of Technical Operations (CC5) elaborated on a concept called *functional delta* related to this, which is essential when assessing new sites and refers to the difference between the actual capability of the autonomous truck and the capability required on a site. Within the scope of this delta, one important parameter was the predictability of operations, that is to what extent transports are planned in advance or scheduled (LFL1, LFL3, CC1, CC2, CC7, UR2), which is in turn connected to the need for repetitive and simple routes (UR1, LFL1, LFL2, LFL3, CC2, CC5, CC7). Moreover, to meet the requirements of the customer, it is essential that the uptime criteria is met and reflected in SLA agreements (RC1, CC1, CC5, CC7, CC8, LFL1, FTE3). Appropriate preconditions for creation of customer satisfaction should exist, since the customer expects to buy an autonomous solution that works (CC4, CC8). The Product Strategy Manager in Autonomous Freight (CC1) states that *"the uptime, predictability and precision of the autonomous vehicle is extremely important to ensure customer satisfaction"*. Currently, a site with low precision requirement and flexible delivery windows is better suited to internal autonomous transport since it allows for uptime problems and vehicle breakdowns without causing interruption to site processes (CC1). Moreover, according to the leader of the solution implementation team (CC5), *"the operational environment and the complexity of the route will determine the ratio of vehicles/driver"*, which is crucial to the business case and perceived value of the autonomous solution (CC4, CC8). The amount of trucks managed by the same operator, or, on the flipside, the percentage share of a route that a vehicle can drive independently, will determine the total operational cost on site (CC4). Hence, route complexity is proportional to site staffing costs, and CC5 describes the optimal operational conditions of a site as *"stable, predictable, open, large, and without traffic or pedestrians"* to minimize the functional delta. Additionally, a presumption related to autonomous technology is that they are more efficient than ordinary vehicles, since they operate without driver constraints (CC3).

4.1.5 Site actor attitudes

Site actor attitudes	
Site characteristic	**Times mentioned**
Collaboration between on-site actors	2

Table 4.5: Characteristics linked to site actor attitudes

An important site characteristic discovered was also the state of on-site collaboration between the actors in a multiple-actor site (UR3, RC1, LFL1). A part of this is the attitude towards autonomy of the site owner (RI3, CC3, CC6, CC8). The commercial part of the case company is that having engaged and active partners in autonomous transformation is extremely facilitative and beneficial (CC3, CC6, CC8). The Senior Vice President of Autonomous Freight (CC8) points out how *"finding more forward-looking customers is an extremely important parameter when deciding which sites to approach, in the same way as when replacing combustion engine trucks with electric trucks".* This alludes to the form factor discussion as well, since for instance the willingness to convert site transport into a new form factor requires a collaborative attitude and engagement for the autonomous solution (CC3, CC8). Two interviewed humanized autonomy researchers (RI1, RI3), emphasizes the importance of the site owner engaging in creating technology acceptance among the involved parties, using education and organized change management. Also external stakeholders, such as road-owners in favor of autonomous trucks are beneficial to implementation, as stated by the Director of Regulatory Affairs (CC6) , saying that *"it is extremely important with proactive partners, for example to have a mature road owner saying that a beneficial traffic environment can be created in collaboration".*

4.2 General characteristics

In the interviews, four types of general characteristics that are not specific to the sites, have been brought up, namely weather, regulatory, and economical conditions. These are outlined in the following paragraphs.

4.2.1 Weather conditions

Weather conditions are critical according to several actors in the case company (CC1,CC2, CC5, CC7, CC8) and an external expert (RI1). According to CC1, *"autonomous systems are sensitive and can be severely affected by water puddles, snow, fog, unpredictable environments with VRUs and obscured angles, these are difficulties that are shared over the entire industry"*, announcing those as being the major challenges of the industry. Rain is a factor that is hard to handle for the autonomous system according to the team leader of technical operations (CC5). Interviewee CC1 concurs, and states that *"operating in the dry climate of Madrid would be optimal"*, referring to the limitations of sensor technology. Moreover, snow and leaves are a problem for autonomous vehicles, creating the need for extra maintenance on the site with operations such as snow and leaves removal according to a research director and a PhD in logistics (RI1). This drives down vehicle uptime (CC8) and creates the need of having backup vehicles to meet SLA requirements (CC5). Hence, weather conditions are a core component in the ODD definition, since they determine and limit the capabilities and the performance of vehicles in the local environment (CC4, CC7). Sites with a high degree of precipitation can be strategically problematic, for instance CC1 claim that coast-near operations and ports will require a as well as a sensor set-up makeover. According to CC5, the site selection is key in order to ensure a favorable climate, a precondition for high-uptime operations.

4.2.2 Regulatory conditions

The weather conditions are directly connected to the regulatory aspects of autonomous vehicles, through the ODD. According to the Director of Regulatory Affairs at Einride (CC6) and a Senior Researcher of R&D Policy (RI2), the ODD definition is the basis of the current permit process, where regulatory exceptions are made for vehicles to drive autonomously under a set of specified conditions. EU law predisposes that the autonomous vehicle must be capable of handling all situations that it is faced with, hence the stability in fenced-off environments have risen as a potential facilitator in the search for a market where it is applicable in its current capacity (CC6, RI2). Meanwhile an autonomous vehicle can legally be granted technological exceptions and special permits from the law, general traffic regulations and VRU safety can in no way be compromised from the perspective of the law (CC6). According to RI2, some types of sites could consistently be more regulatory suitable for autonomous vehicles, due to their requirement of being strictly fenced-off for safety reasons, for instance manufacturing plants or ports with potentially dangerous machinery. However, CC6 claims that as technology develops, the need to search for environments with certain characteristics will be eradicated, as regulations would adapt when the safety requirement is fulfilled. RI2 concurs, claiming that the problem lies within the technology- and monetization rather than regulatory limitations. LFL3 is of the perception that regulatory change is slowing the development down, but does in a similar way point to the need of looking into fenced-off opportunities to start out with. CC6 points out that while it is easier, the amount of sites that actually fulfill the criteria for being completely fenced-off is extremely low. While the technological capabilities are lagging behind, CC6 emphasizes that it is *"extremely important to find proactive and collaborative regions and partners, who are willing to make traffic adaptations that facilitates autonomous vehicle implementation"*, and CC6 presses how future physical- and digital infrastructure must be adapted to support disruptive forms of traffic. To summarize, the joint perception of the legal experts in autonomous transportation is that semi fenced-off and fenced-off opportunities should be pursued in the first instance.

4.2.3 Economic conditions

Economic conditions have been mentioned several times by subjects in the study. As a freight transport expert (FTE1) and a researcher (RI1) puts it, the most important factor to have successful autonomous transport is to have a business opportunity that generates cash flow. Economic conditions can mainly be divided into profitability and operational efficiency.

The profitability considerations have been mentioned both by researchers (UR2, RI1, RI2, RI3), a freight transport expert (FTE1) and internally at the company (CC5, CC8). The most mentioned consideration is that there is a hope that autonomous trucks will give cost savings to the company that operates the trucks (UR2, RI1, RI2, RI3, FTE1, CC8). Higher profit margins will, according to both a university researcher (UR2) and two internal interviews (CC5, CC8) be achieved through an increased number of vehicles on the same site. Moreover, profitability will be impacted by the number of FTE:s that are needed in order for the autonomous driving system to work (CC8), where a lower amount of FTE:s per operating truck will mean higher profitability (CC8). However, this could take some time to occur as a researcher (RI3) suggests that initially the implementation of autonomous trucks will mean creation of new roles and removal of others, making it potentially a zero-sum game.

The operational efficiency considerations are mainly the improved efficiency that autonomous trucks are thought to achieve, this is a view that is supported both inside the case company (CC8) and by external parties in the form of a researcher (UR3), a research consultant (RC1), and freight transport experts (FTE1, FTE3). These efficiencies stem from not needing to adhere to planning restrictions due to driver rest times (FTE1, UR3), improved utilization rates of trucks (CC8) or the ability to drive on night time (RC1). Moreover, there are inefficiencies in short-haul transportation with low staff utilization that autonomous trucks can remove (UR3). Another operational efficiency consideration is the quality of transports, according to the case company (CC8) high quality of delivery, e.g. precision of deliveries, is what the customer demands. Moreover, another employee at the case company (CC1) describes that reliability of service is also very important to ensure high quality of service to the customer. This is also supported by a researcher (RI3) that describes that if the system works in the morning but not in the afternoon there is no need for the service.

Overall, business case viability is evidently one of the most critical aspects in order to succeed in the scaling and adoption of autonomous freight, as stated by RI2, RI3 and CC8. According to CC8, the developers of autonomous technology are in need of demonstrating a solution that breaks even in the daily operations, stating that "*..it must lift beyond being pilots and R&D"*. Moreover, an underpinning assumption of this thesis is that certain factors in the surroundings, or ODD, of an autonomous truck can improve its general level of function (CC4, CC7). In order to have a good business case and a good truck, the development efforts must be based on market needs (RI2, CC1, CC2) but a simpler environment could be a suitable starting point to support the development.

4.2.4 Autonomous loading and unloading

The final consideration regards autonomous loading and unloading of goods. According to a researcher (UR2) there is no gain from autonomous technology if there is a need for two persons who are loading and unloading the vehicle. However, the existing autonomous solutions are costly (UR2). Moreover, the autonomous loading and unloading is context dependent (UR2, UR3 RC1) meaning it is not generalizable for every type of good. It seems that unit goods such as container or trailer goods are more feasible to handle autonomously (UR2, UR3, LFL1). Moreover, there is also an uncertainty regarding who has the responsibility for loading and unloading on site, if the responsibility lies on the autonomous truck provider there is a need to solve this autonomously (CC2), or else it will hurt the provider's profitability. To conclude, according to two persons at the case company (CC2, CC8) and a university researcher (UR2) reaping the benefits of automation will ultimately require automated loading and unloading.

4.3 Site descriptions

The aim of this section is to summarize the data gathered on different types of industrial sites that can be considered when looking for controlled environments suitable for autonomous truck implementation. It describes the characteristics at different types of industrial sites in the context of the current state of technology in autonomous transport.

4.3.1 Dry ports

The findings on dry ports are mainly based on the inputs from UR1, an Associate Professor in Service Management and Logistics, also the specialist who invented the dry port concept.

Dry ports are located anywhere geographically, but as a rule they will have a strong rail-port connection. The flow between the port and the dry port is commonly operated by train, although truck transport also occurs. It is characterized by high frequency transport, which is predictable with a high volume density. However, dry ports are purposefully positioned to serve as an access point for a hinterland that is large in volume and in need of the goods delivered by the port that the dry port is in turn connected to. As a rule, dry ports are strictly fenced-off since they handle non-tolled goods and provide full customs services and in some cases simpler value-adding services. Apart from this, the amount and character of internal flows varies a lot in between the dry port sites, although most dry ports are focused on simple transshipment operations.

Some dry ports are located or directly incorporated in a larger logistics area, but not necessarily. UR1 claims that it is mostly in the flow between port-dry port, dry port-hinterland or dry port-logistics parks that exhibit the characteristics suitable for autonomous vehicles. However the majority of these will require open-road capabilities in the vehicles. Dry port operations would require a truck with a form factor capable of handling container transportation, but according to UR1 most dry ports will be too small to constitute a feasible opportunity for autonomous transport internally. The prospects to identify suitable internal flows to take over are small due to the focus on transshipment, and UR1 concludes by stating that *"only extremely large transport volumes could create a viable case for internal autonomous transport inside dry port, freight volumes must be nothing but gigantic"*.

