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Investigating the Potential Effects of Intelligent Access

Dealing With Contemporary and Future Aspects of Autonomous Driving, High Capacity Transport, Smart Roads and Smart Parking

Master's thesis in Supply Chain Management

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Cover: Illustration generated with OpenAI's DALL · E, depicting a truck, a parking space, and a port, all connected to the Intelligent Access system.

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Abstract

The rapid development of freight transport has introduced challenges related to infrastructure capacity, environmental sustainability, and logistical efficiency. The purpose of this thesis is to investigate contemporary and future aspects of autonomous driving, high capacity transport, smart roads and smart parking to achieve IA for road freight transport and port- and terminal logistics. To the knowledge of the authors, no research that focused on the holistic view of all these areas, encompassing both contemporary and future aspects in relation to Intelligent Access, have been found. The study uses a qualitative research methodology, which combines literature review and expert interviews to analyze current and future frameworks and concepts related to aforementioned areas. It identifies how frameworks like SAE levels for AVs and Performance-Based Standards (PBS) for HCT can be incorporated into IA systems to improve route planning, reduce emissions, and increase infrastructure longevity. Key findings reveal serious barriers to implementation including fragmented regulations, limited infrastructure readiness and challenges in data governance. Nonetheless, the research outlines how coordinated deployment of IA can improve efficiency, reduce environmental impact, and enhance the resilience of freight transport systems. By aligning technical innovations with coherent policy frameworks, this thesis outlines pathways toward a smarter, safer, and more sustainable freight transport ecosystem. The thesis contributes to a general understanding of how digital and automated innovations can support the transition toward sustainable and intelligent logistics networks.

Keywords: Intelligent Access, High Capacity Transport, Autonomous vehicles, Smart Roads, Smart Parking, Ports and Terminals.

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Glossary

Below is the list of concepts, whose meaning was deemed to be less obvious to the reader, that have been used throughout this thesis listed alphabetically:

Term	**Definition**
Autonomous vehicle (AV)	A self-driving vehicle that uses sensors, cameras and algorithms to operate without human input. Autonomous vehicles will be used synonymously with autonomous trucks in this report.
Axle load	Amount of weight carried by a single axle of a vehicle.
Geofencing	Location-based technology that creates a virtual boundary around a specific geographic area.
High capacity transport (HCT)	Longer and heavier vehicles.
Intelligent Access (IA)	Technology that regulates access for abnormal loads and vehicles.
National road authority (NRA)	A government agency responsible for the planning, construction, maintenance, and regulation of a country's main road infrastructure.
Operational Design Domain (ODD)	Refers to the specific conditions under which an autonomous vehicle is designed to operate safely.
Performance-Based Standards (PBS)	A regulatory framework that specifies conditions under which abnormal vehicles can operate.

Platooning	The practice of driving vehicles closely to each other with automated driving systems and vehicle-to-vehicle communication for coordination and control.
Smart Parking	A digital system providing services related to parking.
Smart Roads	Roads that are able to exchange data with the help of digital services.

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1
Introduction

The following introduction provides background information for the report, describes relevant problem areas, and outlines its purpose, research questions, and limitations.

1.1 Background

European integration is heavily dependent on the free transport of individuals, services, and goods (EU, 2021), with road freight playing a central role. Transportation also has a major impact on the economy, contributing more than 9 percent to the EU's gross value added, and transport services employ around 11 million people. Nkesah (2023) describes transport systems as the lifeblood of modern societies, with road freight being widely used due to its flexibility, reliability, and fast delivery. Within the EU, road freight transport accounts for 76 percent of all inland transportation and it is projected to increase by 40 percent by 2030. However, transportation contributes to air, water, and noise pollution while also causing congestion and traffic accidents.

The growing transport volumes could intensify capacity challenges, further worsening congestion (Balko et al., 2018). The congestion problem already costs 140 million euros annually and has a devastating impact on the environment. The Swedish Transport Agency is facing challenges, having estimated a shortfall of 150 billion Swedish kronor for the strategic plan for 2026-2037, which would need to cover both maintenance of existing infrastructure and the planned investments (Davidsson, 2024). Additional budget space will be required in order to implement the investments needed. As pressure on both infrastructure and the environment continues to grow, there's a clear need for smarter, more scalable solutions that can boost transport efficiency while cutting down on negative impacts. In response, a number of promising technologies and concepts are starting to gain real momentum.

One concept that helps to solve problems connected to emissions and traffic congestion is HCT, high-capacity transport. HCT involves using larger, heavier vehicles that can carry more load per trip, which increases efficiency and reduces overall energy consumption (Ye et al., 2014). Another key concept is autonomous driving, a technology enabling vehicles to operate independently without human intervention.

AVs can help to make the road transportation system more efficient, which leads to better infrastructure utilization, and lower emissions (Faisal et al., 2019). Vehicles can have varying levels of automation, which means that, in the future, certain roads may be designated to accommodate specific automation levels.

Connected to the infrastructure, concepts such as smart roads and smart parking may be helpful in the implementation of HCT and AV, and further streamline road freight transport. There are multiple definitions of smart roads, but the main purpose is to increase the communication between infrastructure and vehicles. This can be done by implementing sensors and cameras on the roads to achieve dynamic information sharing regarding road conditions, traffic and weather (Trubia et al., 2020). As for smart parking, it can assist truck drivers by providing information on suitable parking locations, vehicle type restrictions (for example HCT compatibility), security levels, and real-time availability (Rocco et al., 2023).

Seaport logistics plays a vital role in facilitating global trade and is an important part of many supply chains. Seaport logistics requires collaboration among multiple stakeholders to meet the needs of the shipper (customer). Within ports and terminals, there are other requirements to take into consideration when planning the logistics. There are no open roads for public traffic, minimal pedestrian interference, reduced route complexity, and the speed regulations are often lower than on normal roads (Zou et al., 2022). The conditions for integration of autonomous driving and intelligent Access in ports and terminals differ significantly from road freight transport, which makes it an important area to examine.

The interplay among aformentioned innovations has the potential to make road freight transport more efficient and environmentally friendly. Intelligent Access (IA) is a concept that has the assignment to verify that "the right vehicle with the right load is on the right road at the right time" (Asp and Wandel, 2023). HCT, AV, smart roads and smart parking can contribute to IA and help transform the transport sector. However, this transformation is accompanied by numerous challenges regarding infrastructure development, technological integration, regulatory frameworks, and economic viability. To address these challenges and achieve IA, this report examines contemporary and future aspects connected to the aforementioned areas. These aspects include various technologies, concepts, and frameworks related to the different areas, and they are evaluated based on their potential usefulness in the near term or further into the future.

One scenario where Intelligent Access (IA), incorporating smart roads and smart parking, could be particularly relevant is the transportation of goods from a port to another city. This type of freight movement must accommodate not only standard road transport requirements but also the specific, often unique conditions within ports and terminal areas. This report will utilize this scenario to thoroughly explore and illustrate the role of IA within a complex logistical environment characterized by multiple dynamic conditions. The chosen case will highlight IA's practical benefits in a realistic context involving multiple steps and challenges.

The report will be a part of a project called Intelligent Surface Access Community (ISAC), a project within the Conference of European Directors of Roads (CEDR) (CEDR, 2023). It was written in collaboration with Consenso, a Swedish consulting firm specializing in the transportation sector.

1.2 Problem Areas

As mentioned in the background, there is a large problem with congestion and greenhouse gas emissions connected to the road freight transport (Balko et al., 2018). According to Becker et al. (2022), 15 percent of European CO2 emissions were generated by road freight transport in 2022. Currently, more trucks are becoming electric, but the current trajectory for electric trucks is not enough to decrease emissions to a level that aligns with the 2015 Paris Accord. Road freight transport must be made more efficient, with better use of the infrastructure to avoid unnecessary wear and tear. The increasing volume of goods transported annually has resulted in unfavourable growth in road transport, leading to increased wear on roads and substantial repair costs (Knapcikova and Konings, 2018). The infrastructure also needs to be updated to handle the transition to electric vehicles by expanding the charging infrastructure network and thereby avoiding long queues at charging stations (Kumaresan et al., 2023).

Another issue that causes challenges for road infrastructure is the fact that overloaded trucks travel on roads and bridges where they are not allowed (Fiorillo and Ghosn, 2016). This causes disproportionate damage to highways, bridges, and pavements, leading to premature deterioration. Improper loading can also cause damage to packages, as well as personal injury (Aliakbari and Moridpoure, 2016).

On the same topic, safety is a huge concern when it comes to road transport. According to Nowacki et al. (2019), approximately 1.2-1.3 million people die each year because of road accidents. In Europe, heavy goods vehicles are involved in 14.2% of fatal road accidents, highlighting the urgent need to improve safety in heavy freight transport (Schindler et al., 2021).

As for HCTs, while they can help increase road freight efficiency, they cannot access all roads due to infrastructure limitations and regulations (Asp and Wandel, 2023). The adoption of HCTs also faces barriers due to the lack of standardization across Europe (Kharrazi et al., 2017). Another problem that trucks, not only HCTs, faces is the fact that when a temporary permit is needed for a road segment, this can take a couple of days to receive (Trafikverket, 2021a). This requires drivers to plan their routes ahead, which is not always possible. Additionally, finding suitable parking spaces can also pose a significant difficulty for truck drivers, leading to regulatory violations, unsafe parking, and reduced efficiency (Lizbetin and Bartuska, 2020).

When it comes to autonomous vehicles, the main issue today is that they are not allowed on public roads (Van Uytsel, 2021). The technology is not yet fully mature, and the absence of clear rules and regulations regarding autonomous vehicles further hinders their implementation.

As the freight transport industry grows rapidly, it increases the need for more efficient handling of goods. For ports and terminals, there are problems with congestion, which in turn affects the efficiency of the handling process (Jacobsson, 2020). Congestion and inefficient terminal processes increase turnaround times, which extend overall delivery durations and result in increased operational delays and higher costs.

However, despite research having been conducted on autonomous driving, high capacity transport, smart roads, and smart parking in road freight transport and port-and terminal logistics separately, no research that focused on the holistic view, encompassing both contemporary and future aspects in relation to Intelligent Access, have been found according the knowledge of the authors.

1.3 Purpose

Therefore, the purpose of this thesis is to investigate contemporary and future aspects of autonomous driving, high capacity transport, smart roads and smart parking to achieve IA for road freight transport and port- and terminal logistics. A key focus will be on evaluating existing aspects, which includes different technologies, concepts and frameworks, determining their compatibility, and exploring strategies for synchronizing them in an efficient manner.

1.4 Limitations

This project was conducted within a 20-week timeframe and specifically focuses on frameworks and concepts related to autonomous driving, smart roads, smart parking, and High-Capacity Transport (HCT). Additionally, the scope is limited to freight transport, excluding personal transportation. The primary focus has been on European road freight transport although information from countries outside the continent has been used to provide valuable insights.

1.5 Research questions

To fulfil the purpose and the aim of this thesis, the following research questions are outlined.

1. What are the characteristics of autonomous driving, high capacity transport, smart roads and smart parking in road freight transport and port- and terminal *logistics?*

2. What are the contemporary and future aspects of autonomous driving, high capacity transport, smart roads and smart parking for Intelligent Access in road freight transport and port-and terminal logistics?

3. How can these contemporary and future aspects affect Intelligent Access in road freight transport and port-and terminal logistics?

2

Literature review

This section focuses on key concepts that form the foundation for this report, focusing on emerging transportation technologies. These include connectivity, automation, smart infrastructure, high capacity transport, and port and terminal logistics.

2.1 Intelligent Access

The intelligent access (IA) framework is meant to ensure that the right vehicle is on the right road at the right time with the right load and driven at the right speed, according to Asp and Wandel, 2023. The potential benefits of IA include optimizing transport infrastructure usage to its full capacity without increasing the risk of damage or accidents. The technology is also projected to reduce carbon emissions and increase productivity.

The Australian Austroads has investigated the possibility of implementing Intelligent Access for heavy vehicles through the Intelligent Access Program (IAP) initiative (Cai et al., 2010). The program gave heavy vehicles access to an increased number of areas in exchange for their driving data. The data was collected via GPS and transmitted to the appropriate jurisdictions. The data was then analyzed to ensure that heavy vehicles complied with the regulations of each jurisdiction. The analysis was based on Intelligent Access Conditions (IAC), and any non-compliance was reported. Therefore, from a regulatory perspective, the IAP initiative could verify that the right vehicle was on the right road at the right time with the right load and was driven at the right speed.

Kural et al. (2021) describes the dominance of road transport in inland freight across Europe, a trend that is expected to persist for the foreseeable future. Unless there are significant changes in transportation policies, CO2 emissions from freight are projected to double by 2050. The paper further defines Intelligent Access as a means of ensuring that the performance characteristics of a road freight vehicle are matched with the condition and capabilities of specific sections of the infrastructure network. In simpler terms, Intelligent Access ensures that the right vehicle is on the right road at the right time. Intelligent Access for heavy vehicles offers the means to enhance the efficiency of the existing European road network. Furthermore, intelligent access offers benefits to multiple different actors. Vehicle operators are able to make their transport operations more efficient by utilizing new technology and vehicle combinations. National road authorities benefit from collecting data that can be used to monitor infrastructure usage and support decision-making, such as addressing wear and tear through maintenance and repairs. Society as a whole will benefit due to reduced emissions and infrastructure costs.

The paper by Kural et al., 2021 has divided vehicles into four access groups based on the vehicles configuration and properties. The "access group" determines which infrastructure level they are allowed to access and these levels are mainly dependent on five properties.

- Average annual daily traffic
- Lane and/or bridge width
- Accident history
- Cornering space and road slope
- Other road users, parked cars, cyclists

Each vehicle and vehicle combination can be assessed based on its performance envelope, which represents a set of behaviors related to low-speed manoeuvrability, dynamic steering and environmental and infrastructure impact.

2.1.1 Geofencing

Geofencing is a technology that creates a virtual boundary around a geographical area (Reclus and Drouard, 2009). A system can then identify through GPS whether a connected mobile object is within or outside the specific area. The field of transport and logistics could be improved by geofencing. Heavy trucks are generally assigned to reach certain areas such as warehouses, ports or customer facilities. These locations are known as points of interest, and when a vehicle is within a predetermined range, it sends a notification to the location, alerting the staff about the vehicle's whereabouts. Geofencing can also be used to ensure that certain vehicles remain outside designated areas. Vehicles carrying dangerous goods or unusually large loads should not have access to all roads. For example, steep slopes, specific bridges, and other infrastructure that may not be strong enough for certain loads. Geofencing could restrict access to roads if the vehicle is unsuitable for travel in those areas.

The increased demand for freight transport lately has led to increased need for heavy capacity vehicles (Wu et al., 2024). The phenomenon has led to new challenges in truck parking, as the availability of parking areas along highways and in urban regions has not increased at the same rate. Geofencing is seen as a potential solution to urban parking as it utilizes location-based technologies such as GPS, RFID and Bluetooth to create digital boundaries. When a truck crosses this boundary, it can be directed to the most suitable location, reducing unnecessary parking search time.

According to the article, truckers are not fully utilizing designated parking areas due to a lack of visibility (D. Wolf, 2023). Truckers' decision to park often depends on whether other trucks are parked outside the parking lot upon arrival. This may not be a reliable indicator of whether a parking area is truly full, as the article states that spots may still be vacant despite this. The problem seems to be a lack of visibility, and geofencing is one possible solution to the problem. Geofencing could enhance effectiveness by clearly marking the locations of both designated and undesignated areas. Drivers' awareness regarding vacant parking spaces could be increased by leveraging existing technology.

TruckX, a company that provides GPS tracking, ELD compliance, and fleet management solutions for trucking, states that geofencing offers several advantages for fleet management (truckx, 2024). Routes will be easier to optimize by incorporating real-time data from specific geographic areas, ensuring the most efficient path is taken, which in turn reduces fuel and operational costs. The technology addresses issues related to arrival and departure times, enhancing customer service by allowing customers to receive real-time notifications about the delivery vehicle's position. Geofencing could also be used for showing authorities that the company adheres to laws and regulations as reports that show historic driving activity can be generated.

2.1.2 Urban Vehicle Access Regulation

Urban Vehicle Access Regulation (UVAR) is closely related to Intelligent Access. While Intelligent Access focuses on Heavy Combination Transport (HCT), UVAR is primarily aimed at reducing emissions and minimizing congestion within urban areas. UVAR can be defined as a "measure to regulate access to urban infrastructure" according to (Ricci et al., 2017). UVAR can be implemented in various ways, including Area License-Based Pricing, which charges vehicles a fee during specific hours, and Point-Based Restrictions, where access to certain road segments or bridges is prohibited. The three main reasons for adopting UVAR are environmental aims, reducing congestion and raising revenue. UVAR can be used to identify vehicles and restrict access to low-emission zones if they do not meet the required environmental standards.

Five technological options have been identified as useful for implementing UVAR Automatic Number Plate Recognition (ANPR), Dedicated Short-Range Communication (DSRC), Radio-frequency (RFID), Global Navigation Satellite System (GNSS) coupled with mobile communication (GSM), and Tachograph based technology (Ricci et al., 2017).

- ANPR utilizes fibre optics or broadband to transfer information from roadside cameras to a hub where the information is analysed.

- DSRC is based on radio communication between a mobile device and roadside equipment and is primarily used for charging. The technology therefore depends on the vehicle having an on-board unit (OBU) that is able to communicate with the equipment. The technology has not raised privacy concerns even though it stores personal data on the OBU.
- The RFID is very similar to DSRC as an inbuilt antenna resonates the signal for the rosides equipment. The main advantage of RFID compared to DSRC is that the technology is chapter.
- GNSS coupled with GSM technology require less roadside equipment and therefore require less investments than for instance DSRC and ANPR. However, the GNSS OBU cost is higher than the DSRC OBU unit. Moreover, the price of the GNSS units are likely to drop in the future as technology evolves. GNSS is also more flexible, as maps and UVAR conditions such as time, location, and time of day can be updated easily and at minimal cost. The technology offers other interesting features such as real-time monitoring of vehicle travels and stops. GNSS may raise privacy concerns as individual movement profiles can be created.
- Tachograph-based technology, primarily used in heavy goods vehicles, relies on an onboard unit (OBU) linked to the vehicle's odometer. While it involves minimal roadside infrastructure and poses few privacy concerns, the high cost of OBUs remains a drawback.

2.2 Road freight transport

Road freight transport is a mode of transportation that utilizes trucks, vans, and trailers to move goods with road networks. It is well-suited for short to medium-distance shipments, offering flexibility, accessibility, and efficient door-to-door delivery (Stamenković et al., 2017).

Road freight transport faces several challenges today that impact efficiency, cost and sustainability. In urban areas, congestion is one of the main problems that affect the efficiency of road transportation (Liachovičius and Skrickij, 2020). Deliveries during peak hours often result in delays, presenting a highly complex challenge that requires coordinated efforts from multiple stakeholders rather than a single solution. Fewer vehicles on the roads are necessary, for example through political decisions that may increase the attractiveness of using the public transportation system instead of one's car. A way to decrease the need for trucks is mentioned in section 2.5, where HCTs are discussed as a solution to fewer trucks on the roads. Also, better route planning could be a solution to avoid the most congested areas. With Intelligent Access, drivers could receive optimized routes that factor in real-time traffic conditions and provide suitable truck parking options aligned with their rest schedules, ensuring both efficiency and compliance with regulations.

Another problem is a shortage of drivers. According to International Road Transport Union (2024), half of Europe's truck operators are incapable of expanding due to a lack of drivers. One solution to this issue may be the implementation of autonomous vehicles (Liachovičius and Skrickij, 2020). However, implementing autonomous trucks on a large scale would require substantial investment and a fundamental transformation in how hauliers operate. A key enabler of this transition could be the use of Intelligent Access. Intelligent Access can help introduce a safe and efficient deployment of autonomous trucks by ensuring compliance with road regulations, optimizing traffic flow, and enhancing route planning. By optimizing routes, energy consumption can be minimized, which can be advantageous both from an economic and a sustainability point of view.