4.3.2 Manufacturing plants

Manufacturing plants has become a focus segment due to them generally offering simplicity in ODDs and regulations, although they otherwise exhibit significant internal variation based on industry affiliation and geographical location (CC2, CC7). A general observation from the interview study, is that a larger size of plant indicates a higher amount of potentially targettable flows, higher good volumes overall and also larger roads inside the plant (UR3, CC8, FTE3).

The variation in activity between different production facilities makes it hard to create an overview of the different transport needs in the segment. There are some joint functions of flows that exist on a generalizable level in many manufacturing plants, according to the Service Management and Logistics professor UR2. There are the ingoing flows, that usually goes from an on-site distribution center or an assembly plant, to production. Then, there is a category of outgoing flows, where goods and products are moved in a more finalized form from the production unit to further distribution or assembly (UR2, LFL3). The third variant of flows are going between the facilities, for instance storages or different production steps, and it can be viewed as if the different activities performed in the facilities are generating internal transports (UR2, FTE3). According to CC7, UR2 and FTE3, manufacturing plants do in many cases have multiple facilities and activities on the same or adjacent sites. For instance, CC7 mentions that for the manufacturers in the automotive- or home appliances segment it *"makes sense to have all production steps on the same site, in close connection to a tightly clustered supply chain"*, increasing the amount of targettable routes within a similar operational environment. CC2 and UR2 believes that the internal transports between facilities are suitable for automation, however the outgoing transports may be even easier to operate since goods processing is finalized and the need for precision in delivery and uptime is decreased. UR2 states that ingoing transports may be the hardest to operate autonomously, since the process input relies on extremely tight schedules, and the same thing goes for the transport from the surrounding supplier network. Moreover, FTE3 turns the attention to how many industries perform a majority of the production activities indoors, inside factories or warehouses, which may remove the need for transport between the facilities of the plant. In general, manufacturing plants with internal transport that is predictable and flexible in terms of SLA requirements are ideal for the current capabilities of autonomous vehicles (LFL3, CC1, CC7).

Apart from the transportation set up of a manufacturing plant, CC7 emphasizes the importance of industry affiliation since it determines *"several factors; form factor requirement, payload capacity, speed, and special equipment usage".* The Senior Technical Director (CC7) continues by saying that *"the first question I ask when we assess a site is; what are the goods, and how are they packaged?"* and points to the immense need of careful consideration in site selection. An illustrative example of this is provided by FTE3, who claims that while heavy industry, such as mining or lumber, is well-suited in terms of freight volumes, transport precision and uptime requirement, constitutes an technically immense challenge in terms of payload and equipment specialization. On the other hand, sites that handle fast-moving consumer goods have simple and frequent routes, as well as easily manageable cargo, but much unpredictability within operations timing and freight volumes, in combination with tight SLAs (CC7).

CC2 also points out how it is common that manufacturing plants use containers as mobile warehouses, which releases the tractor to other activities in the meantime, and improves the efficiency of the transport vehicle. Hence, the fact that a rigid truck lacks this ability hurts this form factor's performance and operational flexibility that is required by certain environments. As far as the traffic conditions are concerned, this differs greatly considering that some plants will have public roads inside the site (FTE3, CC2), while others are strictly fenced-off for legal reasons, for example due to the presence of dangerous machinery (RI2).

4.3.3 Ports

Throughout both external- and internal case company interviews, a recurring view is that ports would constitute an attractive arena for implementation and development of autonomous trucks (RI2, RI3, UR1, UR2, UR3, FTE3, CC6, CC7, CC8), while the two interviewed Port Development Specialists (LFL2, LFL3) and a specialized Port Research Consultant (RC1) held a more conservative view on the current potential for value creation. However, there was a strong indication that finding suitable flows for automation in a port was preceded by a requirement of a sufficient port size (LFL3, RI3, FTE3, CC8), and FTE3 suggest that *"I go for the largest opportunities in terms of goods density, in Europe that would be Antwerp and Rotterdam, and in Sweden potentially Gothenburg or Trelleborg".*

In terms of flows, inside the port terminal appears to be a bad arena for the autonomous trucks, as it is dominated by highly specialized machinery, such as straddle carriers and port cranes (RC1, UR1, UR2, LFL3). RC1 provide an overview of the ingoing transport flows of container ports, describing that *"firstly the ship is unloaded, and then load units are transported by straddle carriers to the container stack somewhere in the terminal",* and then continues by saying that *"trucks then gains permit to go inside the port and subsequently the terminal, it fetches a load unit with the help of a straddle carrier and then goes off"*. The RoRo port flows are much less predictable according to LFL2 *"trucks arrive at the port, they show their papers and wait for the ship to allow them onboard"* or *"trucks arrive at the port, leave their trailer at a dedicated parking spot, and the port staff fetches the trailer with a tractor truck a place them on the RoRo-ship".* Outgoing flows are generally reversed in both the container- and the RoRo-cases (RC1, LFL2). Flows with potential for autonomous trucks are primarily located in between the parts, facilities or activities of the port (RC1, R13, LFL3, UR2). Consequently, examples of suitable internal flows goes from the container stack in the terminal to inside port-points, such as an intermodal terminal or inside-port staging areas (RC1, RI3, LFL3), also both RoRo- and container ports could potentially benefit from autonomous technology by preparing port entries through trailer staging. However, many of the interviewees have suggested that the potential of finding suitable flows that are external to the port area might be larger than inside (RC1, LFL2, LFL3, UR1, UR2) , since the internal port operations are handled by extremely specialized non-substitutable port equipment (RC1, UR3). These are short-haul routes directly connected to the activities in the hinterland of the port, and ranges to include frequent transports to nearby manufacturing plants (LFL2, LFL3, UR2) as well as jojo-flows to logistics areas or container yards or transshipment centers (LFL2, LFL3, UR1, UR2, UR3, RC1). However, these external opportunities for routes vary greatly between ports, as the connection between ports and the surrounding hinterland differs greatly, and with this the distance and destination of the outbound flows (LFL2).

The internal flows at the container port is strictly fenced-off to the unauthorized (RI2, RC1, CC6), while the RoRo-terminal are open to mixed traffic, as explained by LFL2 *"here drives both heavy industry traffic, but also families going on vacation to Finland"*. This, together with the variation in the parking situation and the cramped environment on the ship of the RoRo-port, causes LFL2 to believe that the transports unrelated to the ships are the feasible ones to target in the RoRo-port. As far as the container port is concerned, the difficulties are rather related to the extremely high demand for efficiency, uptime and reliability in the loading and unloading operations, since the ground close to the quay is expensive and ship docking time is strictly limited (RC1, UR3). In-port transport flows that are not designated to go on the ship, or originate from an existing container stack, may be a more feasible target since the transports there are less sensitive in terms of precision, uptime and durability of the vehicle (CC8, RC1). Moreover, a general characteristic for port transport is that while transports, especially by train, are predictable, the outgoing transport (from the port) is mostly unforeseeable and information sharing with the mixed shipper fleet limited (RC1, LFL3).

The cargo of the port segments require a form factor that handles all sizes of containers, as these are the standard units dominating the European port flows and for which most port-equipment is designed (LFL2, LFL3, RC1, CC1, CC7, CC8). Some ports are already partially automated with AGVs and semi-autonomy (LFL2, RC1), but currently the development has been done in the special port machinery (RC1) and also mostly focused on container transport, leaving RoRo lagging (LFL3). However, LFL3 working with Strategic Development and Innovation in a large port, claims that *"this port is conducting a lot of innovative activities, and believes strongly in trying out and adapting to autonomous technology"*. While the business case and transport density of ports appears promising to the autonomous trucks, CC1 shoots down the opportunity by stating that *"it rains a lot in ports"*, and redraws attention to all complications following a damp climate.

4.3.4 Intermodal terminals

A pervading theme when researching the potential of autonomous trucks at intermodal terminals, was the hesitance in interviewees to provide clear indications of their suitability due to the wide scope of the intermodal concept and the extremely high variation within their operations and size (UR3, FTE3, CC7). A generalized description of the intermodal operation is provided by FTE3, specialist in intermodal operation and working as Investigator of Freight Transportation, stating *"it is forklift trucks or reach stackers that lifts the cargo on- and off the mode of transport. A train arrives, and the cargo is lifted off to a wheeled chassis which goes off directly to the customer, without any intermediary storage"*. Hence, the intermodal operation mostly revolves around transloading operations, thereby *"flows between different parts of the terminal area are necessary in order to find feasible flows to automate"* (UR2). Consequently, both UR2 and UR3 claim that the most interesting flows in an intermodal terminal would be if there exist suitable surrounding facilities, for instance logistics-, storage or production areas, to which short-haul transport flows can be operated. However, FTE3 states that intermodal terminals differ a lot when it comes to their area of distribution, and that outgoing flow can be destined to places requiring long-haul transport. Also, UR3 states that there *"exists places with gigantic transport flows which connect many different transport modes, such as inland waterways, railways, and motorways"* that could possibly be of interest from a scale perspective.

Some final comments about the intermodal terminals is that they are dominated by container and trailer traffic, and require vehicles adapted to handle these types of load units (UR1, LFL3). Moreover, FTE3 claims that most smaller intermodal terminals are fenced-off, and LFL1 turns attention to the existing automation within transloading operations and further emphasizes the potential for this.

4.3.5 Transshipment center

According to UR2, transshipment centers will generally lack internal transports on the facility, since the parameter a great focus is on decreasing the handling costs and amount of internal lifts, and cargo units will be lifted from the incoming vehicle to the outgoing vehicle directly. UR1 concurs with the statement on low potential, and adds that transshipment points are generally not fenced-off. However, RC1 suggests that some transshipment centers have in- and outgoing jojo-transport flows that could be suitable if the capabilities of autonomous vehicles improved. Also, similarly to the intermodal terminal, the need for efficiency makes automation in the transloading operation interesting from an economic perspective (UR2).

4.3.6 Freight village/logistics cluster

UR3 describes the idea of a freight village by saying that *"in some cities the main logistics activities are planned in a unified way, and all logistics actors are gathered together in one area so we don't have to see them".* Generally, these large logistics clusters are located in the hinterland of industry cities, and can function as an orchestrator of the transportation flows into the city and its related industry actors (LFL1, UR3). Ultimately, logistics clusters or freight villages can constitute efficient interfaces between the transport network, industries and cities, and a consequential effect is that these facilities handle voluminous flows of cargo (LFL1), a prerequisite for a viable automation opportunity (CC8). LFL1 is the managing director of the roof organization responsible for German freight villages, and the interviewee points out several flows that may be suitable for automation. As a rule, freight villages lie in close connection to large motorways and intermodal terminals, hence the flow between the terminal and the site companies is a potentially interesting route, that is repetitive, fixed and with high transport volumes. Another opportunity would be the internal routes between actors on the site, as logistics clusters accommodate multiple facilities and different types of value-adding activities between which transport is carried out (LFL1, UR3). These internal routes are predictable and of high-frequency, although operation requires high precision and uptime, due to internally fine tuned scheduling in an environment with very low rates of disturbing or influencing factors (LFL1). The third sort of flow suggested by LFL1, is the outbound transports that are recurring and predictable, for instance German freight villages are often established in close collaboration with actors in the automotive industry, and regularly transport goods to their sites.

The traffic environment of freight villages vary geographically, as German sites are generally intersected by public roads with individual plots fenced-off, while for instance Spanish sites tend to be completely enclosed (LFL1). In spite of this, LFL1 argues that freight villages constitute a promising case for autonomous due to the internal transport frequency and the fact that the site handles a full consignment of goods. However, LFL1 states *"the transport connection that currently has potential for automated transport is a rather small share",* which aligns with the concerns of CC8 related to the form factor needs of logistics clusters. Moreover, both UR3 and LFL1 emphasize the benefits of the existing collaboration in transportation operations and administration, which creates favorable conditions to target joint transports between facilities, and enforce economies of scale in transportation coordination further. Finally, LFL1, claims that *"it is worthwhile to get started with autonomous transport on a small scale, to promote future development"*, showing a positive attitude towards efforts of implementation of innovative technologies.

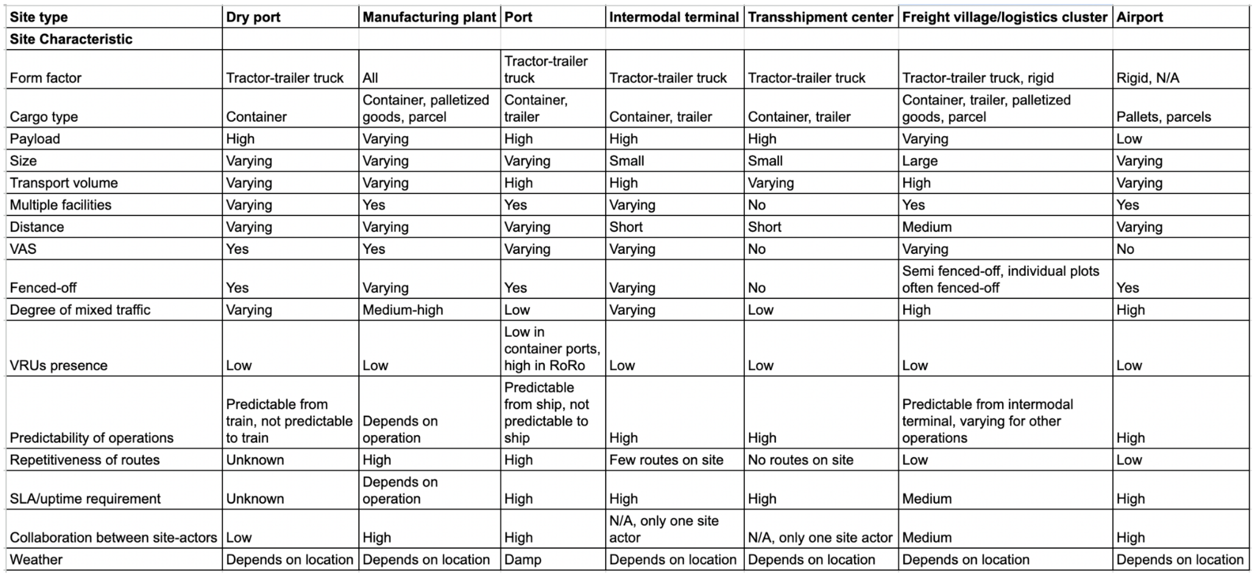
4.3.7 Airports

Airports may be an arena where implementation of autonomous vehicles is feasible, and according to CC7 *"airports may be a good match since the environment is strictly controlled, the backside is that the safety requirements are so high that it would demand even more extensive validation and supervision"*. The distinguishing characteristic of the airports that make them is that it is one of the few environments that fulfill all criteria for being fenced-off from a legal point of view (CC6, FTE3, RI2). Moreover, airports have their own centrally controlled traffic management system and specifically adapted traffic rules (CC6, FTE3), and no unauthorized VRUs or objects can enter the site unnoticed (FTE3, RI2). The cargo of the airports are mainly high value postal goods and to some extent palletized goods (FTE1, FTE3), which is suitable for rigid box trucks (CC7). FTE3 points out the importance of size, stating that automation would likely only be worthwhile in large, international airports, but continues by stating that airports are already to some degree automized, with bands and vehicles following RFID trails.

4.4 Summary of characteristics exhibited by site types

This section will first outline the different site characteristics that each site exhibits, then what the optimal state of the site characteristics is based on the interviews and the theoretical framework. Having defined what the optimal state of the site characteristics is in table 4.6 this will be extended and color coded depending on how close the site characteristic on a specific site is to the optimal state of the characteristic on a specific site, these will be coded in red if the site characteristic on a site is not fitting for autonomous trucks in controlled outdoor environments, yellow if the fit is medium, and green if the fit is good.

Having spoken about the different site characteristics and the different sites, a table is created, summarizing the results up to this point. The data is based on the interviews from industry experts (RC1, FTE1, FTE3, LFL1, LFL2, LFL3), persons from the case company (CC1, CC2, CC6, CC7, CC8) and researchers (UR1, UR2, UR3, RI2, RI3). Furthermore, there is a large degree of internal variation of many sites, hence the table should be looked at as a guidance of how characteristics in general are, but not as one true answer.



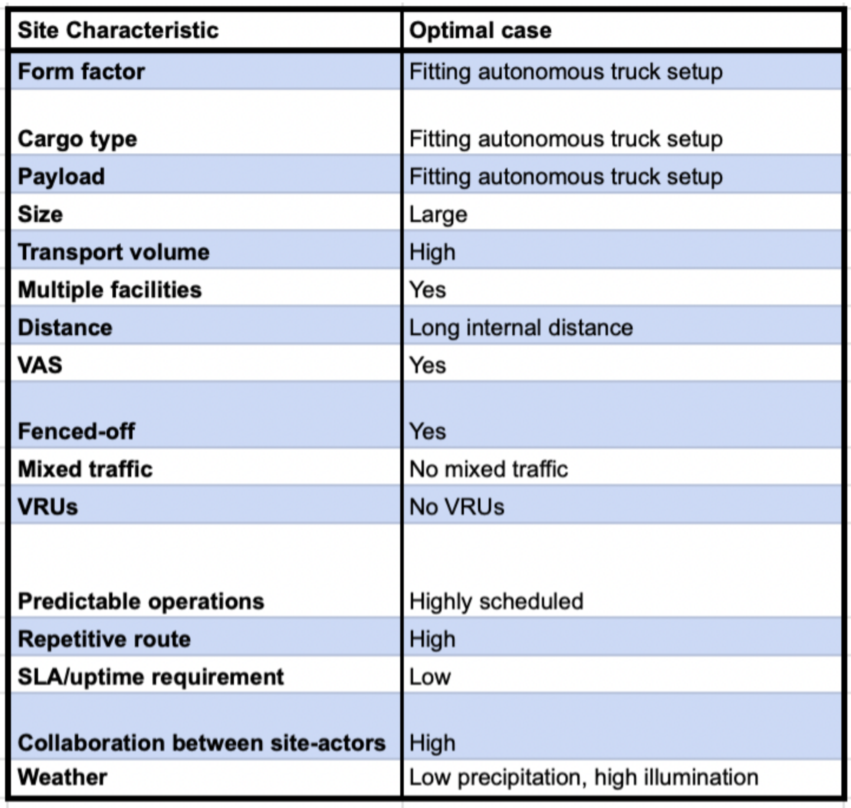
Site type	**Dry port**	**Manufacturing plant**	**Port**	**Intermodal terminal**	**Transshipment center**	**Freight village/logistics cluster**	**Airport**
Site Characteristic							
Form factor	Tractor-trailer truck	All	Tractor-trailer truck	Tractor-trailer truck	Tractor-trailer truck	Tractor-trailer truck, rigid	Rigid, N/A
Cargo type	Container	Container, palletized goods, parcel	Container, trailer	Container, trailer	Container, trailer	Container, trailer, palletized goods, parcel	Pallets, parcels
Payload	High	Varying	High	High	High	Varying	Low
Size	Varying	Varying	Varying	Small	Small	Large	Varying
Transport volume	Varying	Varying	High	High	Varying	High	Varying
Multiple facilities	Varying	Yes	Yes	Varying	No	Yes	Yes
Distance	Varying	Varying	Varying	Short	Short	Medium	Varying
VAS	Yes	Yes	Varying	Varying	No	Varying	No
Fenced-off	Yes	Varying	Yes	Varying	No	Semi fenced-off, individual plots often fenced-off	Yes
Degree of mixed traffic	Varying	Medium-high	Low	Varying	Low	High	High
VRUs presence	Low	Low	Low in container ports, high in RoRo	Low	Low	Low	Low
Predictability of operations	Predictable from train, not predictable to train	Depends on operation	Predictable from ship, not predictable to ship	High	High	Predictable from intermodal terminal, varying for other operations	High
Repetitiveness of routes	Unknown	High	High	Few routes on site	No routes on site	Low	Low
SLA/uptime requirement	Unknown	Depends on operation	High	High	High	Medium	High
Collaboration between site-actors	Low	High	High	N/A, only one site actor	N/A, only one site actor	Medium	High
Weather	Depends on location	Depends on location	Damp	Depends on location	Depends on location	Depends on location	Depends on location

Table 4.6: Descriptions of site characteristics of and site type

4.4.1 Definition of the optimal state of site characteristics

The optimal state of the site characteristics is outlined in this table 4.7. Here we will briefly describe the reason for why the optimal state is in fact optimal, this has been described earlier in the report, but this part will simply repeat them to help the reader understand the rest of the section. The site characteristics form factor, cargo type and payload do not have an optimal state in all cases, instead they should match the autonomous truck setup (CC7, CC2). This means that the optimal form factor for a specific autonomous tractor trailer truck provider is the one that the company possesses. Moreover, the optimal cargo type and payload is the one that the autonomous truck provider is able to handle. An example being if the autonomous truck is a tractor-truck being able to to handle only containers with a high payload, the optimal state for the form factor is “tractor-truck”, the optimal state for the cargo type is “container” and the optimal state for the payload is “any weight from low to high”.The size of the site should be as large as possible due to increasing the chance of finding a suitable flow and increasing the number of autonomous trucks that can be implemented in the same site, lowering the implementation costs (CC8, FTE3, RI1). A characteristic that is linked to the size of the site, the transport volume, should be high as this increases the profitability in operations(CC8). Moreover, in the optimal case, there should be multiple facilities as flows can be found between them (UR2). The distance should be long to make the actual driving the longest part of the operation (RI1). It can be noted that the interviews also said that the short-haul flows are the most uneconomical to have drivers in (UR3). However, in this report, internal flows are assumed to be short in the transport context as a whole, and therefore the long distance is regarded as optimal, given that it is internally on a site.

Moreover, in the optimal case, there should be VAS in order to increase the number of fitting flows (UR2), the value added services mean that some value is added to a product, which in the study is seen as increasing the likeliness of transport. The sites should in the optimal case be fenced-off, this helps as seen in the study the sites to receive regulatory approval (RI1, RI2, RI3, LFL2, LFL3, CC4, CC7). The sites should also in the optimal state not have any mixed traffic and not have VRUs to ensure safe operations (RI1, RI3, LFL1, LFL2, CC1, CC4, CC6. CC7). Moreover, the operations should preferably be predictable, that is following a schedule (LFL1, LFL3, CC1, CC2, CC7, UR2), which makes it easier to plan the autonomous truck operation, the operations should also be repetitive, lowering costs and making it easier to implement (UR1, LFL1, LFL2, LFL3, CC2, CC5, CC7).
The SLA/uptime requirement should be as low as possible, meaning there should not be a necessity to have the autonomous truck operating at full capacity, since the technology is not mature and susceptible to irregularities in uptime (RC1, CC1, CC5, CC7, CC8, LFL1, FTE3). There should also preferably be collaboration between the site actors, creating a more beneficial traffic environment (UR3, RC1, LFL1). Finally, the weather conditions should be favorable, meaning as dry as possible and preferably no snow (CC1,CC2, CC5, CC7, CC8, RI1). Note that these are the optimal states gathered from the interviews at the time of writing this report, there is a possibility that the optimal state changes with the development of technological capabilities, regulatory environment or other factors.