2.3 Port and terminal logistics

Today, many ports and terminals utilize autonomous vehicles, specifically Automated Guided Vehicles (AGVs), to transport containers within enclosed facilities. The use of AGVs is becoming increasingly common in ports worldwide since the operational efficiency is much higher compared to trucks with human drivers (Brenner et al., 2019). The downside with these vehicles is that they are not allowed to drive on public roads. They do not operate with built-in sensors and without self-orientation, meaning instead they are dependent on the guiding system and infrastructure within the terminal.

Some of the largest ports in the world rely on AGVs to achieve high efficiency in their loading and unloading processes. One example is the port of Rotterdam. They have been pioneers when it comes to implementing AGVs and have increased their handling speed and reduced vessel turnaround times for their terminals (Intelligent cargo systems, 2025). For example, they use AGVs from VDL, capable of lifting containers weighing up to 70 tonnes with a top speed of 6 meters per second while still maintaining high accuracy (VDL, 2025). They started implementing automation as early as 1993.

According to Chen (2023), the port of Rotterdam is one of the most efficient ports in the world. The same applies to the ports of Hamburg, Shanghai, and Singapore, which achieve even higher scores on the efficiency ranking from Chen (2023). These ports are among the world's largest hubs for goods handling. The author explores the optimal number of AGVs needed to maximize efficiency while maintaining profitability. He suggests that some ports could benefit from downsizing their AGV fleets, improving profitability at the expense of a slight reduction in efficiency (Chen, 2023). However, for most non-automated ports, implementing AGVs would improve service levels and operational efficiency. Although it would incur higher initial costs, the resulting efficiency gains are expected to outweigh the investment, making it a worthwhile implementation.

To achieve full autonomy across the transport chain, commercial autonomous vehicles must be integrated into terminal operations, enabling seamless door-to-door transport by picking up goods at one terminal and delivering them to another (Brenner et al., 2019). This would require communication between vehicles, infrastructure and transport service providers to ensure accurate and efficient pickup of goods.

To facilitate the operation of autonomous road vehicles in terminals and ports, Brenner et al. (2019) categorize the challenges and limitations into three key areas: vehicle, infrastructure, and communication. When it comes to the vehicle, they must, for example, have the proper sensors and cameras to detect changes in the environment such as weather conditions, variations in lighting, and infrastructure system failures. For requirements connected to the infrastructure, the vehicle must be able to be identified and verified to access the terminal, for example with the use of a camera or by sending and receiving an ID. The same goes for the loading and unloading of the goods to make sure the right load goes where it belongs. Additionally, road traffic regulations need to be adapted to allow trucks designed for public roads to operate within these areas (Brenner et al., 2019). Regarding communication, the primary stakeholders are the trucks, the terminal, and the operator. Information about parking locations and navigation, particularly slot allocations, must be effectively communicated between the truck and the terminal. The remaining information is primarily communicated to the truck by its forwarding company.

Volvo Trucks has developed a fully electric, connected, and autonomous vehicle called Vera (Volvogroup, 2019). One of its first assignments is to transport goods from a logistics center to a port terminal in Gothenburg. It was designed in 2018 and suited to perform repetitive tasks in logistics centers, factories and ports. The distance it can travel is not far, but it can transport high volumes of goods with great precision, which makes it suitable for the port of Gothenburg.

Vera is designed to operate as part of a connected fleet, monitored by a control tower, to enhance efficiency, flexibility, and sustainability. The usage of Vera in Gothenburg's port allows the vehicle to use pre-defined public roads within an industrial area with necessary safety precautions taken. The assignment, which is in collaboration with ferry and logistics company DFDS, is a way for Volvo Trucks to gain experience to allow Vera to be used in more advanced situations in the future (Volvogroup, 2019). Torben Carlsen, CEO of DFDS, describes the role of autonomous transport as very important to the future of logistics, since it allows for transportation with zero emissions and low noise levels, and these types of testing assignments are a great way to accelerate the future development of autonomous logistics solutions.

2.4 Autonomous driving

Autonomous driving is a technology that enables vehicles to navigate and operate without a human driver. Autonomous vehicles will play a vital role in enabling smart cities and have the potential to reduce accidents, greenhouse gas emissions and congestion according to Faisal et al., 2019. Currently, autonomous driving has been divided into six levels. The definition was established by the Society of Automotive Engineers International (SAE) and has been adopted by the National Highway Traffic Safety Administration (NHTSA). The lowest degree of autonomous driving (level 0) requires the driver to perform all the driving, while the highest level (level 5) allows the vehicle to operate without any human interaction. Level 5 is the only level that can actually be described as "autonomous", since vehicles at that level are able to perform all the dynamic driving tasks on their own. However, this definition is not strictly used in the literature as any level of autonomous driving is considered "autonomous". The SAE levels have been adopted by various stakeholders, including policymakers, industry professionals, and academic institutions to enable discussions on the progression and development of automated driving at different levels (Faisal et al., 2019).

The levels depict a degree of automation of functions that a human previously performed and the framework is organised into three aspects of the driving task, namely operational, tactical and strategic (Hopkins and Schwanen, 2021). The operational aspect involves monitoring the surroundings both inside and outside the vehicle. It also includes tasks like braking, accelerating, and steering. Tactical aspects involve responding to signals and stimuli, as well as executing manoeuvres such as turning and changing lanes. Lastly, strategic tasks regard navigation by determining destinations and waypoints. Hopkins and Schwanen (2021) explains that the framework helps define the roles of the human driver and the machine in specific scenarios. The 2014 SAE guidelines outline three steps to explain the levels of automated driving, clarifying when responsibility falls on the human driver, the automated system, or a combination of both. The purpose of the SAE framework is to help establish a regulatory framework for automated vehicles and guide manufacturers and other entities in the safe design and development of AVs (Hopkins and Schwanen, 2021). Autonomous vehicles are also characterized by whether or not they rely on communication provided by external infrastructure to perform their tasks. This version is called Connected Autonomous Vehicles (CAV) (Faisal et al., 2019).

2.4.1 Policy-based frameworks

Policy-based frameworks are used for the regulation and management of access to different resources or areas, and for AVs, they are used to define, manage and distribute traffic rules that AVs must follow (Baldini G and Neisse R, 2020). They have also been used to express rules through policies to regulate the behaviour of system elements, such as constraining speed limits. The authors describe a framework called SecKit that has been used in the area of the Internet of Things (IoT), but can also be used on AVs. The framework is built on components called metamodels, which serve as the foundation for defining and enforcing policy rules. These metamodels enable rule specification by incorporating factors such as time, location, vehicle characteristics, and context. These specifications can be further tailored to help make sure that the right vehicle is on the right road at the right time.

The policy-based framework can also describe rules that are valid for different types of vehicles. There could be speed limits for all vehicles, weight limits on specific roads, and data collection on what type of road the vehicle will travel on, so that it knows if the road is acceptable for an AV to travel on. Another example discussed by Baldini G and Neisse R (2020) is the vehicle's role and whether a hierarchy exists in traffic prioritization, distinguishing between commercial and passenger vehicles. Police cars or ambulances could be given priority when needed, making their callouts more efficient. With all the specifications in place, the framework can help govern the AV's behaviour and specify which types of vehicles, i.e. AVs of different SAE levels or human-driven vehicles, are allowed on certain roads at certain times based on their features and the surrounding conditions.

Baldini G and Neisse R (2020) also examines the necessary actions when new regulations are implemented. To make sure AVs are able to understand and interpret new signs, rules and messages, their software needs to be updated when new regulations are in place. This requires careful planning to ensure updates are implemented ahead of time before the new traffic regulations take effect.

2.4.2 Platooning

One concept that can be relevant for the future of road freight transport and automation is platooning. Sivanandham and Gajanand (2020) define the concept as "the practice of driving vehicles closely to each other with automated driving systems and vehicle-to-vehicle communication for coordination and control". The lead vehicle serves as the platoon leader, coordinating and communicating with the following vehicles. One of the reasons for implementing platooning is that it can help to improve the safety of the roads. Large trucks can be a danger on the roads, but this danger can be reduced by having multiple trucks driving in platoons since it reduces human error by relying on automated driving systems and V2V communication (Sivanandham and Gajanand, 2020). It also mitigates rear-endings because of the coordinated braking and acceleration. Another benefit with platooning is the reduced fuel consumption and lower emissions. Since the vehicles are communicating and connected with each other, it allows for short distances between them. That will reduce the air resistance and improve the fuel efficiency, mostly for the following trucks but also for the leading truck as well (Sivanandham and Gajanand, 2020). It will also lead to increased efficiency in road space usage, i.e. it helps maximize the usage of road infrastructure.

New road infrastructure designs may be necessary, as platooning could require adjustments to both the longitudinal and lateral capacity of roads (Sivanandham and Gajanand, 2020). To be able to implement a higher level of automation, say SAE Level 3-5, the vehicles may need to gather information from the infrastructure, which can make it necessary to further invest in technology and smart roads. Balador et al. (2022) discuss the advantages of platooning of electric vehicles in smart cities. Road usage can be made more efficient with optimized traffic flow and reduced congestion during peak times, improved road capacity utilization and better traffic management through V2I and V2V communication. Route optimization can therefore be enabled, lowering fuel consumption, emissions and congestion.

2.4.3 Operational Design Domain

According to the SAE (SAE, 2021), the operational design domain (ODD) for autonomous driving is the operating conditions which the vehicle is designed to operate under. This could be such as the environment, geography and time of the day. With the popularisation of services such as robo-taxi and vehicle autopilot, safety concerns regarding these inventions has been raised (Sun et al., 2022). The ODD is important for determining how safely an autonomous vehicle can perform under certain conditions, as it helps clearly define what a specific AV system is designed to handle. An ODD can, for example, describe the limitations related to road types, traffic conditions, and weather under which an autonomous vehicle is capable of operating. There is currently no framework that is accepted by both governments and automakers. Moreover, initiatives like ISO 34503:2023 (KÄLLA) and ASAM OpenODD are actively developing standardized approaches for expressing ODD constraints.

2.4.4 UNECE

The United Nations Economic Commission for Europe (UNECE) is one of five regional commissions of the United Nations (UNECE, 2025). It was established to promote economic integration and cooperation among its member countries. One of its primary objectives is to facilitate international trade and transport by establishing norms and standards through the definition of vehicle regulations. Today, UNECE lacks a clear definition of what an autonomous vehicle is, which makes the bureaucracy more difficult when deciding regulations for AVs.

The Unece has suggested a framework to the World Forum for harmonization of vehicle regulation by identifying safety and security principles for automated/autonomous vehicles of level three and higher (UENCE, 2021). To enable autonomous vehicles to improve freight transport, a framework is needed to ensure their safe and secure introduction onto the public roads. An autonomous vehicle should not cause any excessive risk to their environment. This means that within its Operational Design Domain (ODD), the vehicle should not be involved in traffic accidents resulting in injury or death, provided such incidents are reasonably foreseeable and preventable. The article continues by listing common principles that an autonomous vehicle should be able to do in order for it to be considered safe to operate. For instance, the vehicle should be able to detect when it is operating outside its ODD and manufacturers must demonstrate safety by applying a structured engineering process that ensures automated driving systems are rigorously tested, free from unreasonable safety risks, and compliant with applicable traffic laws and safety standards.

2.5 Smart roads

Smart roads is a name for modern transportation infrastructure aiming to improve traffic efficiency, safety and sustainability (Trubia et al., 2020). This can be done by integrating intelligent transport systems and digital devices to allow for seamless communication between vehicles, infrastructure and traffic management services. A smart road can be defined in different ways, and Trubia et al. (2020) present a general definition by explaining that such infrastructure combines digital devices and innovative materials to enable data to be exchanged. One of the core elements of smart roads is Vehicle-to-infrastructure communication (V2I) which enables vehicles to receive updates on road conditions and traffic patterns. This will help to make sure the right vehicle is on the right road, at the right time.

Pompigna and Mauro, 2022 outlines four innovative capabilities of smart roads, namely information interaction, self-awareness, self-adaption and energy harvesting. Information interaction refers to the previously mentioned concept of data exchange and will be the most relevant smart road capability for this report. Self-awareness is explained by Pompigna and Mauro, 2022 as a road that is able to monitor road conditions and traffic status in real-time with the help of sensors and cameras. This data can then be used the predict both when the road is in need of service and when traffic conditions are optimal. Self-adaptation means the road can adjust to circumstances on the road, such as variable speed limits and dynamic lane management. Lastly, energy-harvesting roads can produce renewable energy, such as solar power, to support sustainable infrastructure.

Trubia et al. (2020) discusses the need for smart roads due to the increased wear and tear of road pavements due to the growth of urbanization. They mention that forecasting predicts that 70% of the global population will be living in cities by 2050, which will lead to a larger number of circulating vehicles in these communities and road infrastructures will be exposed to increased wear and tear. Franzò et al. (2018) explain that weather conditions can be continuously monitored, allowing for quicker response measures, such as more efficient snow removal and improved management of severe weather events. Therefore, it will be easier to predict maintenance and increase the efficiency of maintenance services.

2.5.1 Dynamic Lane Management

Amirgholy et al. (2020) mention that different lane management approaches can help to optimize the traffic flow. The aim is to develop an optimal lane management strategy for traffic flows with a combination of human-driven vehicles and autonomous vehicles. This suggests that lane allocation may need to adapt to the fluctuating demand of different vehicle types, i.e. the optimal lane configuration will change as the proportion between human-driven and autonomous vehicles changes (Amirgholy et al., 2020). This would enable the network to accommodate the growing number of autonomous vehicles by dynamically allocating more lanes to AVs in areas or cities with higher AV adoption. Dedicated AV lanes can facilitate their integration while maximizing their advantages, such as platooning and reduced headway distances, increasing the overall throughput and efficiency on the road infrastructure. Amirgholy et al. (2020) explain that this solution could help mitigate the congestion during the transition phase, when human-driven vehicles are being gradually replaced by autonomous vehicles.

Amirgholy et al. (2020) also mentions how cooperative traffic control can enable dynamic adjustments to the lane usage based on real-time data gathering and V2I communication. Traffic congestion during different times of the day can vary a lot, and by collecting data, more informed decisions can be made to enhance the performance of the road infrastructure, and a solution to that could be dynamic lane allocation. Dynamic lane allocation therefore requires road infrastructure that can collect and communicate information to know the traffic conditions in real-time, including traffic volume, speed and weather conditions, for example (Amirgholy et al., 2020). It would also require a centralized control and decision-making system that could process the data and make the decisions on how to allocate the lanes, as well as physical or virtual devices that can indicate to the drivers and vehicles when changes in lanes are made.

2.5.2 Smart Roads In Europe

There are rules on top of national regulations and those of the EU that apply specifically to infrastructure-related technologies. Franzò et al. (2018) references a directive at the European level is the Directive 2010/40/UE1, which is in place to promote innovative technologies for road infrastructure, a so-called Intelligent Transportation System (ITS) that forms a ground for the European transportation system. The directive has an established framework with defined investment priorities, some of them being; optimal usage of data and information relevant to goods transport, homogeneity in the development, V2I, and ITS adoption to make streets safer and goods more secured.

All European countries should have access to comprehensive information on intermodal mobility services and real-time traffic systems (Franzò et al., 2018). Additionally, a standardized emergency call system (eCall) should be implemented. The directive also emphasizes the importance of prioritizing safe truck parking through enhanced information and reservation services.

2.5.3 Smart roads for autonomous vehicles

Mao et al. (2022) note that smart roads have yet to be widely implemented, existing primarily in experimental stages. Investments in smart roads are lacking because it is difficult to motivate the implementation before autonomous vehicles are properly introduced and have a high enough penetration on public roads. If autonomous vehicles fail to become a standardized mode of transportation, investments in smart roads may be viewed as wasted expenditures. Of course, some of the technologies and services provided with the help of smart roads can be utilized by normal vehicles as well, but the main area of application is for autonomous vehicles (Mao et al., 2022). On the other hand, autonomous vehicles need data and infrastructure communication to guarantee safety and reliability, creating a dilemma.

Autonomous vehicles will however not entirely depend on smart roads, meaning the implementation of AVs is not impossible without a smart road infrastructure in place. Mao et al. (2022) argue that road technology and design have always been one step behind vehicle development, and have been adapted when new technologies arise. In the early stages of AV development, such as SAE levels 0-3, smart roads, if implemented at all, would primarily serve to assist human-driven vehicles. Then, when AVs are more developed and reach higher SAE levels, smart roads will be adapted to serve AVs at SAE levels 0-3 and so on.

2.5.4 INFRAMIX

Over the years, a lot of research and initiatives have focused on autonomous vehicles and their functionality while overlooking the need to improve the infrastructure to adapt to these new types of vehicles. The infrastructure needs gradual adaptation to be prepared for the gradual introduction of autonomous vehicles (Lytrivis et al., 2018). Roads have longer lifetimes, 20-30 years, compared to 10 years for cars, which leads to mismatches in investments. INFRAMIX EU is a project that focuses on exploring the advancements in digital infrastructure and upgrades in physical infrastructure to be able to handle the introduction of AVs (Lytrivis et al., 2018).

Lytrivis et al. (2018) explain that the project INFRAMIX main objective is to improve both the physical and digital elements of the road infrastructure to make sure both conventional vehicles and AVs can coexist, i.e. a hybrid road infrastructure. Today, physical infrastructure is built to accommodate conventional vehicles with human drivers. Few projects are held to change that, but an example is CEDR's DRAGON project (Lytrivis et al., 2018).

INFRAMIX propose increased communication units at the side of the roads, CCTV for accident detection, and new development of visual and electronic signalling to inform both conventional vehicles and AVs. When it comes to digital road infrastructure, there are more initiatives in place. Two examples are HD maps and accurate localisation (lane level accuracy) (Lytrivis et al., 2018). These will form the basis of INFRAMIX to support vehicles with accurate positioning information, and dynamic information will come from both the traffic management center and from other vehicles (V2V). For the communication between the vehicles and infrastructure to work, a standardised way of communicating needs to be established, and INFRAMIX has the ambition to address the current gap in the communication of AVs and infrastructure/traffic management centers (Lytrivis et al., 2018).

2.5.5 Green wave

Another concept that can reduce emissions is "The Green Wave ".The Green Wave is a traffic management concept designed to synchronize traffic signals in such a way that vehicles travelling at a specific speed can pass through multiple intersections without stopping (SWARCO, 2025). The purpose of a green wave is to minimize stop-and-go for heavier vehicles, which causes unwanted emissions. However, there are challenges in implementing such a system, as all traffic lights and road users have to be digitally connected. Road users and pedestrians have to move uniformly. Traffic light distance and speed limits have to be coordinated to fit the time interval.

2.6 Smart parking

Smart parking is a digitally enhanced parking system that optimizes parking management by leveraging technologies such as IoT, real-time data and automation (Rocco et al., 2023). The idea is to guide drivers to available parking spaces more efficiently by reducing their search time and thereby also decrease congestion and fuel usage. By using sensors and IoT technology, real-time data is used to provide updates on parking availability to drivers via mobile apps or digital displays (Khalid et al., 2021). Automated solutions such as automated payment further enhance the convenience for drivers.

When implementing these technologies, traffic congestion can be reduced by minimizing unnecessary vehicle movement, while lowering emissions which contributes to sustainability. The driving experience is also enhanced since streamlining the parking experience reduces time and stress for the driver (Rocco et al., 2023). Smart parking can be integrated into other smart city infrastructures such as electric vehicle charging stations and traffic management networks to help drivers find charging stations and prevent bottlenecks by analyzing the traffic flow (Khalid et al., 2021).

2.6.1 Intelligent Truck Parking (ITP)

Directive 2010/40/EU specifies the priorities in the deployment of an intelligent transport system in the field of road transport (EU, 2023). Providing safe and secure parking is a key component of the list of priorities. The directive addresses the need for smart parking by highlighting that information regarding available parking space at secure rest areas are needed for heavy goods vehicles. To achieve this, ITS technology must be integrated into both the vehicles and the parking sites. According to (Sochor and Mbiydzenyuy, 2013), the development of parking infrastructure is crucial, as 44 percent of all journeys in international road freight transport require at least one stop to comply with the working time regulations. The concept of connecting truck drivers to vacant parking spaces are called Intelligent Truck Parking (ITP). ITP collects and analyse data to provide truck drivers with real-time information, which would allow them to easily locate unoccupied parking areas.