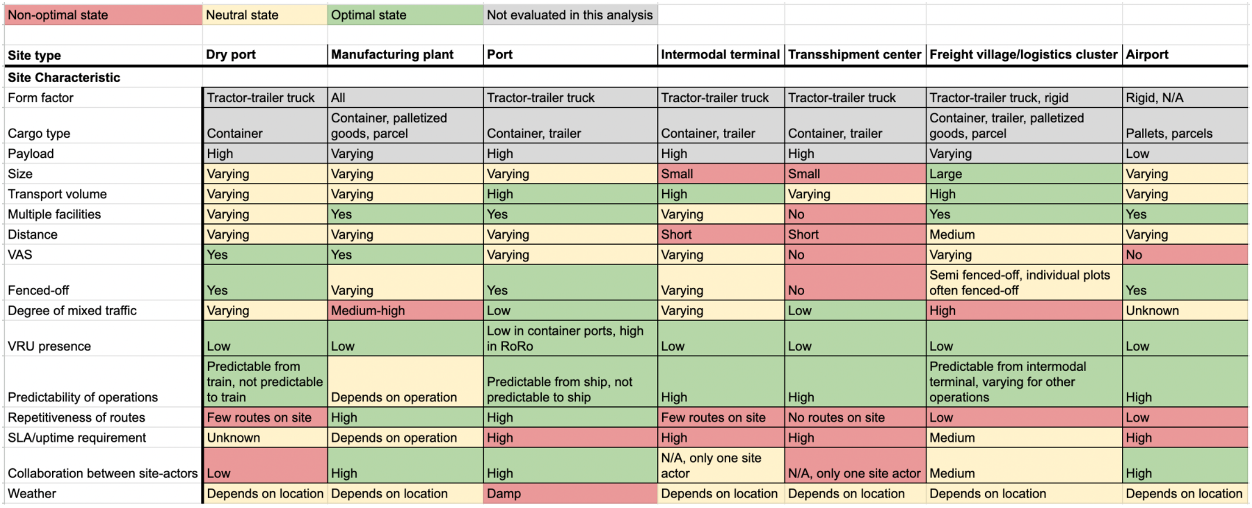


Site Characteristic	Optimal case
Form factor	Fitting autonomous truck setup
Cargo type	Fitting autonomous truck setup
Payload	Fitting autonomous truck setup
Size	Large
Transport volume	High
Multiple facilities	Yes
Distance	Long internal distance
VAS	Yes
Fenced-off	Yes
Mixed traffic	No mixed traffic
VRUs	No VRUs
Predictable operations	Highly scheduled
Repetitive route	High
SLA/uptime requirement	Low
Collaboration between site-actors	High
Weather	Low precipitation, high illumination

Table 4.7: Outlining the optimal state of site characteristics

4.4.2 State of site characteristics at site types

Having defined the optimal state of the characteristics, the next step is to define which site types exhibit characteristics that are closest to the optimal state of supporting the implementation of autonomous trucks therein. This is illustrated in the table below, which is an extension of the table shown in section 4.2.8. The table below shows which state the site characteristics on a specific site is in, which includes non-optimal, neutral, optimal or not evaluated in this specific analysis. Characteristics that are not evaluated in the analysis are not evaluated due to those characteristics being specific to the autonomous truck provider's operational setup.



Non-optimal state	Neutral state	Optimal state	Not evaluated in this analysis

Site type	**Dry port**	**Manufacturing plant**	**Port**	**Intermodal terminal**	**Transshipment center**	**Freight village/logistics cluster**	**Airport**
Site Characteristic							
Form factor	Tractor-trailer truck	All	Tractor-trailer truck	Tractor-trailer truck	Tractor-trailer truck	Tractor-trailer truck, rigid	Rigid, N/A
Cargo type	Container	Container, palletized goods, parcel	Container, trailer	Container, trailer	Container, trailer	Container, trailer, palletized goods, parcel	Pallets, parcels
Payload	High	Varying	High	High	High	Varying	Low
Size	Varying	Varying	Varying	Small	Small	Large	Varying
Transport volume	Varying	Varying	High	High	Varying	High	Varying
Multiple facilities	Varying	Yes	Yes	Varying	No	Yes	Yes
Distance	Varying	Varying	Varying	Short	Short	Medium	Varying
VAS	Yes	Yes	Varying	Varying	No	Varying	No
Fenced-off	Yes	Varying	Yes	Varying	No	Semi fenced-off, individual plots often fenced-off	Yes
Degree of mixed traffic	Varying	Medium-high	Low	Varying	Low	High	Unknown
VRU presence	Low	Low	Low in container ports, high in RoRo	Low	Low	Low	Low
Predictability of operations	Predictable from train, not predictable to train	Depends on operation	Predictable from ship, not predictable to ship	High	High	Predictable from intermodal terminal, varying for other operations	High
Repetitiveness of routes	Few routes on site	High	High	Few routes on site	No routes on site	Low	Low
SLA/uptime requirement	Unknown	Depends on operation	High	High	High	Medium	High
Collaboration between site-actors	Low	High	High	N/A, only one site actor	N/A, only one site actor	Medium	High
Weather	Depends on location	Depends on location	Damp	Depends on location	Depends on location	Depends on location	Depends on location

Table 4.8: Site characteristics and their observed state at each site type

5. Discussion

In this section an evaluation of the importance and impact of the identified site characteristics will be performed, through the lens of the key deployment factors presented by Engström et al. (2019). The site characteristics influence on the deployability of controlled outdoor environments is discussed for the factors *use case, profitability, safety assurance* and *regulations.* Subsequently, the analysis extracts the six most important characteristics and explains the connections that constitute their overall impact on deployment factors, in an effort to facilitate and focus the search for suitable sites. The chapter is concluded by discussing the types of outdoor environments that exhibit high potential for autonomous truck implementation, and exploring their suitability from the different perspectives of the deployment factors.

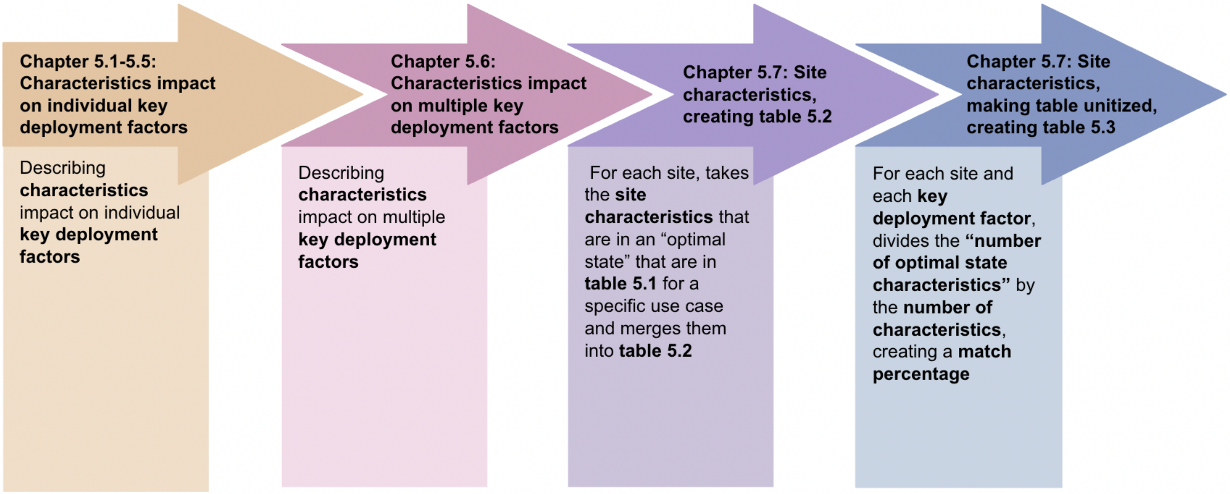


Figure 5.1: Outline of the analysis in the discussion section

In this first part of the discussion a subset of the key deployment factors presented under *2.3. Deployment factors* will be investigated, including use case, profitability, safety assurance and regulatory preconditions. The section is concluded with a discussion of which characteristics that have the greatest accumulated importance on the key deployment factors.

5.1 Impact of site characteristics on the use case

As mentioned in the interviews, the starting point for companies developing this technology is to find transport operations that match what the autonomous trucks are capable of doing. This section discusses which site–connected characteristics that impact its potential use-case on three levels, namely; what happens inside the transport flow, what happens in the surrounding of the flow, as well as the impact of the site actor operating the flow.

5.1.1 Characteristics in the flow impacting the use case

According to the interviews, current capabilities of the technology require low-complexity cases (Engström et al., 2019). Moreover, the authors describe the need for autonomous technology to be implemented in predictable, e.g. scheduled, operations. This lowers the complexity, since the autonomous system performs operations on predetermined time slots, which decreases the uncertainty for the truck. Moreover, the repetitive routes are seen as lowering the complexity of operations. The autonomous technology is generally implemented on a specific pre-recorded route, hence it becomes costly and inefficient to switch the routes, thus re-recording every new route.

Another factor impacting complexity of a flow is the other objects intersecting the roads that are operated by the autonomous truck. In this case, there are two different characteristics to be considered, that is interaction with VRUs and the notion of mixed traffic. Regarding VRUs, both Milford et al. (2019) and several interviewees mention that the interaction between the autonomous vehicles and the VRUs are a challenge in the development of autonomous vehicles. A potential solution for this is the isolation of autonomous trucks could be realized, and both Canis (2019) and the interviewees in this study agree that there is possibility for adaptation of the traffic or the infrastructure to better support the implementation of autonomous vehicles. Low-complexity cases also require the autonomous trucks to drive at a particular speed, to match the pace of the surrounding traffic in order to not be a nuisance or safety risk to regular drivers (van Meldert & De Boeck, 2016). Hence, interviewees agree that use cases on sites where the traffic speed exceeds the capacity of autonomous vehicles must be disregarded. .

Evidently, the list of criteria defining a suitable low-complexity flow may narrow down the number of opportunities of finding suitable internal flows on sites. However, when looking for suitable flows, two leading attributes for screening are the size and type of the site. The reason for the size of the site being important is that the larger the site, the more likely it is to have different flows, which enhances the potential for finding a low-complexity flow.

The type of site is also highly relevant in trying to find sites that have internal low-complexity flows. According to the interviews, manufacturing plants, ports and freight villages tend to exhibit suitable flows due to the nature of the site-activities. In both manufacturing plants and ports, the on-site flows are non-public, therefore without the presence of unauthorized VRUs, and freight villages usually do not contain any non-site related traffic. In the interviews, one example of a low-complexity flow was found in a manufacturing plant, when the goods are transported between production to distribution center or assembly point. The production part of the manufacturing plant finalizes the goods, which are then transported and stored at a distribution center, or further processed at an assembly plant, which both results in predictable and repetitive flows. A production plant generally produces goods according to a certain schedule, and the type of cargo and route through the plant is relatively fixed, hence repetitive. The case improves if the timing of when the goods arrive at the distribution center or the assembly point is not critical, as the extended flexibility of the delivery makes it a good fit for the occasionally unreliable uptime of autonomous trucks.