The problem of finding a safe parking space is noticeable among truck drivers. According to Sochor and Mbiydzenyuy (2013), a survey investigating the difficulty of finding a parking space revealed that a significant percentage of truck drivers struggled to find parking between 4 p.m. to 5 a.m while another survey showed that less than 50 percent of truck stops operated overcapacity between 7 p.m. to 5 a.m. This suggests that the problem is to some degree artificial, since rest stops are not being fully utilized. The issue arises from a lack of information and could therefore be partially resolved by implementing ITP. Due to the difficulty of finding a suitable parking space, truck drivers may resort to parking in unauthorized areas. This is both dangerous for the truck operator and other road users.

Sochor and Mbiydzenyuy (2013) states that heavy goods vehicles were involved in 13 percent of all accidents in the EU in 2011, with 2 percent of those accidents being caused by illegal parking. The risk of cargo theft increases when stopping at an unsecured truck parking area, as 27 percent of all cargo thefts occur in such locations. The difficulty in finding a suitable place to stop may lead drivers to continue driving beyond the legal working hours (Vital et al., 2021). A survey conducted by the AAA Foundation for Traffic Safety revealed that 21 percent of all road accidents resulting in a fatality were caused by drivers being tired. While this data was not specific to trucks, it highlights the potential dangers that an exhausted driver can pose to their surroundings. The environment is also impacted by the inefficient search for a rest stop, as trucks are required to drive additional distances in order to find a suitable location. This unnecessary travel contributes to increased fuel consumption and emissions. Furthermore, if drivers are unable to find a stop with the necessary infrastructure to plug the vehicle into the grid, the truck must idle, leading to increased emissions. The trucking industry is significantly impacted by fuel prices, and a study conducted by the University of California revealed that 8.7 percent of the fuel consumption in long-haul trucks is attributed to idling.

2.6.2 Smart Parking

The Federal Motor Carrier Safety Administration (Lopez-Jacobs and Gannett Fleming, 2018) also stated that driver fatigue is a significant factor in road safety risks. They suggest that one of the most important actions to combat this is by making it easier for drivers to locate parking spaces. The FMCSA Smart Parking project was conducted in Tennessee and the concept required data regarding number and class of vehicle entering and exiting the parking space. By having access to this data and the parking areas capacity, the system could calculate the number of available parking spaces. The count was conducted by a scanner that identified when vehicles enter and exit the parking area. The scanner also measured the vehicle in two dimensions. A Doppler radio capable of determining the vehicle's length was also installed. The information from the scanner and doppler radio was then used to determine the vehicles classification. The system recognized 4 vehicle classification, Small (length: 0-30 feet), larger (length: 30-90 feet), Oversized (length: larger than 90 feet) and "Bobtails" (tractors without trailers).

Cameras were also placed in strategic locations to monitor the parking area situation (Lopez-Jacobs and Gannett Fleming, 2018). The cameras were used to verify that the system accurately detects the number of vehicles and, if not, to assist in its calibration. The information was distributed to its users through dynamic message signs (DMSs), SmartPark web site and SmartPark mobile application. DMS is a physical sign alongside the road that shows the current parking situation and is updated every minute. The new applications were further used to enable parking reservation. Reservations could be made through the website or mobile app. The program also introduced an interactive voice response phone system, allowing drivers without an internet connection to make reservations. The number of reservable spaces was limited to five and they were clearly marked to distinguish them from the non-reservable spaces. The program also allowed users to cancel a reservation, end a reservation early or report a failed reservation. Drivers were asked to check in upon arrival to ensure a successful reservation in the system.

There are multiple companies that work with enhancing the security for Truck drivers while parking. TRAVIS is one of them and they offer a platform where users can find an adequately safe parking area, suited to their needs (TRAVIS, 2025). The company provides access to more than 600 locations in Europe. Through the website, drivers can apply filters based on their specific needs. Once a filter is selected, only parking sites that meet those criteria are displayed on the map. Available filters include CCTV, security guards, showers, and restaurants. Drivers can then reserve a parking space at their preferred location. The platform improves route optimization by minimizing the parking space search time for drivers. Travis offers a map function that lets you input your current location and destination, displaying available parking spaces with your selected filters along the route for easier planning.

Bosch secure truck parking has a similar platform where Truck drivers are able to reserve a parking space based on desired needs (Bosch, 2025). The available filters are mostly the same as for Travis, however, there are some information attributes that differ. For instance, Bosh has additional filters such as extra long trucks and fuel type availability. Bosch also provides pictures from the location. The difference in information attributes are displayed in appendix A.

2.6.3 Alternative fuels

China, the world's largest electric car market, has also emerged as a dominant force in electric truck adoption, accounting for 91 percent of global electric truck sales in 2022 (Hongyang et al., 2023). In 2020, the Chinese national government encouraged battery swapping technology and by 2022, 49.5 percent of all electric trucks sold in China were equipped for battery swapping. Swap-capable trucks usually have a range of 100 km and are primarily used for short-haul operations at ports, mining sites, and in urban logistics. Swapping a battery is estimated to take 3–6 minutes which can be compared to DC fast charging, which can take up to 40 minutes to recharge an electric truck. There are however obstacles as batteries may differ in size, shape and how they are connected to the vehicle. The technology lacks universality, as not all trucks can swap batteries at any station. Additionally, the high cost of a battery swapping station, estimated at around 1 million dollars presents a significant financial challenge.

IRU (2024) highlights the importance of exploring efficient alternative fuels to reduce reliance on fossil fuels. Battery swapping is mentioned as one such solution. The emerging technology offers several benefits such as faster charging, lower acquisition cost and decreased charging space requirements. The lower acquisition cost is due to the new business model where the battery is charged on a pay-per-use basis. The article emphasizes that this business model will play a crucial role in supporting electric fleets, as it reduces the initial costs for fleet operators. Furthermore, there is a strong possibility that this technology will reduce the total cost of ownership for the fleet operators, making it an even more attractive alternative.

2.7 High Capacity Transport

High capacity transport (HCT) refers to vehicles that exceed standard dimensions in term of length, weight, or both (Ye et al., 2014). Vehicles in this category are designed to increase transport efficiency by improving load capacity and reducing energy consumption. Since HCT vehicles can carry a larger load, they require less energy per ton-kilometer which leads to lower fuel consumption and reduced emissions (Asp and Wandel, 2023). Larger load capacity lead to fewer trips needed, reducing the demand for drivers.

Ye et al. (2014) also mention how HCT can lead to lower traffic congestion and infrastructure wear, making the freight transport more sustainable and cost-effective since less trips are required to move the same amount of goods. Lower traffic congestion mean a lower risk of accidents, i.e. enhanced road safety. When it comes to reduced infrastructure wear, Asp and Wandel (2023) mention how HCT vehicles have more axles to distribute the load on which leads to less damages to the road.

While HCT comes with significant advantages, some challenges needs to be addressed to ensure successful implementation. There may be limitations regarding infrastructure, such as bridges that does not support the increased weight, or turning lanes where longer vehicles cannot properly turn. Asp and Wandel (2023) mention that the problem with turning lanes can be mitigated with steerable axles which improve maneuverability and reduce turning space requirements.

2.7.1 HCT in Sweden

In 2018, the Swedish Transport Administration was tasked by the government to assess the feasibility of allowing 34.5 meter-long vehicles to operate on Swedish roads (Trafikverket, 2024). Before conducting a detailed analysis, Trafikverket identified several criteria that needed to be met. These criteria included specifications related to road width, separation between vulnerable road users, overtaking opportunities, vision, and more. Roads were subsequently categorized into three groups: motorways, other meeting-free roads, and non-meeting roads. Each category was analysed based on its unique conditions. A total of 9000 kilometres of national roads were identified as meeting these requirements. Additionally, areas such as ports, combined terminals, distribution and truck centres, and larger industrial zones were recognized as key locations that needed to be considered in order to make the introduction of HCTs worthwhile. Key areas located within 10 km of the main road network are considered to be in connection to it. Some of the roads that connect these areas to the national roads are owned and operated by municipalities meaning that they also have to make an effort to enable HCT. Trafikverket has established the following lane width, road shoulder width and speed criteria for allowing 34.5-meter-long trucks to operate. GCM is an acronym for pedestrian, bicycle and motorized bicycle (Gång, Cykel och Moped) and is considered unprotected road users.

Table 2.1: Lane width, road shoulder width and speed criteria for 34.5-meter-long trucks : Trafikverket, 2024

	Among Traffic			Separate GCM		
Speed (Km/h)	40/50	60/70	80	40/50	60/70	80
Lane Width (m)	3,25	3,5	3,5	3,25	3,25	3,5
Road shoulder width (m)	0,25	0,5	0,75	0–0,25	0–0,25	0,25

BK4 is the highest load-bearing classification in Sweden, allowing vehicles to carry up to 74 metric tons (Trafikverket, 2021b source). Trafikverket estimated that 70-80 percent of the most important national roads will be BK4 compatible by 2029. In 2021, 10 percent of the national roads and 800 bridges required reinforcement to accommodate the increased load. Generally, Trafikverket has said that a bridge should be able to hold up an axle/ bogie load of 12/21. The "Axle/Bogie load 12/21" means that the maximum load a single axle can transfer to the road is 12 tons, and the maximum load a bogie can transfer to the road is 21 tons (Transportstyrelsen, 2023) . A bogie refers to a configuration where two axles are spaced less than 2 meters apart.

More specifically, Trafikverkets has analysed the following bridge constructions and provide recommendations based on the assumption that everything else is in order (Trafikverket, 2021b).

Table 2.2: Bridge criteria for BK4 compatibility: Trafikverket, 2021b

Type of bridge	Span criteria	Variation depending on a bogie load (tons)
Valve bridges, pipe bridges, and simply supported slab and beam bridges	Span is at most 6.0 - 7.2 m	10-20
Continuous slab and beam bridges	Total span is at most 6.0 - 7.2 m	16-30
Single-span beam and slab frames	Span is at most 9.6 - 11.5 m	24-30
Other bridges	-	axle/bogie load of 13/21

Furthermore, Trafikverket estimates that heavily and moderately trafficked sections of the European roads, as well as major national and county roads, will only be marginally affected by allowing BK4 vehicles to operate (Trafikverket, 2021b). They even suggest that road wear may decrease due to a reduced need for trucks. These roads are also constructed to be able to stand larger loads. The roads most affected will be those with weak construction, thin pavement layers, or poor load-bearing capacity, leading to increased wear. These roads are typically part of the low-traffic networks and, to a lesser extent, the medium-traffic networks. If the pavement layer is thinner than 15-20 cm, the risk of wear increases.

2.7.2 Performance Based Standard

Performance-Based Standards (PBS) is a system used in Australia to assess whether a vehicle is safe to operate based on safety criteria and infrastructure criterias (NHVR, 2022). The purpose of the system is to improve safety while encouraging innovation, as vehicle designers have greater flexibility in the design process. The PBS scheme aims to enable the heavy vehicle industry to align the appropriate vehicle with the specific task (NHVR, 2019). The program is a strategy to meet the future demand for land freight vehicles by enabling fewer vehicles to transport the same amount of goods. PBS has a positive economic impact both for hauliers, by reducing the cost per transport unit, and for national road authorities, by minimizing infrastructure wear and maintenance costs. This also benefits the environment, as fewer kilometres traveled result in lower emissions. The increased load has raised concerns about pavement wear, however, PBS vehicles are designed to mitigate this by distributing the weight across more axle groups and longer combinations. The PBS vehicle fleet is significantly younger than the overall heavy vehicle fleet. PBS vehicles are involved in 46 percent fewer major crashes, which can be attributed to their compliance with higher safety standards and the use of the latest technology.

The PBS network classification guidelines categorize road networks into four levels

(NTC, 2007). A Level 1 vehicle has access to all of the other levels while a level 4 vehicle only has access to level 4 road networks. Each jurisdiction must classify the road network to identify weak links and prioritize necessary roadwork. The classification is crucial for land-use planning as vehicles can plan their trips.

2.8 Societal, ethical and ecological aspects

The following section addresses the societal, ethical, and ecological aspects covered in this report.

Societal
Intelligent Access (IA) can contribute to safer roads by regulating which vehicles can access certain roads and at certain times, which can reduce congestion and accident risks. It can also lead to economic benefits since more efficient logistics can reduce costs for both transportation companies but also for the government in terms of reduced need for infrastructure maintenance. One downside when it comes to societal aspects could be that the demand for drivers may reduce with the implementation of autonomous driving, HCT and better route planning.

Ethical
Fully autonomous vehicles have the potential to decrease road accidents and increase safety (reuters). However, accidents are still likely to occur, raising an ethical dilemma: who should be held responsible for a malfunctioning vehicle? There are several suggestions, as owners, manufacturers, software providers, and hardware providers may all be considered responsible when an accident occurs. Could specific individuals at these companies be held personally liable if they were responsible for the component or product that caused the accident? Laws must be established to address this issue before autonomous vehicles can be fully integrated into society. IA requires data from participants which could be sensitive. IA providers must securely store this data and ensure it is not used for their own benefit or that of others.

Ecological
By implementing Intelligent Access (IA), freight logistics can be optimized through advanced route planning and the use of High-Capacity Transport (HCT). This allows freight vehicles to take the most efficient routes, reducing unnecessary mileage and minimizing traffic congestion. As a result, fuel consumption is lowered which leads to better fuel efficiency and a substantial reduction in greenhouse gas emissions. Additionally, by ensuring that the right vehicle is on the right road at the right time, IA contributes to a more balanced distribution of freight traffic, further enhancing sustainability and environmental benefits by reducing traffic congestion. With better route planning and usage of HCT, there will be less wear and tear on roads which extends the road life and decreases the need for maintenance. Fewer road work also lead to less traffic disruption which benefits both commercial and personal transport. The implementation of smart parking and smart roads may also necessitate extensive use of cameras, sensors, and other data-exchange technologies

to facilitate Intelligent Access (IA). However, this increased infrastructure could lead to higher energy consumption.

3

Methodology

This chapter outlines the methodology used for this thesis. The first section explains what type of research approach has been used throughout the report. The following section describes the process of conducting the literature review and its contribution to the report. This is followed by the presentation of the empirical data collection, and finally, the methodology for the analysis is outlined.

3.1 Research Approach

This thesis is conducted using a qualitative research method, integrating a literature review with empirical data collection, which culminates in an analysis and a discussion. According to Hammarberg et al. (2016), qualitative studies are appropriate when investigating processes and analysing policies, regulations and conceptual models. They are used to answer questions about experience, meaning and perspective, often from more than one standpoint. Hammarberg et al. (2016) explains that qualitative studies involve the systematic collection, organization, description and interpretation of textual, verbal or visual data.

Since this report's research questions cover information regarding different aspects connected to smart roads, smart parking , autonomous driving, and high-capacity transport, a qualitative approach is deemed more suitable than a quantitative one. This data is not suited for counting or measurement, making it incompatible with quantitative studies. The effort to synchronize these aspects and evaluate their contribution to contemporary and future Intelligent Access requires exploring the interactions between various stakeholders and technologies, a process that benefits from qualitative insights rather than only numerical data. The qualitative research method allows for a more in-depth investigation of how these aspects work and interact with each other, helps analyse different perspectives of what type of aspects and information attributes are present today, and contributes to discussions on what will be present or useful in the future. To understand the meaning of Intelligent Access would also require the knowledge of experts in different areas to understand its practical implications and perceived value, and this information is better achieved through discussion rather than quantitative studies as discussed by Hammarberg et al. (2016).

3.2 Literature Review

A literature review was conducted to establish an academic context for the research and highlight aspects and theories based on prior studies. According to Knopf (2006), a literature review is performed to uncover gaps in existing research, provide new perspectives for the report, and ensure that the study builds on previous work rather than duplicating existing findings. It also helps to provide a foundation for the empirical research in later phases of the study.

Research question one covers characteristics regarding areas such as autonomous driving, smart roads, smart parking, and HCT. All of these concepts already exist and have been studied for a while, providing plentiful data and resources available for review. A literature review made it possible to analyse these prior studies, define core concepts and characteristics and therefore answer research question one. Research question two addresses contemporary and future aspects for the same areas, information that could also be found in the literature. Therefore, a literature review was deemed a relevant research method to answer some of this report's research questions.

The data gathered in the literature review was not only used to answer research question one and partially answer research question two. As mentioned above, Knopf (2006) explained that literature reviews act as a foundation for the empirical research, an approach also adopted in this report. It made sure the answers to the research questions were grounded in existing knowledge, and that the empirical data collection could be performed with relevant background knowledge to be able to justify and contextualize findings.

The information for the literature review was found using applicable search words such as *autonomous driving*, *smart roads*, *smart parking*, and *HCT*. The main databases used to find relevant sources were Google Scholar, Chalmers Library, and Scopus. Web sources were also used to gather information about autonomous vehicles in ports, smart parking solutions, and existing frameworks for truck parking within Europe.

3.3 Empirical Data Collection

The empirical data collection consisted of interviews with experts on the most relevant topics, and they were held to gain deeper insights to help answer the report's research questions. The interviews provided valuable information and perspectives that would have been difficult to obtain solely through a literature review, particularly regarding future aspects and the implementation of Intelligent Access. Participants were selected based on their expertise in Intelligent Access, autonomous transport, and logistics. They included professionals from industry and academia. In total, 10 experts were interviewed, representing diverse perspectives on the topic.

The interviews were conducted using a semi-structured approach, which is a qualitative method of data collection (Adeoye-Olatunde and Olenik, 2021). The method involves an interview guide with open-ended questions which serves to provide structure and focus to the interview while still allowing for follow-up questions, creating some flexibility for the interviewers to explore ideas that might emerge during the conversation. The interview guide was developed by organizing questions around the research questions, ensuring that both the interviews and responses clearly aligned with the purpose of the report. The interview guide can be seen in Appendix B. According to Adeoye-Olatunde and Olenik (2021), semi-structured interviews are appropriate when the goal is to gain an in-depth understanding of a phenomenon by exploring participants' narratives and perspectives. It is also a preferred data collection method when the objective is to deeply understand a participant's unique perspective, rather than obtaining a generalized overview of the topic.

The interviews were carried out via video calls, facilitating easier scheduling and eliminating the need for travel, thereby increasing convenience and efficiency. This was particularly useful as the interviewees were located in different parts of the world. Video calls also allowed for easy recording and transcription of interviews, simplifying the analysis of the collected material afterwards. The language of the interviews was either English or Swedish, depending on the nationality of the interviewee. Each interview lasted approximately one hour, providing sufficient time to address all questions thoroughly without delving into unnecessary details.

Ethical considerations are fundamental in research involving human participants, to make sure that their rights and privacy are protected. To ensure ethical research practices, participants were informed about the report's objectives and aim, and they were asked for consent to be both recorded and transcribed before the interview started. Prior to the interviews, participants received the interview guide in advance which allowed them to be somewhat prepared to provide comprehensive responses. Data anonymization was applied where necessary to ensure no personally identifiable information was included in the final report.

3.4 Analysis and Discussion

The analysis is based on a use-case where a road haulier travels with either an HCT or an AV from one city to another, reaching a port or a terminal to unload the truck. A matrix has been developed to categorize this use-case into relevant areas, specifically: road hauliers, smart roads for highways and cities, smart parking, and terminals and ports. The aspects, which means technologies, concepts, and frameworks, have been assigned to the specific categories based on their perceived ability to enhance Intelligent Access within those areas. It also considers whether the vehicle is an HCT or an AV, placing the aspects in the row where it is deemed appropriate.