5.1.2 Characteristics around the flow impacting the use case

Moving on, this next section will discuss what happens in the surrounding environment of a transport flow. This is critical, since no transport flow exists in isolation, rather being extensively context-dependent. Hence, the characteristic named “fenced-off” is an important factor when assessing sites, since the fence offers control over which vehicles and VRUs can access the zone of the autonomous trucks. As previously mentioned, this decreases the surrounding uncertainty and the amount of unpredictable edge-cases for the truck to handle. According to the interviewees, a mix of autonomous and non-autonomous vehicles is currently difficult to handle, especially since such vehicle-to-vehicle interaction remains to be developed.. Hence, in an enclosed environment, the risk of unauthorized traffic intersecting the route of the autonomous vehicles decreases, instead the safety of the use case will increase.

Moreover, it can be concluded from the interviews that finding use cases on enclosed sites relies upon whether the site contains multiple facilities or activities, between which some sort of transport is conducted. For instance, manufacturing plants are organizations which have spread out the different production steps in dedicated facilities (Vokurka & Davis, 2004), between which transports are conducted, and there also often transport to on-plant distribution centers where significant product volumes go regularly.

5.1.3 Characteristics of the site actors ordering the truck operation impacting the use case

Finally, the site actor influences the suitability of a use case through their requirements on the transport operations. In the interviews, the service level agreement (SLA) or uptime requirement was pointed out as an important factor. If the site actor has high requirements on the performance of the autonomous truck, in terms of reliability of service and precision of delivery, there is a risk for a low satisfaction if the expectations are not met.

Moreover, most site actors will have a specific way of operating that may, or may not, be compatible with the capabilities of the autonomous truck. An example from the interviews is that some site actors have operations that require a detachable trailer acting as a warehouse-on-wheels. This trailer is deployed on the site and when the trailer is filled, it is picked up by a truck and replaced with an empty container. If this specific trucking operation is to be converted to an autonomous truck operation it requires the autonomous truck trailer to be detachable and reattachable. Moreover, this loading- and unloading of the trailer needs to be done in an autonomous fashion. This is to further stress the point that Engström et al. (2019) stress, that autonomous trucks need to be adopted to the specific truck operation as of now. If that does not happen, the customers need to be as the interviews say, forward-looking and willing to change their specific operations to be able to implement autonomous trucks in their operations.

5.2 Impact of site characteristics on the profitability

This section will discuss the impact of site characteristics on the profitability of autonomous trucks. If an optimally performing autonomous truck would be introduced, substantial impact on the shrinking margins of carrier companies could be brought about, and together with that a disruption of the entire industry (Engström et al., 2019; Sing Muddhar et al., 2016). Yet, interviewees with research- and commercial perspective on autonomous truck development claim that a major reason for the lack of large-scale adoption of is the failure to find an application creating sufficient value (Fagnant & Kockelman, 2015). According to the case study, use case and profitability can not exist without each other, and adoption rates are hampered since the technology is excessively expensive and payback time extensive.

Researchers and industry experts have a relatively detailed understanding of what impacts autonomous trucks can have on profitability. Firstly, autonomous trucks would entail cost reductions for the carrier industry, mainly by removing driver wages from the operating costs. According to the interviews, the realization of this economic benefit is currently depending upon the number of employees required to sustain the autonomous operation. Lowering this amount is a main step towards the goal of starting to break even on the daily operation, and begin to cut down on staff needs. However, the technical challenges related to e.g. weather conditions and sensor technologies are still significantly limiting the autonomous vehicle uptime and performance (Milford et al., 2019). Hence there is a risk that new solutions incur the same, or even a larger amount, of work roles in supporting the operation of the truck. Moreover, the investment is of a magnitude that requires a fast payback time, especially considering the pressured economic state of the modern trucking industry (Engström et al., 2019). Secondly, out of these cost reductions that are realized through autonomous trucking, an important subset of factors can be gathered under the concept of operational efficiency. Moreover, as the technology becomes more intelligent, it may optimize fuel consumption and routing decisions and also improve delivery quality in terms of precision and dependability. However, in line with van Meldert and de Boeck's (2016) claim that the technology is currently only functional under extremely specific conditions, case-specific operational set-ups will determine the advantage derived from autonomous vehicles.

Hence, autonomous technology must offer cost reductions and operational efficiency benefits that are large enough to motivate the initial investment in autonomous technologies. For the business case, it is important to have many suitable flows of high transport volumes on the same site.This can motivate the operation of more vehicles on one site, which improves the feasibility of reaching a break-even point on the autonomous trucks in daily site operations, according to the interviews. Moreover, vehicle capabilities are yet constrained to being extremely ODD-specific when developed (SAE, 2017; Engström et al., 2019; van Meldert & de Boeck, 2016), hence larger transport volumes also gives the opportunity to spread the investment from implementation and development on more trucks. Finally, cost of investment for each site can also decrease when the enclosed environment is easier to operate, due to less operators on site required.

The volume of transport flows on a controlled site will depend on the site specific parameters, such as plant layout, production volumes, market connections as well as characteristics of the industry and the product in question (Vokurka & Davis, 2004). Thus, it is difficult to draw any general conclusions of transport flows and volumes on a site based on facility type, due to the observation of large internal variation. In light of this, site size is the characteristic that gives a strong indication that the site should be further investigated, and provide a sizable opportunity for automation.

According to the interviews, having a suitable form factor will grant access to the most promising transport flows, since all cargo types can be handled. An example of this is the environment of large ports, where the internal transport density is extremely high, but capability to handle containers and high-payloads is an absolute necessity. The inconsistency in form factor requirement between sites places demand for a trailer-agnostic vehicle that can be adapted to the specific goods transported at a site. However, the industry has mainly been focused on developing rigid trucks, and a switch in form factor creates new technological challenges for development that further extend the time horizon until the product is perceived as commercially viable. Hence, form factor needs may prolong the time until the technology delivers sufficient performance, and can give the operational efficiency and cost reduction benefits as described in the literature (Sing Muddhar et al., 2016; Fagnant & Kockelman, 2015).

Another technological constraint to a viable business case is the unresolved problem of autonomous loading and unloading, required to fully decouple the trucks from human operators. Still needing operators to manage these activities would mean a much diminished cost-reduction from driverless transportation on sites where trucks only perform short-haul operations. This means that if the time for loading and unloading is managed manually and also exceeds time spent in self-driving mode, cost reductions may be negligible. As of today, autonomous loading and unloading technologies are similar to the technology of autonomous vehicles, since it is both extremely expensive and it lacks generalizability.

Large investments are made in site-specific solutions, but to access the right transport volumes, the development of form factor, loading and unloading-solutions as well as general capabilities such as vehicle uptime must be prioritized in a strategic way. To access economies of scale in technology development, identifying which capabilities that are more frequently required in controlled environments or categories of these, could enable economic prioritization of development efforts. Potentially, increasing the generalizability of the autonomous truck, could impact the profitability positively, by spreading the investment over not only more vehicles, but also over a greater number of sites.

5.3 Impact of site characteristics on the safety assurance

Aiming towards large-scale deployment of autonomous vehicles, one of the pervading themes throughout the interviews was the challenge of assuring that the autonomous system is safe for the surrounding environment. In the literature, future hopes are high, and Sing Muddhar et al. (2016) state that removal of human errors, such as inattention, speeding and risk-taking, could improve traffic safety and decrease crashes and fatality, with which Slowik & Sharpe (2018) concur. However, the two authors also argue that as the automation level increases, the robustness and security of the software becomes increasingly important, to handle the risk for hacking and human-vehicle handover problems in the transition to full-automation. Today, the key issue is to ensure that the autonomous system handles all potential edge-cases it encounters in an adequate way.

Firstly, the complexity within the assurance dimension will be discussed. According to Engström et al. (2019), having an autonomous vehicle that responds correctly to all possible traffic situations and weather conditions is not sufficient, as long as convincing evidence on the vehicle's capabilities fails to be presented. Today, the autonomous system is designed and approved for strictly specified conditions, and validation and proof of concept are performed under those as well (Engström et al., 2019). Due to the comprehensive safety case that needs to be built prior to operating a vehicle in a specific ODD, it is essential with collaboration among industry actors to deliver the rigorous safety evidence required to get autonomous trucks on the road. The safety specialist at the case company elaborates on the challenges and expenses related to vehicle testing and simulations, a complexity with which Engström et al. (2019) concur. Moreover, interviewees highlight the importance of educating the employees on the controlled sites on how to interact with the autonomous vehicles to ensure security in their work environment.

When working with site specific safety assurance, the most impactful characteristics that facilitate the ODD validation are identified under *4.1.3 Traffic environment*. Logically, the primarily discussed attribute in this segment is if a site is fenced-off from its surroundings. As described, this makes site conditions easier to define, and enables control over what people and vehicles that can enter and operate on the site, which in turn drastically diminishes the amount of edge-cases to be addressed to a technologically manageable level. Sensor technology, the precondition for accurate perception and decision-making of an autonomous vehicle, is together with human-machine and machine-machine interaction appointed the most significant technological challenges to achieve full autonomy (Milford et al., 2019), and would require extensive development to go into environments with a more complex traffic environment.

While operating in enclosed environments appears to be the obvious choice, interviewed researchers emphasize that whether a facility is fenced-off can not be generalized for an entire facility type, and also that the definition for a strictly fenced-off site is extremely narrow. Some conclusions on types can be inferred, for instance sites with customs activities such as ports and dry ports need to be closed, the same goes for sites where high security is required, as for instance airports of manufacturing plants handling dangerous goods or machinery. Less clear cut is to what degree freight villages, intermodal terminals, logistics clusters and transshipment centers are actually fenced-off.

This connects back to the fact that sites must be evaluated on a case-by-case basis when assuring safety. Although a site is to some extent fenced-off from the public environment, implementation of the autonomous truck and trying to make it coexist with manually handled operations can cause safety issue., It is difficult to make the autonomous truck blend into the general traffic in a natural and dynamic way (Sing Muddhar, 2016), and interviewees highlight the insecurities that may occur when autonomous vehicles brake abruptly or fail to integrate to the natural traffic rhythm on the site. Moreover, the interviewees describe the safety risks related to the lack of robustness in the software of the autonomous vehicle which makes it erratic, and the truck can hence risk to transfer its sensitivity to its environment in the form of uncertainty.

Apart from the traffic environment, safety assurance must take into consideration the weather conditions of a site (Wang et al., 2020). As of today, sensor technology is extremely sensitive even to small amounts of precipitation, and it is also reliant upon appropriate light conditions and humidity. Small seasonal changes such as the falling of autumn leaves can disable the system, according to the interviews. This impacts what type of site that is possible to operate as well, for example coast-near sites such as ports can pose a greater challenge in the safety assurance process due to the damp conditions. The weather issue is a large obstacle in the strive towards on-the-road operations, especially as weather conditions are inherently unpredictable.