The analysis considers the use-case with time frames of 0–1 year and 5–10 years in mind. The aspects can be assigned to multiple categories if they are believed to enhance Intelligent Access in each of the selected areas. An estimate has been made regarding when it is feasible to implement and utilize the aspects, considering both short-term (0–1 year) and long-term (5–10 years) time frames. The analysis matrix has been developed to address the lack of a holistic perspective when considering autonomous driving, high capacity transport, smart parking, smart roads within road freight and port- and terminal logistics in relation to Intelligent Access. The analysis matrix therefore considers the entire journey of a high-capacity transport vehicle or autonomous vehicle to a port or terminal located within or near an urban area.

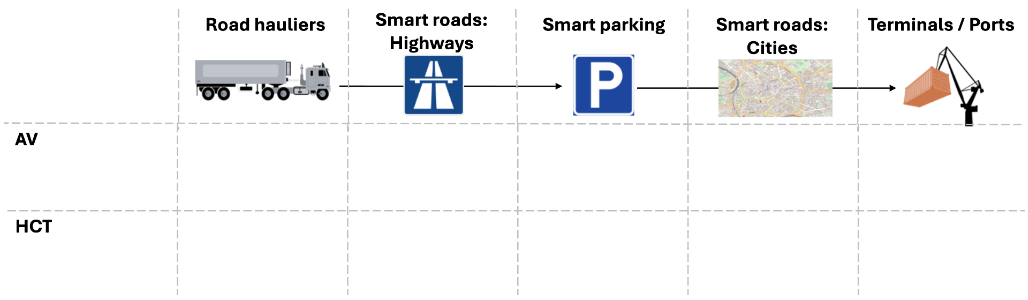

Figure 3.1: Analysis matrix

The discussion has been conducted in a similar manner to the analysis. The potential benefits of each aspect, when incorporated into Intelligent Access, have been considered across short-term (0–1 year) and long-term (5–10 years) time frames. Moreover, just like in the analysis, both HCT and AV is considered separately. The discussion framework have been illustrated with a matrix, displaying the different factors which were considered as areas where IA could have a positive impact, according to CEDR (2023). Some adjustments have been made to CEDR's list of potential Intelligent Access benefits as *controlled introduction of high capacity vehicles/ Autonomous vehicles* have been added and *Streamlined Cross-Border Transport* has been changed to *Improved efficiency in ports and terminals.* Modifications have been made to better align with the potential benefits that Intelligent Access can offer in the context of this thesis.

Most of the factors are self-explained in the matrix. However, some of the factors that have been deemed less obvious is explained down below. The

IA Factors	Better use of existing infrastructure with traffic management based on time and place;	Less degradation of road infrastructure through improved management of weight, speed and routing of heavy vehicles;	Realizing climate objectives by reducing congestion and prioritizing climate-friendly vehicles;	Increasing road safety through, for example, less overloading or improved insight into where safety incidents arise on the road network;	Creation of a level playing field between different haulers/carriers, improving compliance by haulers/carriers with regulations as set out by NRAs;	Improved control of the transport of abnormal loads and dangerous goods;	Controlled introduction of High Capacity Vehicles/ Autonomous Vehicles;	Improved efficiency in ports and terminals;
AV								
HCT								

Figure 3.2: IA framework matrix

Table 3.1: Table explaining less obvious IA factors

Factor	**Explanation**
Creation of a level playing field	Currently, trucks who comply with the law are in disadvantage to does who do not. Therefore, it is important to ensure that law-abiding drivers are not discouraged from continuing their compliance by penalizing those who do not follow the rules.
Improved control of the transport of abnormal loads and dangerous goods	Abnormal loads and dangerous goods pose a significant risk of causing severe damage to their surroundings. Maintaining control over the routes taken by these types of loads and goods is essential to reduce the risk of severe consequences in the event of an accident
Controlled introduction of High Capacity Vehicles /Autonomous Vehicles	High capacity Transport vehicles and autonomous vehicles are restricted from accessing certain roads, as they may pose safety risks to both infrastructure and the surrounding environment. From a regulatory standpoint, some form of control is needed before granting these vehicles road access.

4

Empirical Findings

This chapter presents the empirical findings gathered from the interviews. The interviews were semi-structured and followed the interview guide which can be seen under Appendix B. The experts had experience across a broad range of different fields. The information obtained from the interviews was essential to complement the findings from the literature study.

4.1 Experts

The expert's answers have been summarized under this section. The information have been categorised into 4 parts, *contemporary advancements*, *future advancements*, *information attributes*, and *challenges with implementing IA*. The first category explore what technologies and concepts that exists and can be implemented right now while the second focuses on future developments that may have the potential to enhance IA within 5 - 10 years. The third category aggregates information that the expert believes are of great importance to enable and improve IA. In the final category, the experts offer their insights on the key obstacles that must be addressed to successfully implement IA.

4.1.1 Expert 1

Title: General Manager at an NRA

Areas of experience: IA & HCT

Contemporary advancements

One of the core concepts of the original conception of IA in Australia was that the system would trigger an alert and provide a digital report whenever a vehicle operated outside of its condition of access. The report would then be used for compliance purposes against the transport operator. Since then, the concept has evolved both in terms of policy and technology. From the policy perspective, broader use cases have been identified as an unintended benefit of IA is that the vehicle has to be monitored at all times in order to determine if it complies with regulations. According to the interviewee, this information has been more valuable than the compliance aspect, as heavily trafficked roads can be identified and investments in road networks can be prioritized accordingly. The Australian IA program includes a well-defined incentive structure that encourages transport operators to share their data.

The interviewee commented on PBS and explained that PBS and IA came from the same thinking during the late 90s-early 2000s.

> "So that's worth mentioning, because those two reforms go hand in hand, and you know the intelligent access programme is all about ensuring the right truck is on the right road, PBS is all about making sure the best-performing truck is on the right road“

The interviewee was asked whether any IA frameworks existed apart from the Australian one.

> "We have looked for similar frameworks. We haven't found something that's the equivalent of what we've done in Australia"

The interviewee said that a distinctive feature of the Australian IA program is that it has encouraged providers to operate within the framework. The interviewee compared the Australian IAP program to the EU's procurement of the tachograph, noting that the EU chose to procure the technology directly from a provider rather than establishing an open framework, like the IAP, that would have allowed the market to develop the best possible solution within defined parameters. This has created a monopoly-like situation in which one provider has a large share of the total market. At the beginning of the IAP, there were five providers, and now it is about 20. They all meet the road authorities' criteria but they do it in different ways, which encourages competition and innovation. New Zealand has something similar where they monitor the vehicles and charge them based on their road use. The interviewee believes that this is a hurdle for companies to enter the market as they also have to provide invoicing.

Future advancements

Previously, a “black box” was fitted into the vehicle by a third party who also provided the IA service. More recently, vehicle manufacturers have been considering whether they themselves should provide the technology which would disrupt the current market. The interviewee continued by stating that vehicle manufacturers often have telematic systems already built into their vehicles. However, they are reluctant to use this technology for regulatory purposes. Their mission is to improve the truck for the vehicle owner, which may conflict with the installation of technology intended for compliance. If OEMs reconsider their approach and embrace IA, significant opportunities could emerge. Data such as vehicle mass, loading, emission, vehicle configuration, harsh braking and steering could complement location data. For example, if many drivers brake harshly at a certain road segment, authorities may assess whether safety improvements are needed.

Currently, road usage is indirectly charged through fuel taxes collected at the gas pump. However, as electric and more fuel-efficient vehicles become increasingly common, this source of government revenue is expected to decline. This presents a challenge, as road usage, and the resulting wear and tear, will persist. The interviewee believes that within the next 5 to 10 years, Intelligent Access (IA) will likely be used to collect road-use charges based on metrics such as miles driven.

The interviewee believes that the thinking around IA and autonomous vehicles will converge.

> "Some of the concepts that are coming out of the connected and automated vehicle space, mirror some of the concepts of Intelligent Access. Particularly around having a standardisation around communication protocols so that vehicles can talk to each other and notice other vehicles and roadside infrastructure."

Connected and automated vehicles are beginning to incorporate restriction frameworks similar to those used in the Intelligent Access program, including geofencing and time-based travel limitations. While the two areas have not yet fully integrated, there is strong alignment, and convergence between stakeholders and technology providers is likely. The interviewee argued that autonomous vehicles have not yet emerged primarily due to the absence of a national framework. Currently, different regions have varying regulations and requirements, which pose a challenge from a commercial perspective.

Information attributes

The interviewee described some insights that can be derived from position data:

- Timestamp data- date, time and location data, still most important
- Where most travels occur
- Time of the day movements
- Origin and destination analysis
- Where rest areas need to be located, i.e, where vehicles are stopping at the moment. Are they just stopping on the side of the road, or are they stopping at a designated rest area?

- Identify where there is a high propensity for overspeed

Important information attributes according to the interviewee:

- Loading data and weighing data
- Axle mass of vehicles is important for HCT
- Trifecta (information for jurisdiction)- Location, mass and configuration. This data is being used by the Australian road agency to prioritize infrastructure projects

Future Important information attributes according to the interviewee:

- Harsh braking might be the next important information which might be harder to get as some vehicle manufacturers don't want to collaborate with a third party.
- Mass location
- Distance-based charging
- Pricing

Challenges with implementing IA

The interviewee believes that the biggest challenge regarding the introduction of IA is people. Governments are too focused on the technology rather than providing the market with a framework to operate within. There also needs to be a value proposition for both the transport and technology sectors, as well as for the government.

> "I think the government needs to, through a framework, give the right signals to the marketplace, and the marketplace will respond. And if you've read Adam Smith, the economist, he refers to the invisible hand, to let the market do what it does well. But for a market to function, it needs some rules. You need a framework, you need a common understanding of how things work. That's what the Intelligent Access framework does. It's a common set of rules and market requirements that are understood by everyone, and everyone plays by the same rules."

4.1.2 Expert 2

Title: Professor emeritus in engineering and logistics

Areas of experience: IA & HCT

Contemporary advancements

The interviewee focused mainly on the future advancements of the areas within their expertise, and not so much on the contemporary advancements.

Future advancements

The interviewee mentioned some different future use cases and new types of technologies. For HCT and smart roads, one idea was to introduce specific roads for heavy vehicles that could be a solution for the introduction of heavier trucks in Europe. These roads could relieve other roads from heavy vehicle congestion, and allow for much longer and heavier road transport. Another idea the interviewee had connected to HCT was a way to incentivise both HCT and electric trucks in Europe. The idea was to make it possible to drive two trailers in all of Europe, but only on the condition that you use an electric truck. Since they are around twice as expensive as normal trucks, and in need of charging infrastructures, the initial costs would be high. But these costs would be covered by the extra income earned from being able to drive more goods, which would make the investment lucrative in the future. It would facilitate the expansion of charging infrastructure, reduce road emissions from heavy vehicles, and increase the number of HCTs.

As for automated vehicles, the interviewee sees a future where vehicles are not only self-driving, but also have an AI bot to work as a "driver". AI bots will be much more intelligent than just a self-driving vehicle. These AI bots will be integrated into every truck as well as infrastructure like ports and terminals, interconnected similarly to the Internet of Things. By communicating with each other, they can handle situations that do not occur very often.

The interviewee also discussed a new IA use case: communication between trucks and loading vehicles during the loading of heavy materials. Effective communication ensures that trucks are loaded correctly, with optimal placement of materials to maintain proper axle weights and comply with weight restrictions. Sensors on excavators can transmit weight information directly to trucks, enabling accurate monitoring of the total load weight. The future of smart parking was also mentioned, and the need for charging stations at the parking lots was highlighted by the interviewee. As the electric trucks grow in number, the availability of charging stations becomes crucial. It will also be important, if not even necessary, to be able to reserve charging spots in advance to make sure a longer distance can be driven without the risk of running out of energy.

Information attributes

The interviewee explained how certifications are essential to make sure the equipment needed for information gathering is properly calibrated, so that the shared information can be trusted. Certifications could be seen as an important information attribute, as they enhance the credibility of the information shared. Without accurate information, the IA system would be unusable.

An information attribute connected to smart parking that was discussed by the interviewee was the importance of being able to reserve a charging spot when driving an electric truck. As mentioned earlier, the interviewee emphasizes that reserving charging spots will become nearly essential, allowing vehicles to confidently undertake longer routes without the risk of lacking charging opportunities along the way. With reservable charging spots, the route can be planned more efficiently.

Challenges with implementing IA

According to the interviewee, successful IA implementation requires addressing different stakeholders' interests in sharing information. Many stakeholders may be resistant to sharing their information on matters such as speed and location, which makes it important to provide meaningful incentives to encourage compliance with regulations. Today it is too easy for hauliers to cheat, and according to the interviewee, around 40% of drivers load their vehicles too heavy and almost 100% drive too fast.

> “Everyone goes 89 km/h instead of 80 km/h”.

There have to be incentives to play by the rules instead of cheating. The interviewee also addressed the perspective of authorities, such as Transportstyrelsen and the police, highlighting their reluctance to implement new regulations without compensation. For instance, the interviewee stated,

> "The police don't want to monitor every speeding offender unless they are paid to do so."

For IA to be implemented and accepted, every stakeholder's interest needs to be examined and taken into consideration when designing a system of rules and regulations. The whole system has to be coordinated from end to end, including every stakeholder and their perspective.

4.1.3 Expert 3

Title: Senior Research Project Manager

Areas of experience: HCT

Contemporary advancements

During winter in the north of Sweden, certain roads can support heavier loads due to the stabilizing effect of the cold. These roads are known as frozen load-bearing roads. However, despite the road's increased capacity, the challenges associated with heavy vehicles on bridges remain unchanged. The interviewee explains that they are working on projects designed to address this issue by using geofencing to reduce speed on certain bridges and in designated zones, describing this approach as a form of intelligent access. The technology is already widely used for buses to regulate speed in cities, as well as on sensitive bypasses and near bus stops. The technology has not been adopted for trucks due to the absence of a formal requirement.

Additionally, buses have better conditions for geofencing than trucks because buses follow the same routes with the same vehicles every day. A project involving hybrid buses employed geofencing to regulate speed in specific zones and to transition from the combustion engine to battery power. The program was well received by the drivers, as it eliminated the possibility of speeding up in case of delays. Geofencing was also implemented before a bridge in Gothenburg was set to be demolished. A designated zone was established on the bridge, where drivers were restricted to a speed of 15 km/h. The interviewee believes that High Capacity Transport (HCT) will significantly reduce emissions and improve road safety by decreasing the number of vehicles on the road. Additionally, the interviewee mentioned the 'Green Wave' concept, where traffic lights communicate with HCTs to minimize stops, as a significant amount of emissions are generated when large trucks have to accelerate from a standstill.

The interviewee states that while onboard truck scales are designed to measure axle loads, they are rarely calibrated due to the high cost and effort required. Additionally, there is a lack of regulatory frameworks governing axle load distribution. As a result, truck drivers do their best to load cargo evenly and rely on guesswork, hoping their axle load remains within legal limits.

Future advancements

The interviewee believes that trucks may become larger in the future and refers to Finland, where heavier-loaded trucks are already permitted to operate.

Information attributes

The interviewee believes that axle load bearing is the most important metric to look at to combat road tear since the total weight is only important for bridges.

Challenges with implementing IA

The interviewee described that initiatives to track vehicles by GPS can be very difficult to implement due to GDPR. All drivers who are going to operate the truck will have to give their permission to be tracked. The issue is often sensitive for drivers, as they are reluctant to be tracked and it is also a union issue, as they have a say in the decision. While the technology exists, its implementation is hindered by the regulatory framework surrounding personal data, making it difficult to implement. Furthermore, the interviewee believes that the greatest challenge in implementing Intelligent Access (IA) will be establishing a viable business model. This could involve creating clear economic incentives for those who adopt the system or introducing regulatory frameworks that make its implementation mandatory.

4.1.4 Expert 4

Title: Digitalisation Advisor within the logistics industry

Areas of experience: AV & IA

Contemporary advancements

The operational handling of a truck with a human driver at a port may differ from that of a self-driving truck, but from a logistical point of view, there is not much difference between a truck that is driven by a human and one that is driven by a machine. Today, the difference is the size of the trucks and what types of trailers you can use, since automated vehicles need rigid constructions because of the need for sensors. However, the interviewee is confident that those types of problems will be solved in the future. Otherwise, the functions of the two options are practically the same when it comes to driving goods from one place to another. The interviewee explains that today's autonomous vehicles are not as autonomous and self-going as they may be in the future. They are restricted in where they can drive, at what times of day they are allowed to operate, and the maximum speeds they can travel. Unlike a human driver, a self-driving vehicle cannot simply be instructed to travel to a distant location without predefining numerous decisions along the route. A human driver can independently handle each decision after receiving the destination. The interviewee emphasizes that autonomous trucks will have to be able to drive by themselves, without the need for data from the infrastructure. Smart roads could help the vehicle, but in the end, it has to be able to operate even if the internet connection is lost.

Another project the interviewee was involved in focused on ports, specifically exploring how beacons could assist ports by sending signals when approaching vehicles reached a certain proximity. Location data was automatically shared from the trucks to the port, enabling the port to gain better insight into arrival times and improve scheduling accuracy. The interviewee highlights the potential future benefits of using this information, such as automatically opening port gates upon the truck's arrival and having containers ready for immediate loading, thereby minimizing delays and buffer times during the transportation process.

The interviewee discusses the involvement in a platform for truck parking and how that service could be compared to Intelligent Access. The platform should in a safe way be able to provide parking spaces to reserve so that truck drivers can have a guaranteed parking space that is also safe. Parking can be a bottleneck, and providing information that helps parking lot operators increase utilization while assisting truck drivers in easily finding available spaces would be highly beneficial.

The interviewee defines IA as:

> “A way to optimise the access to a certain resource so that as many people as possible become as pleased as possible."

The resource could be anything—from access to a shipping container to a taxi.

Future advancements

The interviewee believes that roads may be classified based on different SAE levels that allow different levels of automation on different roads. Furthermore, in the future, regulations must clearly define a new vehicle category such as the autonomous truck. UNECE provides a regulatory framework with technical and safety standards for road vehicles, and they have to integrate autonomous vehicles into that framework to allow for its implementation. Today, laws and regulations are connected to normal trucks, which makes it bureaucratically difficult to regulate laws regarding automated trucks.

The interviewee believes that, in the future, there will need to be roadside service stations dedicated to repairing autonomous vehicles in case of breakdowns, along with an expanded charging infrastructure to maximize vehicle uptime and ensure continuous operation. Moreover, for IA to function effectively, artificial intelligence will play a crucial role in managing and processing the substantial volume of data being transferred, according to the interviewee.

Information attributes

In the Northern climate, weather can have a big impact on the driving conditions and therefore it could be useful to share dynamic data on the current weather conditions.

The interviewee mentioned that dangerous goods are not allowed to be transported with autonomous vehicles. Therefore, the type of goods transported is an important information attribute for autonomous vehicles.

Challenges with implementing IA

The interviewee discussed the importance of taking the perspective of different stakeholders into account when looking at the benefits of IA. For trucks going to pick up a container in a port, the benefit of not having to wait for the container is obvious, since it minimizes their time from door to door. But when it comes to the port, if they save an hour of time when receiving data on when trucks arrive, what is this hour used for? Can it be used to increase the number of handled containers and therefore increase the revenue, or is there another bottleneck that makes the hour saved unnecessary? To quote the interviewee:

> "It’s like when you leave half a mozzarella in the fridge after cooking—it

usually just sits there until you throw it away a week later. Keeping it doesn't offer any real benefit."

The point the interviewee made was that it is necessary to establish every stakeholder's benefit from IA to understand its utility. Therefore, the positive effects of IA can be broken down into optimizing bottlenecks. If better information sharing reduces a process by ten minutes, these ten minutes must be of some value for it to be an improvement.

The interviewee believes that a key challenge in implementing Intelligent Access (IA) is to determine appropriate system boundaries. This involves determining what data should be included or excluded and identifying which aspects of the system can be effectively managed. If the system boundaries are too narrow, the result may lead to local sub-optimization. However, if they are too broad, the system could become overly complex.

4.1.5 Expert 5

Title: Research Consultant within sustainable transport and logistics

Areas of experience: IA & AV

Contemporary advancements

The interviewee states that the SAE level framework is commonly used for distinguishing levels of autonomy. However, when the interviewee speaks with colleagues who are developing autonomous driving, they say that the levels may be a bit misleading, and they tend to step away from this commonly used framework. The reason the SAE framework is misleading is due to that it only considers the vehicle and to not take into account the environment, as you need some sort of control tower to control the vehicle. The interviewee says that there is a “chicken and egg” situation for autonomous driving. OEMs are developing autonomous driving but not as quickly as they could since they do not experience a true demand for the service. Logistic companies do not know what the cost-to-benefit ratio will be.

The interviewee discusses problems regarding smart infrastructure. OEMs want to ensure their customers' safety, but if they rely on external data and it turns out to be inaccurate, who is held responsible if something goes wrong? furthermore, the interviewee has not seen any larger development towards smart infrastructure besides smart traffic lights. NRAs do not have a lot of money and can not afford to make such large investments. There is a better case for smart infrastructure within a predefined area where the vehicles are automated rather than autonomous.

It is essential to integrate both the description of the Operational Design Domain (ODD) and the specific vehicle functionality within that ODD when considering

Intelligent Access in relation to automated vehicles. Access can be granted if a particular road segment falls within a vehicle's ODD. However, if it lies outside the defined ODD, further evaluation is needed to determine whether access should still be permitted. This distinction is important, as manufacturers are typically very precise in specifying the conditions under which their vehicles are designed to operate safely.

Future advancements

There is preparation that has to be done before a logistics company can integrate AVs into their fleet. First, standardisation and digitalization process on their container terminals before they can proceed with AVs. Then the AV needs information on planning, which means it needs to digitally connect to the transport management system. Some tasks will probably also in the beginning still have to be done manually, such as loading and connecting trailers. These actions also have to be taken into consideration.

AVs present new business model opportunities for OEMs as they maybe lease the vehicles to the transport companies instead of selling them. Additionally, platooning might come back as the technology that was developed for platooning is now used for making autonomous vehicles. And if autonomous vehicles enter the roads, it makes sense to let them platoon at least during the night. For platooning to work, you need scale, and to have scale, you need different truck companies to collaborate, and for this to occur, you need standardisation to make things interoperable. Standardisation is also favourable from a regulatory perspective as NRAs don't have to consider a bunch of different information sharing systems. The interviewee believes that there has to be a European standard for intelligent access, otherwise, the regulatory burden on companies would become too great.

Information attributes

Ports are currently testing number plate recognition systems to streamline driver access and facilitate the sharing of transfer documents. However, for autonomous vehicles, further digitalization is required to enable seamless port entry. This could involve the AV either recognizing its designated destination, similar to a human driver, or connecting directly to the port's navigation system, which would guide it to the correct location.

Challenges with implementing IA

The interviewee believes that the legal aspect of IA is and will be challenge. Furthermore, the interviewee questions who should be in charge of checking the compliance, the government or a separate entity.

4.1.6 Expert 6

Title: Post Doctoral Researcher

Areas of experience: IA

Contemporary advancements

The interviewee gained experience with Intelligent Access through a project that explored the potential socio-economic benefits of the concept. The interviewee defined Intelligent Access in the following way:

> "Intelligent Access basically involves defining which roads are suitable for specific types of heavy vehicles, as well as outlining when and under what conditions those vehicles are permitted to use them"

According to the interviewee, IA is not necessarily a technological solution, but rather a means of establishing incentives for stakeholder collaboration. In the context of the project the interviewee participated in, IA was viewed not as a generic framework, but rather as a digital service.

The information provided by IA is crucial for making informed decisions about infrastructure. The interviewee spoke to the national road authorities about what traffic workers want from IA, and they said that they noticed that some roads experience wear and tear more often than others, which costs a lot of money. The national road authorities, therefore, consider using IA to reduce wear and tear by potentially restricting access or requiring permits for certain roads, depending on the tonnage of the vehicles. For example, if a road is overloaded and has reached its maximum weight capacity, IA could assist in re-routing traffic.

The interviewee believes that IA can be applied to enable smart roads. It makes a lot of sense to look at traffic information for smart roads. Depending on weather conditions, certain hazardous areas can be restricted by geofencing technology. Furthermore, if a big event is occurring, certain vehicles might be prohibited from accessing certain areas.

The interviewee believes that national road authorities could have a platform that shares data regarding roadwork. This information could then be utilized by navigation systems for road optimizations. Through this platform, drivers could also apply for digital permits to cross, for instance, a bridge that they otherwise would not be allowed to. Right now, there are permits that truck drivers have to apply for, and these processes can take up to 2 weeks. Therefore, if road conditions have changed quickly so that passing through a certain place would require a permit, truck drivers have to make changes to their route as they are not able to apply for a permit on time.

Future advancements

The interviewee believes that there is a need for an integrated ecosystem so that a driver does not have to download multiple apps for each separate thing (parking, navigation, smart roads, etc). This would be a vision for 5-10 years down the line.

In 5-10 years, the interviewee believes it's crucial that technology is integrated into the same ecosystem so that drivers are not faced with too much separate technology. The ecosystem can be monitored by certain authorities and the information within the ecosystem can be shared among different stakeholders.

Information attributes

Charging status is highlighted as an important information attribute, where and when to recharge. It might be more efficient for the truck driver to charge 40% at one stop and 30% at another, rather than charging 100% at a single location.

Roadwork and tunnel closure, for instance, are information attributes that would be important in cities and on highways. The interviewee mentioned that there are 3 types of roadworks. Planned roadwork; when infrastructure has to be repaired, moving roadwork; for instance, gardening along the highway, and real-time stationary road work; when an accident has occurred.

Challenges with implementing IA

The interviewee believes that logistics companies might be reluctant to take part in IA as it might cost too much money. For example, if a company previously used a certain bridge but is now prohibited from doing so due to IA regulations, it could end up costing them money. Therefore, a balanced approach is needed, something that has yet to be fully established.

The biggest challenge to implementing intelligent access, according to the interviewee, is that it is expensive to pilot and test, which might be a problem when trying to convince public authorities. There needs to be a political push for it to happen. Smaller logistics companies might struggle to adopt all of these technologies. The interviewee highlights that it might be difficult for an IA platform owner to make money as the industry already experiences slim margins. It is also important to create some sort of standardized guideline or strong protocols. The interviewee believes that governance can become difficult as there is a lot of data that has to be considered.

For a successful implementation, the interviewee believes that incentives are important. For instance, faster permits and reduced fines if they follow the rules and use more appropriate routing options. Punishment when rules are not followed is also highlighted as important.

4.1.7 Expert 7

Title: Department Manager at a freight forwarder company

Areas of experience: HCT & AV

Contemporary advancements

The interviewee participated in a pilot project involving the testing of an alternative vehicle combination. This trial was conducted in collaboration with other stakeholders, but the special permit allowing the test has since expired. Currently, trucks are permitted to carry two forty-foot trailers, but they must be connected using a dolly. The alternative vehicle combination permit allowed the trailers to be directly connected using a "link." The link was necessary to fulfil the turning radius requirements. The interviewee says the link solution offers many benefits for the truck drivers. It is easier to operate and manoeuvre in reverse while also reducing the time required for truck drivers to connect the trailers. The reason the truck becomes easier to operate is due to the fact that the truck driver only has to consider two pivot points instead of three. It is especially beneficial in port operations, where drivers are required to reverse into the pick-up point. This vehicle combination is not legal because it does not meet the required axle distance regulations. Furthermore, the interviewee discusses the challenges of transporting goods using a High Capacity Transport (HCT) vehicle to points of interest that are not accessible via roads with the correct classification. If they want to access this road, they need to apply for a permit from the road operator which usually is the municipality.

Future advancements

The interviewee described that the current port drop-off or pick-up operations are inefficient and inconvenient. When arriving at the port, the truck operator receives a visitation card. However, it does not specify the exact time for drop-off or pick-up. As a result, the driver can enter the port at any time during its operating hours on the assigned day. The interviewee therefore believes that information sharing that signals to the port that the truck is about to arrive within a certain period will be beneficial for both parties. Ports could use this time to prepare for the drop-off or pick-up, hence decreasing the turnaround time.

The interviewee did not find a booking system, where truck drivers receive a two-hour time slot, appealing. Ports favour it because it helps manage truck flow by setting a maximum limit on arrivals within those two hours. However, when delays occur, either from the port or the drivers' side, the entire system is disrupted. Instead, a dynamic system would be preferred where the truck communicates with the port regarding its estimated time to arrive.

The interviewee believes that trucks will become even larger and that the use of HCT will increase in the future. Allowing other vehicle combinations is highlighted as a crucial change needed for this to happen.

Information attributes

The interviewee emphasized the need for secure parking spaces due to a rising number of thefts targeting their containers. Reservable parking space is also considered to be beneficial, as truck drivers face strict work-time limits which sometimes results in parking unnecessarily early. Information on whether the parking space is designed to accommodate 34.5-meter trucks was also a key information attribute. Parking spaces are not constructed for HCT, which will cause problems as the number of these trucks increases. A general map of parking spaces would be appreciated, as current information relies on the truck driver's experience on a particular route.

The interviewee finds that important information attributes are such as vehicle combination length, weight and axle load. These attributes help determine the most optimal route for the truck.

Challenges with implementing IA

They believe that a big challenge for Intelligent access is that people may be reluctant to share their information and that it has to show clear financial benefits for the hauliers.

4.1.8 Expert 8

Title: Senior Solutions Architect at a forklift manufacturer

Areas of experience: Ports & AV

Contemporary advancements

The interviewee explained that today, the entrance to the port of Gothenburg is fully automated. The license plate and account number of the truck are registered at the entrance, and an instruction on where the truck should go is given to the driver. For an autonomous vehicle, the interviewee believes it would work in a similar way, but with the position information going to the vehicle instead of the driver. At the Port of Gothenburg, the current entrance procedure could potentially accommodate autonomous vehicles without significant modifications. However, the physical layout may need to be reassessed to ensure efficient traffic flows and fully leverage the benefits of AVs.

The interviewee discussed how the AGVs in ports are designed and what type of technology they have. Considering the environment they operate in, they do not have to be as smart as autonomous vehicles that drive on public roads. But the technology constantly improves, and more and more AGVs are used that can read the environment, instead of following a preprogrammed route or using a scanner to triangulate the position.

Future advancements

The interviewee believes the design and layout of ports will change in the future to accommodate autonomous vehicles. Today, the ports are constructed for human-operated trucks, and autonomous vehicles have other limitations that need to be considered. AVs require minimal interference to operate effectively, which poses challenges in mixed traffic environments where they must interact with human-driven vehicles.

One potential future layout feature mentioned by the interviewee is the establishment of a designated loading and unloading zone just outside the port. In this setup, external trucks would drop off and pick up containers, while smaller AGVs would handle transport between the zone and the container's location in the port. There, a second type of AGV, specialized in lifting containers to greater heights, would handle stacking, ensuring an efficient and streamlined container flow. In this way, these external autonomous trucks have a short handover time, which saves them time, and they can be used more efficiently without needing to drive right up to the container. It is also a way to avoid manually driven external trucks from entering the port, to avoid interfering with the AGVs that work in the port area.

The interviewee believes that future AGVs will need to operate within flexible infrastructures capable of adapting to fluctuating volumes and dynamic use of space. Ports are expected to adopt more efficient, compact, and adaptable layouts, which will require AGVs that are versatile and not constrained by rigid designs.

Information attributes

The interviewee did not say much regarding information attributes, but only mentioned that for a port, the estimated time of arrival for both the landside and seaside is important for planning, scheduling and queue time management.

Challenges with implementing IA

Mixed traffic involving both AVs and human-driven vehicles presents several challenges. For instance, human drivers may perceive autonomous vehicles as too slow, leading to impatience and potentially risky behaviour, which can increase the likelihood of accidents and errors.

> "Vehicles will not be 100% autonomous overnight, the change will happen gradually. Hence, mixed traffic will be important to take into consideration."

IA-enforced rules, such as speed limits or access restrictions, may be followed by autonomous vehicles but ignored by human drivers, leading to enforcement and compliance challenges. This weakens overall system performance, as Intelligent Access works best when all users operate in sync. As the interviewee noted, while a fully autonomous fleet would maximize IA's potential, the gradual shift toward autonomy requires IA systems to accommodate the complexity and unpredictability of mixed traffic for years to come.

The interviewee also points out that it will be important to try to implement a 100% autonomous fleet as quickly as possible to avoid the challenges with mixed traffic, but that it is unavoidable for many years.

4.1.9 Expert 9

Title: Program Manager at a large port in Europe

Areas of experience: Ports, IA & AV

Contemporary advancements

The interviewee mentioned that there are use cases in the Netherlands for Intelligent Access, such as zero-emission zones where diesel and petrol trucks are restricted using geofencing technology. It can also be applied to the transport of dangerous goods, ensuring that such cargo is not carried on prohibited routes, including certain highways, tunnels, and other sensitive areas.

In the port of Rotterdam, it is between the terminal and the carrier to schedule the appointment, there is no general rule that the port of Rotterdam has as port authority. Their main objective is to make sure the whole process is going smoothly and that there is no congestion on the roads to the port and to the terminals. They try to help the whole logistics ecosystem to avoid long waiting times in the daily operations at the terminals. The interviewee mentioned that the port of Rotterdam uses an app to share information with its terminals and drivers, to show the waiting times at the different terminals. It makes it easier for drivers to plan their transport and avoid long waiting times.

> “If you are planning to go to a terminal but you see that the waiting time is two hours, you can reschedule your day and make some other stops before you go to the terminal, making your day more efficient.”

The port of Rotterdam works with 30-40 transport companies, which share their onboard data so that they can see where the trucks are and how long they are staying at the terminal. By calculating the dwelling time for every truck, they can calculate the mean waiting time and share the information using their app. The app also shows available parking spaces at the different terminals, so that truck drivers know if there is a space for them when they arrive. The interviewee explained that the app is still developing and that they plan to have a function that shows the estimated waiting time two to three hours forward, to allow for even better planning for the truck drivers.

The interviewee explained that the port of Rotterdam does not have any trucks since they are a port authority, but instead provides the port infrastructure. They then hire companies to do their business in the port. However, they still have responsibility for upholding a physical and digital infrastructure to accommodate both normal vehicles and autonomous vehicles. They want to be a port that is innovative and stimulates the use of autonomous transport by having an appropriate infrastructure.

Super Echo Combi is discussed as a Dutch form of HCT, where the truck is 32 meters long. It is not yet legal to drive on public roads in the Netherlands, so the port of Rotterdam has not made any major changes or investments to be able to accommodate these longer vehicles, according to the interviewee. The port is already designed to accommodate 25-meter-long trucks, and the Super Echo Combi has the same requirements for cornering. That means there is not much that has to be changed in the layout of the port to accommodate longer vehicles. The necessary changes mentioned by the interviewee were that parking spaces have to be made longer, and there may have to be changes for the loading and unloading of boxes from the chassis.

The interviewee discussed that OEMs do not want to rely on road authorities for data and information to drive autonomous vehicles on public roads. Instead, they want their vehicles to be smart enough to drive independently on the roads without having to rely on smart infrastructure. Smart roads should, therefore, be seen more as a helpful tool than as a crucial part of the introduction of AVs.

The triple helix is a concept mentioned by the interviewee. It relates to the cooperation between the government, the knowledge institutes and the industry. This form of co-creating and collaboration is crucial for autonomous transport, according to the interviewee.

The interviewee believes IA is one of the enablers for introducing autonomous transport, since more data needs to be shared when drivers are not present, for example, when entering a port or a terminal.

Future advancements

The introduction of electric trucks is important to adjust for by building and expanding the port's charging infrastructure to provide the possibility for trucks to charge

The interviewee explained that now you can see that terminal owners experiment with state-of-the-art autonomous vehicles to operate on their premises instead of the current, rather inflexible, AGVs.

Within the Port of Rotterdam, there is an exchange route connecting the terminals to the container areas. The interviewee explained that a customer has asked for permission to pilot a project involving the use of an autonomous truck on this route. If the pilot proves successful, it could pave the way for a broader deployment of autonomous trucks in the future.

The interviewee believes it will be a slow process, at least in the Netherlands, to introduce AVs on public roads. The interviewee discussed the importance of ODD, Operational Design Domain. These should be designed simply in the beginning and be increased in complexity to allow for a slow progression. But there will be no commercial interest in using AVs until there is permission to drive on public roads.

Information attributes

The interviewee explained that the actuality of the information shared is very important, and that in the Netherlands, it is quite a big concern because the Dutch government is not very keen on having actual data available to share with all the parties. The quality of the data is, according to the interviewee, one of the most critical aspects, as it is the baseline for a good working system.

The interviewee mentioned that it could be useful for the port of Rotterdam if the total weight of the trucks could be determined and shared, maybe using IA. The consequences of overloaded trucks in the port area could be degradation of the infrastructure, for example, tunnels and viaducts. A heavily loaded truck is also more unsafe, especially when getting around corners, since the manoeuvring is more difficult. The interviewee also discussed a third aspect, which is the commercial aspect. The port of Rotterdam wants to have a level playing field for all parties.

> "If you are driving with an overload, it is not fair to others who do not drive with an overload."

Today, weighing trucks is not possible for the port of Rotterdam, and checks done by the government are done only two or three times a year, but the interviewee believes future vehicles will be able to weigh their load and share that information accurately.

Challenges with implementing IA

The biggest challenge to the introduction of IA is, according to the interviewee, to gather enough reliable data for the IA system, and how the government can check if the data is reliable or not. There have to be control over the system, otherwise it will not work.

4.1.10 Expert 10

Title: Project Manager at a large vehicle manufacturer

Areas of experience: HCT & IA

Contemporary advancements

The interviewee explained how IA can be used to grant access to larger vehicles in Northern Sweden on frozen roads, and how it can help to open and close roads depending on the weather and the road condition.

The interviewee discussed how IA can be used in Sweden to allow 74-tonne vehicles on roads classified with BK 4. It could be used in the same way as the tachograph in trucks today is used, but with more information, like how fast you drive over certain bridges. Bridges may have varying speed limits based on vehicle weight. Using IA combined with geofencing, trucks with different weights and loads can automatically have their maximum speed adjusted to match the specified limit for their particular weight category.

The interviewee pointed out the difference between the perspective of IA in Australia and Sweden. In Australia, it is mainly used to punish those who do not follow the rules, while in Sweden, it is seen more as a tool to help drivers follow the rules.

> "Instead of issuing tickets to those who speed, IA can guide drivers to maintain the correct speed from the start."

Future advancements

According to the interviewee, the future needs a system that works in the same way for all of Europe when it comes to HCT. An increasing number of countries are now approving larger vehicles, and transport corridors are being established through Germany and France. The interviewee believes that with the implementation of IA, new opportunities could emerge, such as allowing HCT vehicles to operate on Sundays, which is currently prohibited in those countries. IA could help authorities feel more confident and assured about the safety and compliance of the transport operations and therefore allow access to a higher extent. A supervised process would also lead to fewer accidents per vehicle, and speed limits and axle weights would be followed to a higher extent.

The interviewee highlighted the importance of being able to reserve a charging spot for electric vehicles, since it takes time to charge them and standing in line would not be optimal. There also have to be charging spots designed so that a longer vehicle with multiple trailers doesn't have to disconnect anything to get to the charger.

Information attributes

Factory-installed vehicle equipment is preferred over retrofitted systems because it can provide more comprehensive data, such as axle pressure, and can leverage IA to implement features like restricting acceleration beyond a specified limit.

The most essential information attributes are speed, position, time and weight, according to the interviewee.

Electric vehicles will be more common in the future, and since they are heavier, the axle pressure will be even more important to check so that trucks are not overloaded.

Challenges with implementing IA

One challenge with IA is determining how it can provide benefits exclusively to its users. Non-users can still access roads and violate rules, and tracking and penalizing these violations is often too difficult. The interviewee argued that there has to be a clear business model in place to specify what the purpose of the data sharing is, what the users get in return for sharing their data, and how it affects those who do not share their data.