5.4 Impact of site characteristics on the regulatory preconditions

The main point of this section is that regulations are directly dependent upon safety concerns. Both the interviews and Collingwood (2017) conclude that regulations may hamper and slow down the development of the technology, due to this safety focus. It is also central to the regulatory precondition for autonomous trucks that the permission to operate on site and their specific ODD is granted on a case-to-case basis (Carp, 2018). This means that the autonomous truck provider needs to prove that the autonomous truck is safe within its permit constraints, in order words construct a safety case. Most of the characteristics of sites that contribute to facilitating the regulatory process, also helps to ensure that the autonomous trucks are not harmful to surrounding VRUs.

First off, the characteristic “fenced-off” benefits the regulatory safety case due to the ability to know the delimitations of the ODD. These delimitations help to understand which vehicles are allowed to be in the area and which VRUs the autonomous truck could potentially encounter. Moreover, speed limits could be set inside the fenced-off area in a way that suits the capability of the autonomous truck. Additionally, the weather conditions are a factor from the regulatory perspective and in the ODD. The interview study has shown that permits are given for a specific set of weather conditions, e.g. no snow, and they are based on an assessment of what the autonomous system can handle.

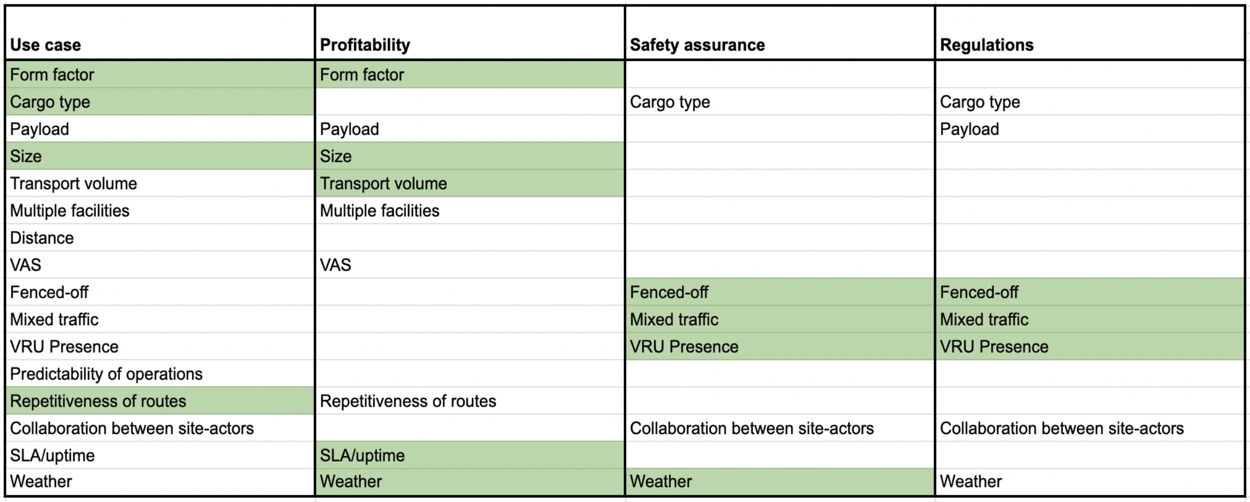
Another important factor in the regulatory preconditions is the type of cargo. The interview study has shed some light on this factor, e.g. vulnerable or dangerous goods are too riskful to be handled autonomously in case of an accident. Since the safety case can not be strengthened for these types of goods, there are no regulatory grounds for its approval.

Another characteristic impacting the regulatory preconditions, are the attitude of surrounding site actors and institutions, specifically the government and the local police authority. The attitude of the government determines the formulation of new regulatory frameworks and if these promote easy implementation of autonomous trucks, it will facilitate future permission processes. Additionally, the attitude of the local police authority matters since they ultimately are the ones that decide if an area can be regarded as fenced-off or not, hence experience the regulatory advantages connected to that. Moreover, if site actors have a positive attitude towards autonomous technology, there is a possibility for adaptation of the site. This could enable collaboration in creating more favorable conditions for autonomous truck safety, and consequently more favorable regulatory preconditions. For instance, it could be restricting which vulnerable road users are allowed to be in contact with the autonomous vehicle, or making separate lanes or areas for the autonomous vehicle, removing it from mixed traffic. This creates an easier and safer environment for the vehicle to operate, paving the way for an facilitated permit process.

Manufacturing plants is an example of a site that exhibits characteristics facilitating the permit process, as this type of site could potentially have local fenced-off parts for machinery or to be fenced-off in its totality. Moreover, collaboration between the site actors exists to a high degree, due to how workers of the manufacturing plants collaborate in producing goods (Sule, 2008). Another example is the port, which is an excellent fit in terms of regulations due to a few characteristics, namely fenced-off, lack of mixed traffic and VRUs as well as collaboration between on-site actors. According to the interviews, ports are in general key security points for nations, this is why they have strict security requirements and are therefore fenced-off. The security requirements are also why there are a low amount of VRUs and why the traffic is strictly controlled on the port premise.

5.6 Impact of site characteristics on all key deployment factors

In the previous sections, the characteristics of importance to the selection of controlled outdoor environments has been discussed from a deployment perspective (Engström et al., 2019). The authors claim that if these factors individually are in favorable states and if these coincide at one site, preconditions for successful deployment of autonomous trucks exist. Hence, none of the four deployment factors can be considered in isolation, due to their high degree of interdependence. The following analysis has been conducted in order to extract which of the characteristics that exhibit connections with multiple of the deployment factors, to guide the identification of suitable sites. Table 5.1 provides a summarized picture on which characteristics impact which deployment factor, and also how many characteristics that are relevant for each. Characteristics deemed particularly important by the interviewees are highlighted in green.



Use case	Profitability	Safety assurance	Regulations
Form factor	Form factor		
Cargo type		Cargo type	Cargo type
Payload	Payload		Payload
Size	Size		
Transport volume	Transport volume		
Multiple facilities	Multiple facilities		
Distance			
VAS	VAS		
Fenced-off		Fenced-off	Fenced-off
Mixed traffic		Mixed traffic	Mixed traffic
VRU Presence		VRU Presence	VRU Presence
Predictability of operations			
Repetitiveness of routes	Repetitiveness of routes		
Collaboration between site-actors		Collaboration between site-actors	Collaboration between site-actors
SLA/uptime	SLA/uptime		
Weather	Weather	Weather	Weather

Table 5.1: Key deployment factors and the characteristics deemed as relevant

As illustrated in Table 5.1, some characteristics are of greater overall impact, as they are directly connected to multiple deployment factors. Additionally, some characteristics are so important for one deployment dimension that the entire opportunity relies on finding a site where the characteristic matches the need of current vehicle capability. For the autonomous truck developers, this creates a situation where autonomous truck developers have an extensive list of criteria when searching for suitable transport flows to operate. Hence, flows will either have to be adapted to suit the capabilities of the vehicle, or the vehicle capabilities improved, preferably in a strategic way.

Two tightly connected criterias are cargo type and form factor, as explained in *5.1.2 Characteristics of sites that support profitability*. The cargo type on the site determines its form factor need, and a cargo-agnostic truck that is compatible with all common types of load units remains to be developed. Firstly, the development of new vehicle platforms is both time consuming and costly (Fagnant & Kockelman, 2015). Moreover, vulnerable or dangerous cargo will make the obtaining of permission impossible, due to the lack of operator supervision which disqualifies them from a regulatory perspective in the foreseeable future. According to the interviews, form factor need and cargo type are generally fixed parameters, since they stem from the core activities of a site. Due to this, the potential use case relies on the form factor, and in order to achieve profitability in operations developers must ensure that their vehicle fulfills the requirements on form and cargo in a sufficient amount of environments. Otherwise, the expensive autonomous product may end-up without either use case, profit or market. Evidently, the combined impact of cargo type and form factor, plays an important role in determining the size of the targettable market and in what types of use cases the technology can be applied (Engström et al., 2019).

Moreover, the two attributes size and transport volume are found to both be of extremely high significance in finding suitable and profitable use cases. A larger site area increases the need for internal transportation, hence the likelihood of finding a flow with manageable requirements and surrounding conditions increases too. If the transport density of a site is too low, the potential cost reductions and operational efficiency wins will be too small to motivate the initial investment (Engström et al., 2019). Site size can under certain circumstances be disregarded, for instance if the site has a high volume flow suitable for autonomous trucks, while sufficient transport volumes are an absolute deployment criteria from both a use case and profitability point of view. Mostly, site size and transport volumes can be considered fixed parameters of a site, from which vehicle requirements stem. The relationship between profitability and use case are summarized through the concept of finding *"targettable transport volumes"*. The word *targettable* is a way of designating all characteristics that make a transport flow on a site possible to operate with an autonomous truck in its current capacity. For *transport volume,* this is what must be high to make the investment worthwhile, as well as the spread of investment on a sufficient number of trucks. Moreover, profitability is driven by uptime, which predisposes how well-operational efficiency promises can be realized (Sing Muddhar et al., 2016). Currently, it is clear that profitability is limited by the absence of good use cases matching the criterias underlying the word *"targettable"*, inhibiting value from autonomous vehicles from being created.

A pervading theme in both interviews and literature, is the identification of sites that are fenced-off. Currently, this can contribute to the remedy of technological challenges within vehicle perception and traffic interaction immensely, until the trucks perception system is robust enough to interact safely with a public traffic environment (van Meldert & de Boeck, 2016; Fagnant & Kockelman, 2015). In contrast to the form factor and cargo type characteristics, surrounding adaptation is possible to make sites available for current autonomous trucks by fencing them in and restraining access, however long-term development will focus on moving the truck outside the closures (Canis, 2019). As permission for operation of autonomous vehicles is granted upon rigorous safety validation, all means of improving safety will automatically improve the regulatory preconditions of a site as well.

Weather conditions are still severely impacting the capabilities on all deployment dimensions, as it can quickly disrupt the sensor technology (Mildford et al., 2019). This in turn reduces the vehicle uptime, as operation would be impossible from both a safety and regulations perspective. If the truck stands still on the site, nor profitability neither usefulness of the deployment exists. Currently, the weather issues are so critical that one of the primary selection criterias must be in which geographical region deployment is planned, being the only way to facilitate the operation of the current autonomous truck.

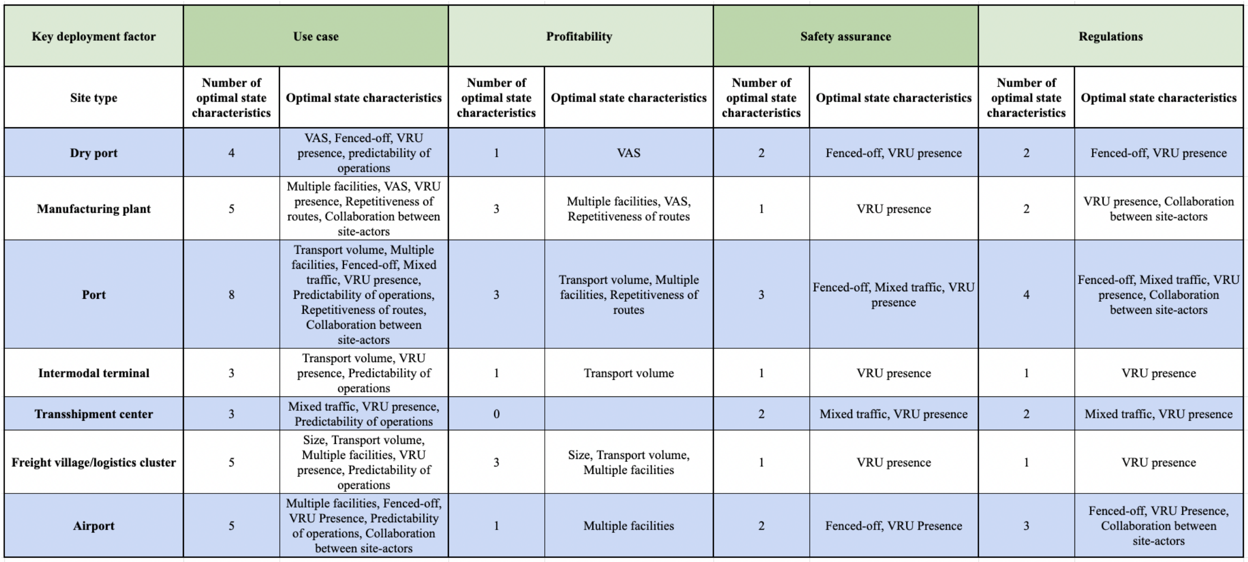
Through development of vehicles that are cargo-agnostic and an improved perception system, the autonomous truck has potential to reduce the list of criteria necessary when selecting a site. Also, a similar increase of use cases would create a necessary push for regulatory revision and adaptation (Carp, 2018). As stated by one of the interviewees, with regard to the current vehicle capabilities, looking for suitable deployment capabilities is essentially *"looking for a needle in a haystack".* This places demand for strategic technology development and adaptation, that creates opportunities to operate in as many environments as possible.