Another challenge with the implementation of IA, according to the interviewee, is that European countries today have different agendas when it comes to the future of road freight transport and IA. There needs to be a more holistic view of IA in the European Union. The interviewee emphasized that smaller-scale projects could serve as practical demonstrations of the technology, showcasing its effectiveness and facilitating broader implementation across Europe. As an example, the interviewee referenced the development of mobile telecommunications:

> "Sweden, Norway, Finland, and Denmark had a network of thousands of users with Nokia and Ericsson, and the Nordic mobile telecom then spread to the rest of Europe. The same thing could work with IA."

5

Analysis

This chapter aims to analyze the empirical findings in combination with the literature review in order to answer research questions 2 and 3. The aspects found in the literature review and the interviews are presented below, divided into separate categories. Firstly, are they related to HCT or AV? Secondly, are they implementable in the contemporary future, or will they have more impact in 5-10 years? Finally, they are grouped into distinct categories, namely road hauliers, smart roads for highways, smart parking, smart roads for cities, and terminals/ports. The matrix in every section shows which aspects have been found, and to what category they could be of most use. Some aspects fall under multiple categories, and the following sections explain the reasoning behind the placement of each aspect.

5.1 0-1 years

This section describes what contemporary aspects have been discovered related to HCT and AV.

5.1.1 HCT

Below is a matrix depicting the different aspects, each of which is explained under its respective heading.

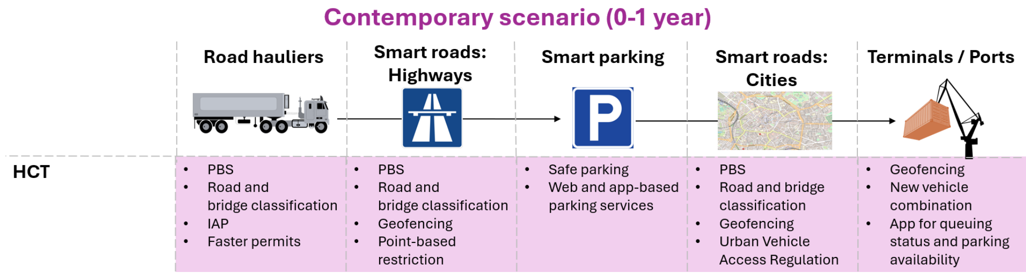

Figure 5.1: HCT 0-1 years

Road hauliers

RQ2

1. Hauliers that operate HCTs, are in need of being aware of the current legal frameworks regarding HCT. For instance, they need to be aware of which roads and bridges they are allowed to use. In Sweden, this is regulated through the BK classification system while in Australia the PBS system is used which is described under Section 2.7. The BK classification only permits HCT trucks to access roads that are classified as BK4. Expert 7 described that if they, as freight forwarders, would like to access a road by HCT that is not BK4 classified, they have to ask for permission from the road owner, typically the municipality, to temporarily open up the road for the larger vehicle. The Intelligent Access Program relies on a classified road network to determine whether a vehicle is operating within its permitted limits

2. Expert 6 touch upon the problem regarding the time it takes to receive an approved permit to access road or bridge. The process can take several days which is a problem for the road haulier as they would like to optimize their route planning.

RQ3

1. PBS, when incorporated into IA, would allow HCTs to access a larger part of the road network which would help increase efficiency on the roads, i.e. using the infrastructure in a better way.

2. Expert 6 believes that data useful for the permit authority in deciding whether a vehicle should be granted access can be shared through a Intelligent Access systems such as IAP. This could accelerate the permit process and benefit hauliers by reducing waiting times. This would solve the problem stated in Section 1.2, that permits sometimes takes too long time to receive.

Smart roads: highways

RQ2

1. PBS, BK classification and other HCT regulatory frameworks need to be used to

classify each road within a road network. This is important as maps that describe where HCTs are allowed to operate are dependent on this type of information.

2. As described under Subsection 2.1.1, geofencing can ensure that certain vehicles remain outside designated areas. For example, geofencing can restrict access to certain areas if the vehicle is abnormally large or is carrying hazardous materials. Moreover, Expert 3 describes how geofencing has been used to control vehicle speed over a bridge before it was going to be demolished. The expert is working on a project to explore whether a similar solution can be implemented for bridges in northern Sweden, where heavier vehicles operate due to the increased load capacity of roads in colder climates.

3. Furthermore, point-based restriction, as mentioned under Subsection 2.1.2, could be used today to restrict HCT vehicles from accessing vulnerable infrastructure such as bridges and tunnels along the highway.

RQ3

1. For instance, if Intelligent Access were introduced as a compliance tool, similar to the system used in Australia, it would need to be able to detect when an HCT vehicle exceeds its permitted level of access. This would help avoid heavy vehicles from travelling on roads and bridges where they are not allowed, a problem that was mentioned in Section 1.2.

2. Expert 6 explains how geofencing can be used to restrict access to road areas that may be hazardous due to, for example, weather conditions. The expert continued by saying that roadwork can be geofenced to decrease accidents.

3. Automatic Number Plate Recognition (ANPR) can be used to ensure vehicle compliance by referencing a database of license plates linked to each vehicle's legal weight, length, height, or axle load. This would make sure the road infrastructure is not overloaded.

Smart parking

RQ2

1. Current smart parking services are app- or web-based platforms that provide truck drivers with parking area information such as availability, amenities, safety standards, and more. The two websites that was examined under Subsection 2.6.2 was TRAVIS and Bosch. They provide a similar service, however, they do differ somewhat as the parking area information is not entirely the same as can be seen in Appendix A. The websites are limited by the number of parking areas with which they collaborate. For instance, in some areas there is a very large supply of parking spots while in others there is almost none. Furthermore, if the truck driver has specific parking area preferences, the problem becomes increasingly complex.

RQ3

1. Expert 6 emphasises the need for secure parking as they have noticed a rising number of thefts targeting their container. Therefore smart parking, when incorporated into intelligent access, has the potential to address the issues outlined in Section 1.2, including regulatory violations, unsafe parking, and low efficiency.

Smart roads: cities

The same reasoning behind classifying highways based on certain criteria similarly applies to smart roads in cities. There might however be other aspects to consider when classifying a road within a city than on a highway like pedestrian traffic. Expert 6 believes that geofencing could be utilized to restrict access to certain parts within a city if, for example, a large event is taking place.

RQ2

Urban vehicle access regulation, which is closely related to IA, can be used to restrict access to roads within a city. Currently, it is mainly used to reduce congestion and emissions by charging vehicles based on their environmental class and when they enter the city perimeter. This is usually done through Automatic Number Plate recognition (ANPR) that utilize a database to check the environmental class or to issue an invoice.

RQ3

It is therefore likely that point-based restriction could be used to verify that HCT vehicles comply with city access regulations in a similar manner. Therefore, UVAR could help address the issue of oversized trucks operating in areas where they should not. This would address the problems regarding non-compliance and road safety, as discussed in Section 1.2.

Terminals/Ports

RQ2

1. By using technology such as geofencing, ports and terminals could get an estimation of when trucks arrive to be able to optimize the loading and unloading processes.

2.Geofencing is not the only type of technology that could be used. As mentioned by Expert 9, the port of Rotterdam uses an app that collects data from many of its customers to show the mean waiting time at different terminals, as well as parking space availability.

3. Expert 6 describes the problem of arriving in a port with an HCT vehicle. The truck driver has to reverse into the drop-off point which is very difficult when operating two trailers. The expert has been involved in a project that aims to make this process less of a problem. The interviewee calls it the "link solution" and as described previously, it makes it easier to reverse.

RQ3

1. This could reduce the turnaround time for trucks in ports and save time for both road hauliers and port terminals.

2. The IA system could also utilize this information by transmitting it to trucks, equipping them with valuable data to make more informed and efficient route planning decisions.

3. The new vehicle combination is not jet approved but could be in the near future. The solutions mentioned in this section would help increase the efficiency in ports and terminals, which was mentioned as a problem in Section 1.2.

5.1.2 AV

This section describes what contemporary aspects have been found related to AV. As of now and for the foreseeable future, autonomous vehicles are unlikely to be widely present on European roads, if at all. Therefore, the focus on the contemporary future is on preparing for the introduction of AVs, which will serve as the central theme and perspective of this section of the analysis. It will explore how these aspects, in combination with Intelligent Access (IA), can support and facilitate the future implementation of AVs.

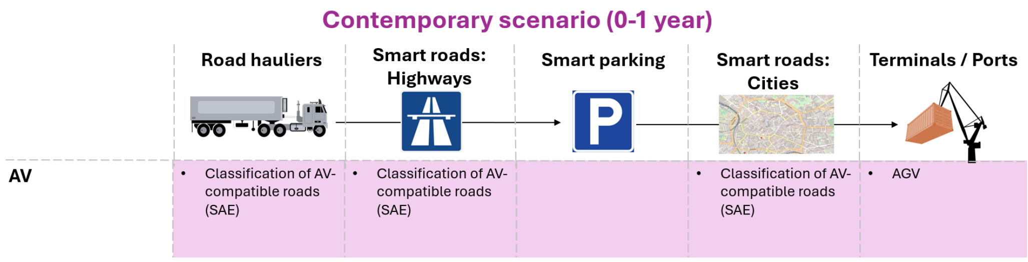

Figure 5.2: AV 0-1 years

Road hauliers

RQ2

1. One of the most accepted frameworks for describing the functionality and automation of a vehicle is the SAE framework. The SAE framework is central to understanding what levels of autonomy are feasible in road freight, especially since IA may eventually rely on the AV's level to determine access permissions or route eligibility. As suggested by Expert 4, one proposed application is that road authorities can use the SAE framework to classify roads in the same way as the Swedish roads are classified by the BK classification. Different roads have different conditions for

autonomous driving, and could therefore be classified according to the appropriate SAE level.

RQ3

1. IA could regulate road access based on a vehicle's SAE automation level, permitting autonomous driving only on roads suited to the vehicle's capabilities. This usage of SAE levels is aligned with what was stated under Section 2.4, that SAE levels have been adopted by various stakeholders to enable discussions on the progression and development of automated driving at different levels. It also addresses a concern raised by Expert 5, who noted that the SAE framework does not consider environmental factors. This gap is bridged by assigning SAE levels to roads based on their specific conditions and surroundings.

While it may take time for vehicles and regulatory bodies to fully implement the SAE framework in practice, the classification of road segments by required SAE level could be established within the 0–1 year timeframe. This would provide immediate value for road hauliers, who may already operate vehicles with Level 1 or 2 automation features such as adaptive cruise control and lane-keeping assistance. With an SAE-classified road map in IA, hauliers would gain visibility into where such functions can be used safely and legally, enabling more efficient and informed route planning, even in the short term. This would help make the introduction of AVs on public roads easier, which is mentioned in Section 1.2 as one of the current main problems with AVs.

Smart roads: highways

RQ2

1. The usage of SAE levels to classify roads was described in the section above. This type of road classification could be defined as a way to make a road smart, meaning there is a map illustrating how different roads have different SAE levels based on their conditions. Highways are to most likely roads to be used for testing and early implementation of autonomous vehicles, since they have minimal intersections and pedestrian interaction. Although these tests may be further in the future, the classification can be made in the near future. As stated under Section 2.4, the implementation of AVs will be gradual and slow.

RQ3

1. By connecting the SAE classification to IA, the framework can be established and thereby help the introduction of AVs. This also correlates to what was mentioned under Subsection 2.5.4 regarding the INFRAMIX project, that there is a need for a digital infrastructure to help introduce AVs on public roads.

Smart parking

Currently, there are no significant advancements related to smart parking, as automated vehicles are still in the development phase, and they also do not require parking in the same way human-driven vehicles do. Therefore, no aspect was found connected to smart parking and autonomous vehicles that could be implemented in the near future.

Smart roads: cities

RQ2

1. In the same way SAE levels can be used to classify highways as stated above, they can also be used to classify roads within cities. What specifies roads in cities is that there is usually a more dynamic environment, with pedestrians, intersections, and more traffic. These roads are primarily suited for Level 4 and Level 5 automation and will present greater challenges for autonomous vehicles, and widespread deployment in such environments is likely still several years away.

RQ3

1. As a result, the application of SAE levels in urban areas through IA is expected to be a longer-term development. However, as previously mentioned, the road classification process can begin within the next 0–1 years, providing vehicle manufacturers and road hauliers with a standardized framework indicating where different levels of automation can be deployed. The framework can then be incorporated into IA, which can be used to grant access to autonomous or semi-autonomous vehicles based on their respective SAE level. As mentioned above, this would simplify the introduction of AVs on public roads, a problem stated in Section 1.2.

Terminals/Ports

RQ2

1. AGVs are one of the most mature and operational forms of automation within freight and logistics today. Expert 9 explained how AGVs are used in the port of Rotterdam, and as stated under Section 2.3, the use of AGVs increases the efficiency of port and terminal operations. Since it is already in commercial use, and has been for several years, the concept is categorized in the 0-1 year timeframe.

RQ3

1. As they operate within a confined area, it can be said that they function within a controlled IA system, receiving information such as container weight, placement, and infrastructure limitations. This system could also be broadened to allow for external information to reach the AGVs, such as estimated time of arrival from both the landside (trucks) and seaside (cargoships), as mentioned by Expert 8. By receiving information when trucks arrive, the AGVs can better plan their operations to minimize waiting time for the trucks, which may allow the port to handle more containers and increase its revenue. Expert 4 emphasized the importance of ensuring that the time saved through improved operational efficiency is used pro-

ductively. Otherwise, the investment in acquiring external data and implementing the IA system would be unjustified. AGVs can therefore enhance efficiency in ports, addressing the problem outlined in Section 1.2.

5.2 5-10 years

This section explores the aspects that are useful in the 5-10 years timeframe.

5.2.1 HCT

Below is a matrix depicting the different aspects, each of which is explained under its respective heading.

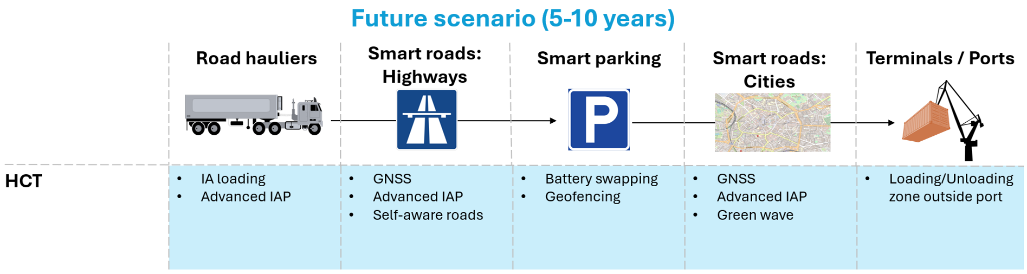

Figure 5.3: HCT 5-10 years

Road hauliers

RQ2

1. One use case for IA mentioned by Expert 2 is facilitating communication between trucks and loading vehicles during the handling of heavy materials. Effective communication ensures that trucks are loaded correctly, with optimal placement of materials to maintain proper axle weights and comply with weight restrictions. Sensors on excavators can transmit weight information directly to trucks, enabling accurate monitoring of the total load weight.

2. Expert 1 addressed the OEMs role in enabling and improving IA. The expert believes that if OEMs become more willing to integrate technology that supports IA, the effectiveness of IA will improve dramatically. This would also eliminate the need for fitting an IA "black box" within the vehicle as the position data can be shared directly through the truck's telematic system. Moreover, information that Expert 1 believes will be important in the future for national road authorities are data regarding harsh breaking and axle load. This data could drastically improve road

infrastructure. Axle load is especially important for bridges and harsh breaking data could be used for infrastructure prioritization. Expert 10 also highlighted the increased importance of axle load in the future as electric trucks are becoming more common on the roads. Electric truck weighs more than conventional trucks, which will increase the pressure on axles, making that information attribute more important. This improved form of IAP has been labelled as Advance IAP in the analysis to distinguish it from the currently used IAP system in Australia.

RQ3

1. IA loading would address the problem outlined in Section 1.2, that improper loaded vehicles can causes injuries, damages to packages, and wear and tear on the road infrastructure.

2. By accessing more data, issues such as inefficient use of infrastructure and unnecessary wear and tear, as mentioned in Section 1.2, can be addressed when this information is shared with the intelligent access system.

Smart roads: highways

RQ2

1. GNSS combined with GSM technology, as mentioned in Section 2.1.2, is very similar to the IAP system used in Australia. The key difference lies in their focus where the IAP is mainly concerned with protecting road infrastructure, while UVAR targets urban congestion and pollution. The GNSS technology is beneficial to its counterparts (ANPR, DSRC, RFID) due to it requiring minimal roadside equipment. However, the cost of a GNSS onboard unit is currently relatively high, though it is likely to decrease as the technology continues to evolve.

2. Under Section 2.5, a concept called self-aware roads was presented as a way for roads to collect data regarding road condition and traffic status with the use of sensors and cameras.

3. Advanced IAP brings the same benefits for smart roads highways as for road hauliers.

RQ3

1. GNSS conditions, such as location and time of the day, can be updated easily and shapely. A key issue with both GNSS and IAP systems is related to privacy concerns, which several experts identified as a barrier to implementation, especially given the strict GDPR regulations in Europe.

2. Self-aware roads could be highly valuable for IA, as it enables the collection of relevant real-time data that can be shared with both trucks and road authorities. It is also significant for the future of autonomous vehicles, which could benefit greatly from this type of information to enhance their decision-making and operational effi-

ciency. Self-aware roads could help minimize the degradation of road infrastructure, and help increase the efficiency of the roads. These are both issues outlined in Section 1.2.

3. Advanced IAP brings the same benefits for smart roads highways as for road hauliers.

Smart parking

RQ2

1. Battery swapping could make electric trucks more appealing by significantly reducing charging time, hence allowing trucks to cover longer distances. As discussed under the Subsection 2.6.3, battery swapping could play a key role in popularizing electric trucks by lowering the initial acquisition cost. The service allows users to pay for battery usage on a per-use basis. The problem with battery swapping is the lack of standardisation as batteries can vary in sizes. It is therefore important that the truck driver would be aware of what type of battery a specific battery swapping provider has access to. Swapping a battery is estimated to take 3–6 minutes which is significantly less than DC fast charging which can take up to 40 minutes when recharging an electric truck.

2. As noted in the geofencing section, the lack of visibility into designated parking areas poses a risk of underutilizing available parking spaces. Geofencing is proposed as a technology that could assist in eliminating this uncertainty by informing the driver about the correct number of vacant parking spaces.

RQ3

1. & 2. The implementation of battery swapping and geofencing can significantly enhance the efficiency and reliability of parking, addressing two key challenges identified in Section 1.2.

Smart roads: cities

The concepts mentioned under Smart roads: highways, GNSS and IAP, are also relevant for this section. The GNSS and IAP could for instance restrict access to a city if the vehicle does not meet the environmental conditions.

RQ2

1. Expert 3 mentioned Green wave as a future technology that could decrees emissions in cities. The Green wave has the ability to reduce heavy vehicle stoppage by communicating traffic light information. The truck driver are then able to control there speed accordingly. This is important because heavy vehicles produce significant emissions during frequent stop-and-go movements.

2. Advanced IAP brings the same benefits for smart roads highways as for road

hauliers.

RQ3

1. The Green wave could therefore reduce emissions, effectively addressing the issue of road freight transport emissions highlighted in Section 1.2.

2. Advanced IAP brings the same benefits for smart roads highways as for road hauliers.

Terminals/Ports

RQ2

1. Expert 8 discussed a forward-looking concept involving the creation of designated loading and unloading zones located just outside the port perimeter. This would avoid external traffic within the port, reducing the traffic congestion, and the external trucks have a shorter handover time. For the system to work smoothly, it would require accurate coordination of arrival times, vehicle details, and container information. An IA system could support this by handling real-time scheduling, verifying digital access, and managing communication between external trucks and the port's internal logistics.

RQ3

1. Designated loading and unloading zones would help ensure quick, reliable, and secure container transfers and improve both scalability and readiness for automation within port operations. This is also relevant for AV ports and terminals within the 5–10 year timeframe and would help address the issue highlighted in Section 1.2, namely inefficiencies in port and terminal operations.