5.7 Suitability of controlled outdoor environments in autonomous truck operations

In this section the suitability of specific sites to the autonomous truck technology will be examined. This is done by measuring the match between the optimal state characteristics on specific sites, with the characteristics connected to the key deployment factors.

Having Table 4.8 from *4.2.8 Summary of site characteristics on site types* as a basis, the next step in understanding the suitability of sites for the implementation of autonomous trucks is to understand which site exhibits characteristics that are sufficiently close to the optimal state for implementation of autonomous trucks. Moreover, the key deployment-factor perspective is added, and connected to the site specific characteristics exhibited.

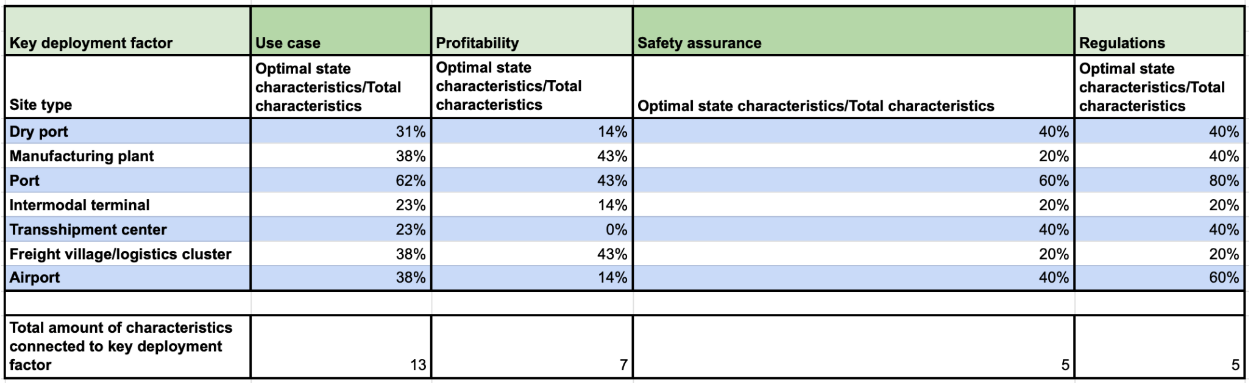
Next, a brief description of the construction of Table 5.2 and Table 5.3 is provided. First, the characteristics that are marked as green in Table 4.8, hence defined as being in optimal state, are compared to the factors in Table 5.1, outlining the relevance of individual characteristics. If a characteristic is indicated as green in Table 4.8 and deemed relevant from a particular key deployment perspective in Table 5.1, it is counted, otherwise disregarded. From this analysis, Table 5.2 has been derived:



Key deployment factor	Use case		Profitability		Safety assurance		Regulations	
Site type	**Number of optimal state characteristics**	**Optimal state characteristics**	**Number of optimal state characteristics**	**Optimal state characteristics**	**Number of optimal state characteristics**	**Optimal state characteristics**	**Number of optimal state characteristics**	**Optimal state characteristics**
Dry port	4	VAS, Fenced-off, VRU presence, predictability of operations	1	VAS	2	Fenced-off, VRU presence	2	Fenced-off, VRU presence
Manufacturing plant	5	Multiple facilities, VAS, VRU presence, Repetitiveness of routes, Collaboration between site-actors	3	Multiple facilities, VAS, Repetitiveness of routes	1	VRU presence	2	VRU presence, Collaboration between site-actors
Port	8	Transport volume, Multiple facilities, Fenced-off, Mixed traffic, VRU presence, Predictability of operations, Repetitiveness of routes, Collaboration between site-actors	3	Transport volume, Multiple facilities, Repetitiveness of routes	3	Fenced-off, Mixed traffic, VRU presence	4	Fenced-off, Mixed traffic, VRU presence, Collaboration between site-actors
Intermodal terminal	3	Transport volume, VRU presence, Predictability of operations	1	Transport volume	1	VRU presence	1	VRU presence
Transshipment center	3	Mixed traffic, VRU presence, Predictability of operations	0		2	Mixed traffic, VRU presence	2	Mixed traffic, VRU presence
Freight village/logistics cluster	5	Size, Transport volume, Multiple facilities, VRU presence, Predictability of operations	3	Size, Transport volume, Multiple facilities	1	VRU presence	1	VRU presence
Airport	5	Multiple facilities, Fenced-off, VRU Presence, Predictability of operations, Collaboration between site-actors	1	Multiple facilities	2	Fenced-off, VRU Presence	3	Fenced-off, VRU Presence, Collaboration between site-actors

Table 5.2: The site type characteristics in the optimal state that are connected to key deployment factors

With Table 5.2 as foundation, Table 5.3 is created. This table consists of site type, key deployment factor in the same way as Table 5.2, however the number of optimal state key deployment factors are divided by the total number characteristics related to key deployment factor, hence visualized as percentage share of the optimal condition factors.



Key deployment factor	Use case	Profitability	Safety assurance	Regulations
Site type	Optimal state characteristics/Total characteristics	Optimal state characteristics/Total characteristics	Optimal state characteristics/Total characteristics	Optimal state characteristics/Total characteristics
Dry port	31%	14%	40%	40%
Manufacturing plant	38%	43%	20%	40%
Port	62%	43%	60%	80%
Intermodal terminal	23%	14%	20%	20%
Transshipment center	23%	0%	40%	40%
Freight village/logistics cluster	38%	43%	20%	20%
Airport	38%	14%	40%	60%
Total amount of characteristics connected to key deployment factor	13	7	5	5

Table 5.3: Optimal state characteristics divided by total characteristics

The table 5.3 supports the discussion about suitability of different site types for the implementation of autonomous trucks. Judging from Table 5.3, it is clear that ports are a well-suited type of site. Ports exhibit a 62% match between the characteristics that are in an optimal state versus the total characteristics connected to the key deployment factor use case. It had a 43% match from a profitability perspective, a 60% match from a safety assurance perspective and a 80% match from a regulatory point of view. Of the sites studied in this report, ports have the highest match in percentage from all deployment perspectives viewed as a while, meaning that in terms of use case, profitability, safety assurance and regulations, ports exhibit a high suitability for autonomous trucks. However, a key factor to stress here is that form factor, cargo type and payload were disregarded in this analysis, as illustrated in Table 4.8, the reason being that they are dependent on the operational truck setup of the autonomous truck provider. In ports it is a precondition to have an autonomous truck with the form factor tractor-truck, with the ability to handle the cargo type container, as well as a high payload. This further demonstrates the point previously mentioned in this discussion that the autonomous truck needs to be adapted to the conditions on the site. Here, the form factor and the cargo type that fits the site operations is vital if there is hope to win contracts in the business, it is what is called a must-have. However, as described in the literature, AGV:s are widely adopted in the port segment (Ioannu et al., 2000), autonomous trucks must therefore compete with this incumbent technology, and create more or different value for the port operators (Engström et al., 2019).

Two other suitable types of sites are manufacturing plants and freight villages/logistics clusters. Both exhibit a 38% match rate on the use case, 43% match rate from a profitability standpoint, a 25 % match from a safety assurance perspective, and finally from a regulatory perspective, manufacturing plants have 40%, compared to 20% for freight village/logistics clusters. When comparing the 38% match rate on the use case for manufacturing plants and freight villages, it is possible to see some differences. Firstly, the sites both have low amounts of VRUs and multiple facilities. However, the manufacturing plant has value added services, repetitiveness of routes and collaboration between site-actors whereas freight villages have a large size, a high transport volume and predictability of operations. Given this, the use case suitability is favorable from different perspectives. Manufacturing plants have value added services and repetitiveness of routes, hence it is likely that the case flows could be better suited for autonomous trucks. In the case of freight villages/logistics clusters, sites are quite large, meaning more opportunities could be found, i.e, more flows could be present. However, as emphasis is placed on finding suitable flows there could be potential for the manufacturing plant to come out as the winner if comparing the two from a use case perspective.

Moreover, the sites have the same match rate on profitability (38%), however due to different reasons. Manufacturing plants have multiple facilities, value added services and repetitive routes while freight villages/logistics clusters have a large size, high transport volume and multiple facilities. This is not to say that some manufacturing plants do not have a high transport volume and a large size, it is simply hard to make generalizations about the size of manufacturing plants, given that it varies a lot (Vokurka & Davis, 2004). However, if a large manufacturing plant which both exhibits a large transport volume and a large size would be assessed, there would be a 71% match from a profitability standpoint. On the other hand, in the case of small manufacturing plants with low transport volumes, the freight village could present a better opportunity given that transport volume is an important profitability characteristic. From a regulatory perspective, the reason for manufacturing plants being better matches is that they have more natural collaboration between on-site actors.

Moreover, a finding from the interview study is that some manufacturing plants and freight villages are fenced-off. As previously explained, fenced-off is an important characteristic from a regulatory perspective due to its impact on the safety case which in turn constitutes the basis of the permit process, hence it is of highest interest to consider each individual case here. Due to the potential for elevated suitability of fenced-off sites from both a regulatory- and safety perspective, working with partial fencing of specific parts of otherwise well-suited sites to create individual spaces that are suitable for autonomous trucks is an interesting measure of adaptation.

Finally, the case of airports will be discussed, on which interviewees have expressed divided opinions. The airport exhibits both a good use case (38%), though, from a profitability point of view the match is only 14%. Angle of safety assurance and regulations is much more promising, with matches of 40% and 60% respectively. Hence, every aspect looks promising except for the business case. According to Engström et al. (2019), a poor business case will disqualify the airports as potential arenas for the implementation of the technology. As mentioned before in the report, the actors in the logistics industry operate on small margins (Slowik & Sharpe, 2018), and if a return on investment is not realized quickly as profits are lacking in a site, the whole use case falls apart (Engström et al., 2019). If airports exhibiting more optimal state characteristics, such as large size and a large transport volume, could be identified, the opportunity would be more attractive. The same thing can be said if payload- or form factor requirements align between the airports and the autonomous truck developer. Considering this, the point that it is important to be aware of the match between the individual capabilities of the autonomous truck and the characteristics that individual sites exhibit, is further strengthened. The internal variation between logistics centers and manufacturing plants (Vokurka & Davis, 2004; Notteboom et al., 2017) makes it difficult to generalize characteristics of the site types. Therefore, it is appropriate to as an autonomous truck developer do an in-depth analysis of each site to better understand the particular case and the specific site conditions.

To conclude, ports stand out from the other sites in terms of suitability on all dimensions, paving the way for autonomous truck implementation in them. However, AGV:s are widely adopted in ports, autonomous trucks would therefore have to compete with them. Next in line in terms of suitability are manufacturing plants, freight villages and airports. Moreover, it can be concluded that individual sites within the same type can have different conditions than what is shown in this report, hence it is important to study each site individually. Finally, site-adaptation is a potential path to improve site suitability in relation to autonomous trucks.

6. Conclusion

The purpose of this report has been to investigate both what the suitable characteristics of controlled outdoor environments are in the context of autonomous trucks and which of these controlled outdoor environments exhibit characteristics that can support operations of autonomous trucks. The characteristics found were compared to key deployment factors and the results from that enabled the development of data on which sites are suitable for implementation of autonomous trucks.

The theoretical framework consisted of three building blocks including transport automation, controlled outdoor environments as well as a description of the key deployment factors. In transport automation, the stage was set for the technological state-of-the-art in autonomous trucking, the controlled outdoor environment part shed light on the types of sites considered for implementation, and finally the key deployment factors acted as guidance for the analysis on to what extent sites can support autonomous trucks. Subsequently, the empirical findings were presented, outlining the key characteristics of controlled outdoor environments in relation to autonomous trucks, and to what extent different controlled sites exhibited these suitable characteristics. The majority of the key characteristics were site specific, meaning that they were linked to the activities on a certain site and its physical layout. These site specific characteristics found in the study were divided in categories, namely vehicle requirements, size of automation opportunity, traffic environment, operational conditions and site actor attitudes. Some of the characteristics were more general, meaning that they did not have a connection to a certain site. The general characteristics were weather conditions, regulatory conditions, economic conditions and autonomous loading and unloading.

Hence, the theoretical framework and the empirical findings were combined, and further elaborated in the discussion. Here, the impact of the site characteristics on key deployment factors were discussed, as well as the internal relation between the key deployment factors. Lastly, a discussion was conducted about the suitability of the sites. Here the deviations of sites in relation to the optimal state was discussed from the different deployment perspectives, and based on this criteria, more suitable sites could be distinguished from the less suited ones.

Based on the discussion, the site characteristics found to highly impact multiple key deployment factors was cargo type, form factor, fenced-off, size, transport volume and weather conditions. The cargo type and form factor determine which load units that are possible to handle, hence a mismatch on these dimensions will disqualify the truck from the possibility of a use-case and the operation of potentially profitable transport volumes. The characteristic fenced-off is of utmost importance to deployability, and its potential impact is closely linked to the basic idea of implementation in controlled outdoor environments. Fenced-off areas are less uncertain environments from a safety perspective, since it is easier to control which people and vehicles that can access the premises, decreasing the issues related to mixed traffic and contact with VRUs. Size of the automation opportunity is also a vital parameter to use case and profitability. Here, a key implication of the characteristics site size and transport volume is that they help to identify high-volume low-complexity flows. Finally, weather conditions were found to impact all the key deployment factors, making it crucial to implement the technology in locations and geographies where the weather condition favors capability of autonomous trucks. Regarding the internal relations between key deployment factors, use-case and profitability exhibited a strong link, since profitability of autonomous trucks depends upon the identification of suitable deployment opportunities where the benefits of the technology can start to be realized. Moreover, regulations and safety are found to have a tight relationship, since the strength of the safety case is currently conclusive to gain permission to operate an autonomous truck, hence they will improve proportionally.

In the discussion on the suitability of sites; ports, manufacturing plants, freight villages/logistics clusters are found to be most suitable for the implementation of autonomous trucks. However, it is important to consider that some of the characteristics were not evaluated in this analysis as they are specific to the setup of the individual truck provider. Moreover, the implementation of autonomous trucks is context dependent and the sites are found to exhibit a high degree of internal variation. Therefore, it is vital that the autonomous truck providers conduct a site evaluation on every site, and the display of promising characteristics should be viewed as a primary indication of potential suitability.

In the end, the goal is to reach an on-the-road large-scale deployment of autonomous trucks. The large-scale deployment will require the technology to be capable of handling the wide variety of environments that are currently operated by non-autonomous trucks, even though adaptation of the surrounding infrastructure could relieve the issue slightly. As of today, even in controlled outdoor environments, vehicle capabilities require considerable improvement to fulfill the requirements of the majority of sites. In doing this, the development of capabilities can be prioritized strategically, sequenced in a way that gradually opens up as much market space as possible. However, for the initial implementation of the technology, there is a purpose in finding suitable environments that match the vehicle capabilities today (Engström et al., 2019).

Finally, Engström et al. (2019) state that "*if large scale efficiencies, safety and economic benefits predicted by current trials are realized in operations, there may be a hockey stick adoption of trucking automation*". Considering this, it can be concluded that the future adoption of autonomous trucks will depend on the identification of well-suited use cases that are both safe and profitable. In essence, this means that controlled outdoor environments have the potential to act as a vehicle, driving the development of autonomous technology forward.

6.1 Future research

This report has provided insight into which characteristics of a controlled outdoor environment that indicate suitability for implementation of autonomous trucks on a site, and the report has also aimed to connect these attributes to different general site types. Future research could deepen the understanding of different controlled outdoor environments, by focusing on better understanding the internal variation within site types, as well as extending the scope of this report and search for other promising environments. A concrete example of extended research could be to dedicate a specific study to investigate airports in an autonomous context, to understand more about the trucks that are operating on the premises of these, and what requirements on autonomous trucks in this environment would be.

Another interesting topic disregarded in this thesis, would be the creation of a practical and quantitative methodology for large scale localization of suitable sites. In a similar research paper, the indications on importance of characteristics and potential suitability of site types could be used as a basis in the search for relevant data sets.

Finally, the focus of this study has mainly been to identify sites where the physical- and operational conditions would support implementation of autonomous trucks. In reality, other social-, organizational-, or business related barriers may exist to implementation, for instance the amount of competition in a specific segment or the opposition of unions. Considering the results of this thesis, this would be an interesting path to pursue in order to nuance the suitability concept.

7. Managerial implications

In this chapter, the managerial implications of this report will be outlined, with basis in the empirical findings and the following discussion. Here, practical implications for the identification of suitable sites for autonomous trucks will be presented, along with indications on how technology development should proceed, to maximize the opportunity for on-road deployment in the long-term.

Size of site, transport volume, fenced-off and weather conditions are highly important characteristics and should be considered in the site choice

A few highly relevant site characteristics with impact on multiple deployment factors were identified in this report. Firstly, the size of the site and the on-site transport volume are deemed important, since a large size increases the likelihood of finding suitable internal flows for the technology of sufficiently high transport volume. Moreover, transport volume determines the number of autonomous trucks that can be implemented on a site, which in turn impacts revenue, operating- and investment costs. Then, identifying fenced-off areas are of utmost importance, since this facilitates the building of a strong safety case on a site, hence also the regulatory permission process. The increased safety stems from the increased possibility of controlling which VRUs have access to the premises, and to which degree the traffic is mixed. Finally, the importance of the on-site weather conditions should not be underestimated. Permits for autonomous truck operation are granted with a specific set of weather conditions in mind. Currently, the amount of rain, snow or other specific weather conditions directly correlates with the uptime and safety of the autonomous truck. In the first case, on-site weather conditions should be taken into careful consideration prior to implementation decisions.

Ports, manufacturing plants, and freight villages may be well-suited cases to further investigate as implementation opportunities for autonomous vehicles

Judging from the analysis with several deployment factors in mind,, the ports emerge as the clear winner from the use-case, profitability, safety and regulatory perspectives. A major advantage of ports is the high transport-density on the site, which makes them an attractive business case.. However, there is a need for a form factor that supports the transportation of containers. Moreover, manufacturing plants could be a suitable case, since they have high potential to exhibit suitable low-complexity flows. Given that the right manufacturing company is partnered with, transport volumes, site size and the state of fencing may match requirements as well. However, a high internal variation exists between manufacturing plants, based on what is produced and what exists on the perimeter. Furthermore, freight villages may be a well-fitting case for the technology. These also have a high potential for large internal freight volumes from the intermodal terminal to on-site facilities, as well as in between the abundant number of on-site facilities..

Develop the technology to fit the form factor/cargo type most prevalent in the industry

Having a form factor that fits the operating environment is crucial for the implementation of autonomous trucks in controlled outdoor environments. This means that actors should aim to develop the form factor applicable in the highest number of use cases, which for controlled outdoor environments may be the tractor-truck, according to the empirical findings. If an actor has opted for another setup of the truck, extending the form factor to include tractor-truck would unlock use cases in ports and freight villages, two promising use cases. Ideally, a trailer-agnostic solution should be developed, this is due to the possibility of tailoring the trailer to the individual customer.

Collaboration with site actors to adapt the ODD of the site for the purpose of the autonomous truck

The study has concluded that one way of increasing the match between technological capabilities of the autonomous trucks and on-site requirements, is to adapt it in collaboration with site-actors. This could be to simplify the ODD through infrastructure adaptation, which simultaneously facilitates the regulatory permit possibility. For instance, this could be by fencing-off parts or the whole, or creating separate lanes for the autonomous truck. This implies that the relationship between the site actor and the autonomous truck provider is important, and that attitudes of partners should be taken into account in site selection.

Work to solve each part of the autonomous equation

Finally, the study has concluded that all of the parts of the autonomous truck deployment-equation needs to be solved, and that the variables are highly interdependent. In practice, this means that the use case must be suitable for the technology, the profitability needs to be sufficiently high for the investment to be worth it, the technology must be safe enough for the trucks to operate without concern. Moreover, the regulatory requirements that are in place create the need for the autonomous truck company to work with regulatory authorities to get the necessary permits to operate the technology. Hence, a holistic approach to the deployment challenge is required, since building blocks need to be in place to enable successful deployment of autonomous trucks.

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A Appendix

A.1 Interview guide case company example interview

Tell us about what you do at the case company

1. What is the process for site selection today (before site analysis)?
    a. Does this also tie in to the level of automation?
2. What needs to be done from the point where a site is identified as autonomous suitable (technically manageable) to the point that it is safe to drive in that ODD?

3. What are the largest barriers for autonomous trucks implementation on sites today?

4. Are there any sites that we should exclude directly from a safety perspective?
    a. Vulnerable goods?
    b. Specific industries?
5. What is the optimal ODD for Einride to work on for AET:s in the industrial site segment?
    a. Seaport
    b. Airport
    c. Distribution center
    d. Intermodal/Transmodal
    e. Production sites?
    f. Mining?
6. Which information needs to be included in a pre-study of locations of industrial sites in order for it to be relevant?
7.
8. What is the current capability to communicate with other vehicles?

A.2 Interview guide site interview

Tell us about yourself

1. Tell us about the site

2. What activities do you conduct at the site?

3. What value could autonomy create in the site?

4. How is the flow of goods planned?

5. Are the goods following a predictable schedule?

6. How important is the timing of delivery in the different operations?

7. What type of goods flow through the site

8. How is it packaged?

9. Are there usually a lot of transports on site?

10. Can you outline the characteristics of the route that is suitable for automation?

11. Are there many actors on the site?

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