5.2.2 AV

This section explores the expected developments in autonomous vehicles within a 5–10 year horizon, focusing on how future aspects could enable integration with Intelligent Access in road freight transport and port-and-terminal logistics. Regarding the future of autonomous vehicles, it is difficult to predict the time frame of new implementations and developments. This is important to keep in mind, as the analysis focuses on anticipated possibilities within a 5–10 year horizon, though in reality, some aspects may lie much further ahead. With that in mind, this section mainly reflects insights shared by experts during the interview study, as it addresses a more speculative time frame beyond the immediate 0–1 year horizon. Therefore, some aspects discussed are more exploratory in nature, while others are supported by findings from the literature review.

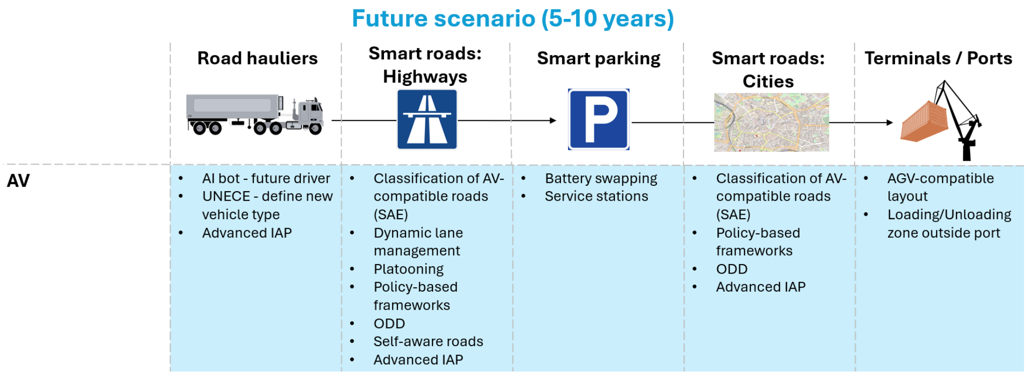

Figure 5.4: AV 5-10 years

Expert 1 discussed how connected and automated vehicles are beginning to incorporate restriction frameworks similar to those used in the Intelligent Access program, including geofencing and time-based travel limitations. The interviewee argued that autonomous vehicles have not yet emerged primarily due to the absence of a national framework. Currently, different regions have varying regulations and requirements, which pose a challenge from a commercial perspective.

Road hauliers

RQ2

1. As Expert 2 discussed, there is a possibility that in the future, autonomous vehicles will be driven by AI bots, making the vehicles much smarter and capable of making more informed decisions on the road. This level of autonomy could reduce human error and create a form of “automated negotiation systems” for access, especially at bottlenecks like terminals or congestion-prone city zones. AI bots can enhance driving efficiency, leading to better use of the infrastructure and reduced wear and tear, hence addressing problems stated in Section 1.2.

2. Expert 4 highlighted the importance of UNECE to add autonomous vehicles to the list of defined vehicles. By defining an AV, there can be better defined operational, legal, and safety standards and frameworks, which would help the implementation of AVs on public roads. These standardized frameworks could then provide a backbone for regulations that can be supervised with IA.

3. For Advanced IAP, the same reasons and arguments mentioned for HCT can be made for AVs.

RQ3

1. With AI bots in both trucks and the infrastructure of ports, they could simplify the communication between them and enhance the effects of Intelligent Access. They can receive and send data to the environment and be programmed to always comply

with the IA rules, making compliance an issue of the past.

2. As mentioned under Subsection 2.4.4, the UNECE framework states that an AV must be able to detect if it is operating outside its ODD, a task that an IA system could help facilitate by collecting information regarding the roads and environment, and matching it to the capabilities of the vehicle. This could simplify the introduction of AVs, tackling the regulatory issues mentioned in Section 1.2.

3. For Advanced IAP, the same reasons and arguments mentioned for HCT can be made for AVs.

Smart roads: highways

RQ2

1. Classifying roads according to the SAE level system has already been explained in Subsection 5.1.2, but for the 5-10 year horizon, this classification can have a bigger impact and be used in a larger context.

2. Under Section 2.5, dynamic lane management is mentioned as a solution to introducing AVs on highways. By collecting data from the roads, such as traffic congestion, accidents, and roadworks, smart roads can allocate lanes specifically for AVs during certain times of the day, so-called AV corridors. This simplifies the AV implementation, and minimizes the mix och manually driven vehicles and AVs.

3. Another concept mentioned in the interview study, and in under Subsection 2.4.2, is platooning. Expert 5 discussed the possibility of platooning in the future and highlighted the need for standardisation within the autonomous vehicle industry to enable collaboration between multiple truck companies.

4. When new traffic rules are introduced, or old ones are changed, it will be necessary to update the software of AVs to make sure they are up-to-code. Under Subsection 2.4.1 , this challenge was addressed through a concept known as policy-based frameworks. These frameworks can be used for defining, managing and distributing traffic rules for AVs. Another application for policy-based frameworks is the prioritization of traffic based on pre-defined hierarchies. For instance, emergency vehicles such as police cars and ambulances could be granted dynamic priority by communicating directly with the infrastructure during call-outs.

5. Two experts mentioned Operational Design Domain (ODD) as a way to enable access control of autonomous vehicles. Truck manufacturers use ODDs to define conditions in which AVs can operate safely, and by integrating them into Intelligent Access, you can grant access to roads based on the vehicle's capabilities. This will make it easier to understand where AVs are allowed to operate.

6. Self-aware roads is described in Subsection 5.1.3, and works the same for both HCT and AVs.

7. Advanced IAP is described in Subsection 5.1.3, and works the same for both HCT and AVs.

RQ3

1. The SAE framework for classifying roads is described in Subsection 5.1.2 how it can be implemented in IA. The same goes for 5-10 years, but now the technology for AVs are expected to be more mature, which means the SAE framework in IA can be used more for compliance, together with a controlled introduction of AVs onto public roads.

2. As mentioned under Section 2.5, dynamic lane management needs an overseeing system that collects the data from the roads, allocates lanes, and communicates this to the vehicles. This would be an appropriate task for IA. By assigning lanes specifically for AVs, these lanes can therefore be given a higher SAE level and allow a higher level of automation. This streamlines the introduction of AVs which was mentioned as an issue in Section 1.2.

3. Platooning needs a standardized system for IA as well, in order to function without any regulatory issues. Platooning is therefore regarded as a concept for the more distant future. If AV corridors are introduced as mentioned above, this would increase to possibility of introducing platooning and make road freight transport more efficient, addressing the problem relating to road efficiency in Section 1.2.

4. Through integration with IA systems, policy-based frameworks can ensure that only AVs with up-to-date regulatory software are granted access to certain road segments or zones. This would enable real-time enforcement of traffic compliance at the software level, rather than relying solely on physical enforcement mechanisms. Ensuring compliance with regulations can be helpful when implementing AVs on public roads. As for the second application of policy-based frameworks, the IA system could automatically reassign traffic signals or restrict access to certain roads in favour of these vehicles, thereby improving emergency response times while maintaining safe and efficient flow for other traffic. Policy-based frameworks are applicable for both smart roads on highways and in cities.

5. When incorporating ODDs into the IA system, it can be used to grant or revoke access to roads for autonomous vehicles based on the vehicle's specifications and capabilities. That means, the IA system uses these ODDs that manufacturers have specified to ensure compliance and that vehicles only use automation on roads where is possible.

6. Self-aware roads is described in Subsection 5.1.3, and works the same for both HCT and AVs.

7. Advanced IAP is described in Subsection 5.1.3, and works the same for both HCT and AVs.

Smart parking

RQ2

1. As mentioned in Subsection 5.1.2, parking is not a necessity for autonomous vehicles since no driver needs to rest. Instead, smart parking can involve other functions and services to accommodate the vehicle instead of the driver. Charging is one example. In the future, more vehicles will run on electricity, but today, the process of charging large electric vehicles takes a lot of time. In Section 5.2.1, a concept called battery swapping was described as a solution to this problem. Instead of charging the battery in the vehicle, the battery is swapped for a new, fully charged. It significantly reduces downtime, making the charging process more efficient. This addresses an issue mentioned in Section 1.2, that long queues to charging stations needs to be avoided by improving the charging infrastructure.

2. To minimize the downtime of AVs, service stations will also be needed, according to Expert 4. Their strategic placement along key transport corridors would ensure that AVs can operate continuously with minimal interruptions.

RQ3

1. Battery swapping stations could be integrated into the IA system, enabling autonomous vehicles to optimize route planning and maintain continuous operation. Information such as location, time-slot reservations, and queue durations could be communicated through the IA system, which could also govern and manage access to these locations.

2. These can be incorporated into IA in the same way as battery swapping stations, with location, time-slot reservations, and queue time as useful information attributes. When AVs gain access to these locations through IA, they can plan their routes more effectively and operate with greater efficiency. It could also lead to a easier introduction of AVs, a problem stated in Section 1.2.

Smart roads: cities

RQ2

1. As mentioned before, SAE classifications can have a bigger impact in the distant future than in a 0-1 year perspective. City road segments could be designated for specific SAE levels to balance automation benefits with safety and social acceptance. For instance, AVs operating at Level 4 might be allowed to perform night-time deliveries in pedestrian-heavy districts, while Level 2 vehicles remain restricted to busier roads and times.

2. What was written above regarding policy-based frameworks for smart highways is also applicable to smart roads in cities.

3. ODDs are described above for smart roads and highways, and the same applies to smart roads cities.

4. Advanced IAP is described in Subsection 5.1.3, and works the same for both HCT and AVs.

RQ3

1. For IA, SAE levels would allow flexible control of access permissions based on time, zone, and vehicle characteristics. It could support the introduction of AVs on public roads, addressing what is identified in Section 1.2 as the primary challenge facing autonomous vehicles today.

2. What was written above regarding policy-based frameworks for smart highways is also applicable to smart roads in cities.

3. ODDs are described above for smart roads and highways, and the same applies to smart roads cities.

4. Advanced IAP is described in Subsection 5.1.3, and works the same for both HCT and AVs.

Terminals/Ports

RQ2

1. Expert 8 discussed how ports with AGVs have to design their infrastructure to be AGV-compatible. These changes can be done gradually and may take a longer time to fully implement than 5-10 years, but it is an important step when going fully automated. Before external trucks are automated, more ports will use AGVs and more sophisticated autonomous vehicles for their internal processes, leading to a mix between automated on manually driven vehicles. This will have to be considered when designing ports, as it could be a problem for otherwise.

2. Loading/Unloading zone outside port is explained in Subsection 5.1.3 for HCT 5-10 years, and it would work the same for AVs as well.

RQ3

1. For AGV-compatible layouts to work, IA could be used to govern the access to the port, verifying vehicle ID, load compliance, and slot assignments and manage the connection between the AGV fleet and the external trucks. By having either V2V communication between AGVs and trucks or I2V between the port and the trucks, the container handover process can be optimized. This would improve overall port efficiency, an issue identified in Section 1.2.

2. Loading/Unloading zone outside port is explained in Subsection 5.1.3 for HCT 5-10 years, and it would work the same for AVs as well.

6
Discussion

The first section of this chapter presents the potential benefits that the aspects connected to autonomous vehicles and high-capacity transport can deliver in both the short term (0–1 years) and long term (5–10 years). These benefits arise from the integration of the different aspects into Intelligent Access systems. The second section presents additional reflections and insights that have emerged throughout the course of this report.

6.1 How aspects affect IA

This section of the discussion explores how the previously analyzed aspects are integrated into the IA matrix, which was developed to assess how they influence Intelligent Access in road freight transport, as well as terminal and port logistics.

6.1.1 HCT aspects 0-1 years

This section presents the potential benefits that high capacity transport can deliver within 0–1 years through the integration of different aspects into Intelligent Access.

IA Factors	Better use of existing infrastructure with traffic management based on time and place;	Less degradation of road infrastructure through improved management of weight, speed and routing of heavy vehicles;	Realizing climate objectives by reducing congestion and prioritizing climate-friendly vehicles;	Increasing road safety through, for example, less overloading or improved insight into where safety incidents arise on the road network;	Creation of a level playing field between different haulers/carriers, improving compliance by haulers/carriers with regulations as set out by NRAs;	Improved control of the transport of abnormal loads and dangerous goods;	Controlled introduction of High Capacity Vehicles/ Autonomous Vehicles;	Improved efficiency in ports and terminals;
HCT	• PBS • Geofencing • Web and app-based parking services • Faster permits • Road and bridge classification • Urban Vehicle Access Regulation	• PBS • Geofencing • Road and bridge classification • Point-based restriction • IAP	• Geofencing • Urban Vehicle Access Regulation	• Geofencing • Safe parking • Web and app-based parking services • Faster permits	• IAP • Faster permits • Point-based restriction	• IAP	• PBS • IAP • Road and bridge classification • Point-based restriction	• New vehicle combination • App for queuing status and parking availability

Figure 6.1: HCT 0-1 years

PBS and road and bridge classification

PBS and road and bridge classification have been recognized as frameworks that offer numerous significant benefits. By integrating the framework into the IA system, national road authorities can ensure that the right vehicle is matched with the appropriate road or bridge. This will enable the safe introduction of HCTs, which in turn will improve the utilization of existing infrastructure and reduce emissions as HCTs emit less per ton of transported goods compared to regular trucks. Increased use of HCTs will also lead to less degradation of infrastructure, as fewer trucks will be required to perform the same transport tasks. Safety will increase since fewer vehicles will be operating on the roads. All of these issues are mentioned as problems in Section 1.2.

Geofencing

Geofencing can be used to restrict vehicles from certain parts of a road network which can offer several benefits to the road infrastructure. It can improve use of existing infrastructure by ensuring that the right vehicle is on the right road which in turn leads to less degradation of the infrastructure. For instance, HCT vehicles should not have access to all parts of the road network as it may damage the infrastructure. Geofencing can also be used to realize climate objectives within a city by restricting access to vehicles that do not meet stipulated emission standards. The technology could also help prevent overloading on bridges and other sensitive infrastructure by limiting the amount of throttle a vehicle is permitted to use and thereby addressing the problems regarding degradation of road infrastructure and road freight transport emissions stated in Section 1.2.

Web and app-based parking services/safe parking

By integrating web and app-based parking services into IA, drivers' journey will be improved as it makes it more predictable. Less time will be wasted searching for a suitable rest stop as parking spaces will be able to be reserved in advance. It will also enhance road safety by reducing the number of illegal parking incidents, which often result from rigid permitted working hours and limited knowledge of available parking spaces. By parking illegally, the driver exposes themselves to risk, therefore, the service also makes parking safer which addresses the problem mentioned in Section 1.2.

Faster permits

Faster permits will make better use of existing infrastructure as more vehicles will be allowed to travel on specific roads, tunnels or bridges that they otherwise would not be allowed to. By streamlining the process through integration with the IA system, hauliers can more efficiently operate HCTs, making it easier to carry out their tasks and encouraging greater investment in this vehicle type. By making permits easier to get access to, more hauliers will get them. This will enhance legal compliance, contributing to a more level playing field within the industry. Slow permit processes is mentioned in Section 1.2 as problem for hauliers, which is addressed with this solution.

IAP

IAP today bring many benefits to the NRA is Australia. It creates a level playing field by making non-compliance costly. IAP also supports the controlled introduction of HCTs by ensuring that infrastructure limits are not exceeded. This in turn leads to less degradation of road infrastructure. IAP improves oversight of abnormal loads and hazardous materials by preventing their access to unauthorized areas. IAP therefore have the ability to solve the issue regarding complican stated in Section 1.2.

Point-based restriction

Point-based restriction could be used in the near future to monitor traffic activity to make sure that road and bridge limits are not exceeded, hence minimizing infrastructure degradation which is an issue raised in Section 1.2. By monitoring truck activity, the technology creates a level playing field by ensuring that drivers who not comply with regulations are fined. Moreover, the technology supports a controlled introduction of HCT, based on the reasoning outlined above. In conjunction with Automatic Number Plate Recognition (ANPR), this can serve as a forerunner to IA before it becomes fully implemented.

Urban vehicle access regulation

By integrating UVAR objectives and technologies into IA, many benefits can be achieved. most notably, it has the potential to make cities more environmentally friendly by reducing congestion and denying non polluting vehicles access. Infrastructure will be better utilized as congestion is a major factor contributing to its inefficiency. Emissions and inefficient infrastructure use are two problems mentioned in Section 1.2, which can be addressed with the help of UVAR.

New vehicle combination

New vehicle combination, like the "link solution", would make process in port more efficient which was stated as a problem in Section 1.2. By integrating the "link solution" into the regulatory framework, IA could grant access for the new vehicle combination in the same way it does for other HCTs.

App for queuing status and parking availability

By incorporating queuing status and parking availability into the IA system, the handling of containers in ports will become more efficient. Truck driver could adjust there arrival time based on the queuing time and parking availability to make their visit to the port as short as possible. IA can in this way help minimize the problem regarding inefficient ports, as stated in Section 1.2.

6.1.2 AV aspects 0-1 years

This section presents the potential benefits that autonomous vehicles can deliver within 0–1 years through the integration of different aspects into Intelligent Access.

IA Factors	Better use of existing infrastructure with traffic management based on time and place;	Less degradation of road infrastructure through improved management of weight, speed and routing of heavy vehicles;	Realizing climate objectives by reducing congestion and prioritizing climate-friendly vehicles;	Increasing road safety through, for example, less overloading or improved insight into where safety incidents arise on the road network;	Creation of a level playing field between different haulers/carriers, improving compliance by haulers/carriers with regulations as set out by NRAs;	Improved control of the transport of abnormal loads and dangerous goods;	Controlled introduction of High Capacity Vehicles/ Autonomous Vehicles;	Improved efficiency in ports and terminals;
AV	• Classification of AV-compatible roads (SAE)						• Classification of AV-compatible roads (SAE)	• AGV

Figure 6.2: AV 0-1 years

Classification of AV-compatible roads (SAE)

By classifying roads according to the SAE levels, the map covering the different levels on different roads can be integrated into the IA system to make sure the right vehicle is on the right road at the right time. Restricting certain automation levels to specific roads allows for more efficient use of infrastructure by aligning vehicle capabilities with traffic conditions based on location and time. Therefore, this framework together with IA is categorized as a way to use the infrastructure in a better way.

The classification of AV-compatible roads (SAE) also helps to introduce AVs in a controlled way, by having a standardized framework to determine which vehicles are permitted on which roads and thereby addressing the issue stated in Section

1.2. For example, highways with clear markings and low pedestrian traffic might be approved for level 3 and above, with IA preventing vehicles with lower levels from operating beyond their capabilities. When the technology matures, the levels can be gradually updated to allow higher levels of automation on more roads. This framework therefore leads to a more controlled introduction of AVs.

AGV

AGVs have been described throughout the report as an efficient substitute for manually driven vehicles within confined areas. Since they only operate within the port or terminal, there are fewer unknown variables and infrastructure limitations, and therefore it is a simpler environment to adopt automation in. By integrating external data such as truck and ship estimated time of arrival with the help of IA, AGVs can anticipate tasks and better coordinate their routes and schedules. Implementing AGVs together with IA will increase the operational efficiency in the ports, minimizing the problem mentioned in Section 1.2, and allowing more containers to be processed.

6.1.3 HCT aspects 5-10 years

This section presents the potential benefits that high capacity transport can deliver within 5-10 years through the integration of different aspects into Intelligent Access.

IA Factors	Better use of existing infrastructure with traffic management based on time and place;	Less degradation of road infrastructure through improved management of weight, speed and routing of heavy vehicles;	Realizing climate objectives by reducing congestion and prioritizing climate-friendly vehicles;	Increasing road safety through, for example, less overloading or improved insight into where safety incidents arise on the road network;	Creation of a level playing field between different haulers/carriers, improving compliance by haulers/carriers with regulations as set out by NRAs;	Improved control of the transport of abnormal loads and dangerous goods;	Controlled introduction of High Capacity Vehicles/ Autonomous Vehicles;	Improved efficiency in ports and terminals;
HCT	• Battery swapping • Geofencing	• IA loading • Advanced IAP • Self-aware roads	• Green wave • GNSS • Advanced IAP	• IA loading • Advanced IAP • Self-aware roads	• Advanced IAP	• Advanced IAP	• Advanced IAP	• Loading/ Unloading zone outside port • Dynamic arrival estimation

Figure 6.3: HCT 5-10 years

IA loading

IA loading helps reduce the risk of overloading and axle overloading, which in turn decreases road degradation and improve road safety. Two issues which were mentioned under Section 1.2.

Advanced IAP

Less road degradation will occur by incorporating weight distribution and axle load into the IA system. This will will provide valuable knowledge to the NRAs which can be used to upgrade roads and bridges before it is to late. By also using this information for compliance, fewer drivers will load their vehicles incorrectly which in turn will make roads safer. By discouraging manipulation of load capacity and distribution, advanced IAP helps ensure fairer competition among road hauliers. Similarly as in the case of IAP 0-1 year, Advanced IAP will also enhance the control of abnormal and dangerous goods while simultaneously supporting the safe introduction of HCTs on the roads. Many of the issues tackled by advanced IAP are mention in Section 1.2 as problems facing the road freight transport industry.

GNSS

GNSS as part of the UVAR can be integrated into the IA system to improve environmental objectives within cities by restricting polluting vehicles from entering which ,in turn, address the problems related to emissions in Section 1.2.

Self-aware roads

Self-aware roads can, with the help of sensors and cameras, detect where traffic congestion is peaking and where the wear and tear on the roads is most likely the highest. With this information uploaded into the IA system, road authorities have a better understanding of where investments into the infrastructure should be made, which in the long run will reduce the degradation of the infrastructure. The traffic information collected from the self-aware roads can also be used by trucks to determine which route to take, which can lead to less congested roads and thereby increased safety. The insight into where safety incidents arise also increases, and this information can be used by the road authorities to make informed decisions on investments to increase safety. Infrastructure can be used in a better way, and road degradations can be minimized, which are both problems highlighted in Section 1.2.

Battery swapping

Being able to swap an empty battery for a new, fully charged one will save time for electric trucks in the future. This solution will lead to a better use of charging stations since less time can be spent waiting, and more trucks can be served per hour. The infrastructure is therefore used in a better, more time-efficient way than if a truck had to charge its battery for 40 minutes, causing queues and reducing road time. The potential to reduce congestion through battery swapping directly addresses the congestion-related issue highlighted in Section 1.2.

Geofencing

Geofencing used for parking monitoring can improve the use of existing infrastructure by reduce time spent on finding a suitable resting area. This IA application can help reduce inefficient use of infrastructure which is a problem stated in Section 1.2.

Green wave

By reducing stoppage for heavy vehicles, Green wave can assist in realizing climate objectives within cities when integrated into IA. Polution connected to heavy vehicles is a huge problem, as mentioned in Section 1.2, and this usage of IA can help reduce it.

Loading/Unloading zone outside port

A dedicated loading and unloading zone outside the port minimizes the congestion within the port and terminal area, since external trucks don't have to go inside to pick up or leave the load. The port's infrastructure can therefore be used in a better, more efficient way when the internal vehicles don't have to consider outside traffic. It will also lead to less degradation within the port terminal, as it minimizes heavy vehicles from using the infrastructure inside the port. This is especially beneficial for structurally sensitive areas such as bridges and tunnels, which are often more vulnerable to damage.

Less traffic inside the port leads to less congestion, and external trucks have a shorter route to travel when reaching the port. This causes less emissions, and the port can be seen as an emission-free zone. Less congestion will also help improve the operational efficiency within the port, as the internal vehicles can operate without needing to consider external vehicles within the port area. This addresses the issue of inefficient port and terminal operations highlighted in Section 1.2.

6.1.4 AV 5-10 years

This section presents the potential benefits that autonomous vehicles can deliver within 5-10 years through the integration of different aspects into Intelligent Access.

IA Factors	Better use of existing infrastructure with traffic management based on time and place;	Less degradation of road infrastructure through improved management of weight, speed and routing of heavy vehicles;	Realizing climate objectives by reducing congestion and prioritizing climate-friendly vehicles;	Increasing road safety through, for example, less overloading or improved insight into where safety incidents arise on the road network;	Creation of a level playing field between different haulers/carriers, improving compliance by haulers/carriers with regulations as set out by NRAs;	Improved control of the transport of abnormal loads and dangerous goods;	Controlled introduction of High Capacity Vehicles/ Autonomous Vehicles;	Improved efficiency in ports and terminals;
AV	• AI-Bot • Platooning • Classification of AV-compatible roads (SAE) • Loading/ Unloading zone outside port • AGV-compatible layout • Dynamic lane management • Battery swapping	• AI-Bot • IA loading • Loading/ Unloading zone outside port • Self-aware roads	• AI-Bot • Platooning • Loading/ Unloading zone outside port	• IA loading • Advanced IAP • Self-aware roads • Dynamic lane management	• Policy-based frameworks • ODD • Advanced IAP	• Advanced IAP	• UNECE • Service stations • Classification of AV-compatible roads (SAE) • Policy-based frameworks • Dynamic lane management	• AGV-compatible layout • Loading/ Unloading zone outside port

Figure 6.4: AV 5-10 years

AI bot –future driver

The future of AI is unpredictable, but as Expert 2 said, there is a possibility that AVs will have AI-bots controlling the vehicle in the future. These bots will be able to use AI technology to process both internal vehicle data and external inputs from IA systems in a more sophisticated way, leading to better decision-making and more efficient driving. Therefore, the infrastructure will be used in a better way, leading to less traffic congestion and less degradation of roads. The vehicles will also be able to be operated in a more environmentally friendly way, reducing congestion and lowering emissions, which will lead to greener logistics. For these reasons, AI-bot is categorized as leading to better use of infrastructure, less road degradation and lowering emissions, all of which are problems stated in Section 1.2.

UNECE - define new vehicle type

If UNECE defines a new vehicle type, namely an automated vehicle, it will lead to more standardization when it comes to operational, legal, and safety standards. This will lead to a more controlled introduction of AVs to public roads and help speed up the process, which is the reason the concept is categorized under that column in the matrix. Helping the AV introduction addresses the problem regarding AVs in Section 1.2.

IA loading

IA loading can achieve the same benefits for AV as for HCT, see Subsection 5.2.3.

Advanced IAP

The same reasoning and arguments used in Subsection 6.1.3 for HCT 5-10 years.

Classification of AV-compatible roads (SAE)

This framework is categorized similarly to the AVs 0-1 years, as it focuses on using the infrastructure in a better way and helping introduce AVs in a controlled way. The same arguments that was applied to the 0-1 year timeframe can also be applied for the 5-10 year perspective.

Dynamic lane management

Dynamic lane management helps use the infrastructure in a better way. It allows AVs to avoid mixing with manually driven vehicles during certain traffic conditions and allocates traffic more efficiently. IA systems can grant or revoke access to certain lanes, based on conditions such as time, traffic congestion, and SAE level of the vehicle. This will also increase the safety on the roads, since avoiding mixing automated vehicles with human-driven vehicles reduces unpredictable interactions. This tackles the safety concerns, as well as inefficient use of infrastructure, outlined in Section 1.2.

Having dedicated lanes for AVs at certain traffic and road conditions will also help control the introduction of AVs on public roads. It will be easier to test AVs without having to mix with human-driven vehicles, and safety can therefore be increased.

Platooning

Platooning allows trucks to travel with closer distance, which takes up less space and therefore uses the infrastructure in a better way. Since it also reduces the air resistance for most of the trucks in the platoon, it contributes to lower fuel consumption and reduces congestion, which leads to greener logistics. Emissions and inefficient use of infrastructure are both problems stated in Section 1.2, which platooning confronts.

Policy-based frameworks

By implementing policy-based frameworks into the IA system, it creates a more level playing field for hauliers since it makes sure every vehicle is fully updated regarding traffic rules and regulations. Every AV that is allowed on the roads is equally updated, and compliance is therefore guaranteed. By ensuring that the vehicles comply with the rules and regulations, the introduction of AVs is better controlled. Section 1.2 highlights that AVs are currently restricted from public roads, and these types of frameworks could help overcome that barrier.

ODD

By using ODD's and incorporating them into IA, the IA system can make sure to grant or revoke access to certain road segments based on what ODD that the vehicle has. This will enhance the compliance by hauliers and carriers, since their vehicles have to follow the regulations based on what the manufacturers have specified regarding the vehicle. The incorporation of ODDs into IA would therefore potentially improve compliance which was an area of concern mentioned in 1.2.

Self-aware roads

The same reasoning and arguments used in Subsection 6.1.3 for HCT 5-10 years.

Battery swapping

The same reasoning and arguments used in Subsection 6.1.3 for HCT 5-10 years.

Service stations

By incorporating service stations along the roads for AVs to use, AVs can use these stations when needed if something breaks down in the hardware of the vehicle. This helps ensure that only roadworthy vehicles are in operation, leading to a more controlled introduction of AVs. IA can be used to locate service stations for AVs, check for wait times, and reserve available slots as needed. Service stations thereby address road safety concerns and support the controlled introduction of autonomous vehicles, two issues mentioned in Section 1.2.

AGV-compatible layout

By improving the layout of ports to better suit AGVs, the infrastructure is used in a better way to fully achieve the benefits of the AGVs. AGVs- compatible layouts therefore addresses the issue regarding port inefficiency as mention under Section 1.2. With dedicated AGV lanes and minimal conflict points with human-driven vehicles, congestion and waiting time can be reduced. This leads to better efficiency in the operational processes in the port. When the port is integrated into the IA system, the AGV-compatible layout can be digitally managed, improving internal logistics and reducing turnaround time for external trucks.

Loading/Unloading zone outside port

The same reasoning and arguments used in Subsection 6.1.3 for HCT 5-10 years.

6.2 Further Reflections

In this section, reflections are presented based on thoughts derived from the literature review and the interview study. It includes both problems with IA as well as suggestions for future development.

Data sharing

Firstly, one of the main problems that was identified with IA was the data sharing aspect of the technology. Multiple experts said that this was the single most problematic side to IA, especially since Europe has very strict privacy laws in the form of GDPR. In the road freight transport industry, there is also a resistance to sharing data regarding the driver and their position, as it might infringe upon their privacy. This type of information is crucial for IA to work. Expert 1 discussed this issue with regard to how IA has been implemented in Australia. Australia almost has as strict privacy laws as the EU. However, the expert explained that this issue was addressed by ensuring that only vehicle-related information was collected, with no data gathered about the driver. While this might be true, a road haulier company, when faced with a ticket from the IA system, can easily determine which driver caused it by checking the company's driver schedule. Therefore, personal driving data will be shared indirectly. For the IA system to work for everyone, including the drivers, this issue needs to be considered. One suggestion is to disallow companies from using that type of information to fire or reprimand drivers, to ensure their privacy.

Furthermore, companies will most likely be reluctant to share their data if there is no incentive structure that motivates them to take part in the IA system. There have to be clear objectives and benefits for every involved party, otherwise, the work and investments will be seen as unnecessary. Transport companies already operate on slim margins, which means that there is not a lot of room for investments in the first place. Therefore, incentives and benefits are of high importance for IA to work.

Standards in Europe

European countries have different road and bridge standards, classifications and HCT regulatory frameworks which hinder the full potential of HCTs. For instance, a Swedish HCT truck would not be able to travel to Spain by road. Harmonized HCT frameworks and regulations across Europe would help the HCT implementation and make cross-border road freight transport easier and more efficient. For example, if every European country allows the same length and weight for trucks, as well as axle load, the need to reload trucks when entering a new country would disappear.

In the near future, AVs is likely to play a major part in the transportation industry across Europe. Using the same reasoning as for HCT, there will be a need to standardize rules and regulations for AVs as well. This will be more challenging since there are more parameters to consider for AVs than HCTs. It would be highly beneficial if the government and the OEMs agree upon a common framework that contains AV standardization based on ODD constraints. As mentioned in section 2.4, there are currently frameworks like this in development. By implementing ODDs in the IA system, vehicles can be granted access to roads that fit their respective ODD, enforcing the right vehicle on the right road. This framework, along with previously mentioned ones like the SAE road classification, needs to be harmonized across Europe to ensure an efficient and coordinated implementation of autonomous vehicles.

On the same topic, the creation of EU-wide standards is necessary to ensure IA functionality beyond national borders. If every country has its own system and regulations, cross-border transport will be more difficult than it needs to be. A fragmented system would hinder a unified implementation of HCTs and AVs, while a harmonized IA system could define shared access conditions such as SAE levels, vehicle length, parking locations, and axle weight limits.

Smart vehicles or Smart infrastructure?

Smart roads will demand large investments from NRAs. Will this be necessary if AVs become as good or better than a human-driven vehicle? A fully self-driving car should be able to operate without any need for internet connection, meaning it should not need to rely on smart infrastructure. Therefore, investments in smart infrastructure may be unnecessary as they will not be needed for the introduction of AVs. OEMs are also unwilling to use third-party data to ensure vehicle operability, since problems can arise from accidents that happen based on faulty data. Smart infrastructure may therefore not be needed from the perspective of vehicle operators.

However, smart infrastructure could assist NRAs in predicting road and bridge degradation by measuring traffic and weather conditions and sharing that data. This data enables informed decisions about infrastructure investments, helping to prevent significant damage to roads, bridges, and tunnels before it is too late. With that said, before making large investments in smart roads, the potential benefits have to be compared to the costs. Moreover, smart infrastructure makes sense when it is an enclosed area, like ports or terminals. Vehicles in these environments are more automated than autonomous, meaning they cannot make their own decisions, and are therefore dependent on smart infrastructure.

Concluding reflection

This report presents many technological solutions, which could make it challenging for drivers to keep up with the various apps and services required to perform their job effectively and correctly. It is therefore necessary to integrate all these apps and services into a single, unified ecosystem, as described by Expert 6. For instance, it was noticed that truck parking apps did not cover all of Europe. It is therefore more or less impossible to travel through all of Europe by using one single app and the task became even more difficult once criteria were added to the parking facility. Keeping track of every parking app or installing a separate ’black box’ to comply with each country’s IA regulations would be too complex. There needs to be a system that consolidates all this information and presents it to the driver in a simple, accessible way.

7
Conclusion

The purpose of this thesis was to investigate contemporary and future aspects of autonomous driving, HCT, smart roads and smart parking to achieve IA for road freight transport and port- and terminal logistics. Three research questions were raised: What are the characteristics of autonomous driving, high capacity transport, smart roads and smart parking in road freight transport and port- and terminal logistics?, What are the contemporary and future aspects of autonomous driving, high capacity transport, smart roads and smart parking for Intelligent Access in road freight transport and port-and terminal logistics?, and How can these contemporary and future aspects affect Intelligent Access in road freight transport and port-and terminal logistics? A literature review was conducted, followed by an interview study including 10 interviews, to answer these questions and analyze the contemporary and future possible concepts that could use and enhance IA.

The key findings reveal that standardization, digital infrastructure, and coordinated policy frameworks will be crucial in enabling the successful implementation of IA. By exploring aspects such as High-Capacity Transport (HCT), autonomous vehicles (AVs), smart roads, and smart parking, the thesis has investigated how these areas can make road freight transport more efficient, safer, and more environmentally friendly.

The empirical findings from expert interviews reinforced the theoretical insights and gave some new perspectives. Some of the IA benefits that were highlighted by the experts included faster permit process, improved compliance and reduced emissions. However, concerns about implementing an IA system were also raised as the system may infringe on driver's privacy. Reluctance to sharing data was also mentioned as a challenge if there were no incentive structures in place.

The analysis of contemporary and future aspects showed that while many technical solutions and regulatory frameworks already exist or are in development, such as geofencing, road classifications, Performance Based Standards, and the Intelligent Access Program, fragmented regulations and infrastructure readiness remain major barriers. Differing regulations across EU member states pose challenges to scaling IA solutions across borders. This gap highlights the importance of a harmonized policy approach.

Despite the challenges associated with IA, the potential benefits of the system are significant. IA systems can contribute to better use of existing road capacity, lower environmental impact, and increased safety through more controlled access based on vehicle and infrastructure compatibility. In ports and terminals, IA can help to make operations more efficient and coordinate access in real time. Future development should prioritize the integration of AV and HCT policies with IA frameworks, ensuring that technological progress is matched with governance structures that support widespread, equitable, and secure implementation.

The analysis matrix can be used to evaluate the entire journey of a High-Capacity Transport vehicle or Autonomous Vehicle from a holistic perspective. It provides guidance to National Road Authorities and other stakeholders aiming to optimize road freight transport—by ensuring the right vehicle, with the right load, is on the right road at the right time. Additionally, findings from the literature review and empirical data highlight how Intelligent Access can support National Road Authorities in facilitating the controlled introduction of autonomous vehicles.

Further research is recommended to investigate more specifically how operational design domains can be integrated into Intelligent Access to streamline the introduction of autonomous vehicles. Furthermore, future research should focus on how Intelligent Access can support the harmonized introduction of High Capacity Transport across Europe.

By laying the groundwork for controlled and sustainable implementation of emerging technologies, concepts, and frameworks, this thesis contributes to the broader discourse on the digital transformation of freight mobility in Europe.

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A

Appendix A

Information Attributes Smart Parking

TRAVIS

Truck Wash

- Cleaning load compartment
- Self-service programs
- NAO Certified
- Disinfection of load compartment

Tank Cleaning

- ECD
- Disinfection of load compartment

Repair Truck Parking

- Cleaning load compartment
- Self-service programs
- NAO Certified
- Disinfection of load compartment

Truck Parking

- Compare prices

- Fence height > 1.80m and fully surrounded
- Lightning is on at night
- Camera security
- Security guard
- Toilet (24h accessible)
- Shower (24h accessible)
- Wifi
- Acceptance of running refrigerated trailers
- Electric charging available for refrigerated trailers
- ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road in English)
- Long time parking (more than 7 days)
- Decoupling of trailers (Trailer drop off)
- Hotel
- Restaurant

Truck charging

Bosch Secure Truck Parking

Security

- Restricted vehicle access
- CCTV
- Guard personnel (24 hours) or control center
- Gate
- Lighting
- Certified
- Personal access control
- Extra long truck allowed

For the driver

- Restroom
- WIFI
- 24/7
- Reservable
- Accommodation
- Restaurant / Shop
- Shower
- App parking

For truck

- Diesel
- Electric charging
- Truck wash
- Truck repair
- Mobile ticket payment
- Petrol station
- Liquefied natural gas
- Hydrogen
- Electricity supply for Frigo
- Decoupling of trailer

Authentication

- Licence plate
- QR-code
- Reception parking
- Flow parking
- Internetlink

Additionally

- Opening hours
- Parking fees (net)
- Parking spaces
- Now available
- Service provider
- Description
- Entry

B

Appendix B

Interview Guide

This master's thesis is part of the European funded research project ISAC (Intelligent Surface Access Community) that aims to improve Intelligent Access (IA) to optimize infrastructure capacity and promote more environmentally sustainable freight transport. IA is achieved when "the right vehicle with the right load is on the right road at the right time". The purpose of this thesis is to explore what and how automated driving, high-capacity transport (HCT), smart roads, and smart parking can affect IA for road freight transport and terminal-port logistics. The thesis addresses this purpose by identifying what frameworks are contemporary and planned for the future and how they, respectively, can affect IA.

General:

1. Can you briefly describe your background and experience related to autonomous driving, smart roads, smart parking, or HCT?
2. How familiar are you with intelligent access in road freight transport and port-terminal logistics, and if you are, how do you define it?

RQ2: What are the Contemporary and future autonomous driving, smart roads and smart parking frameworks for intelligent access in road freight transport and port- and terminal logistics.

1. What existing frameworks are currently being used for autonomous driving, smart roads, smart parking and HCT?
2. From the list of information attributes that are connected to the relevant frameworks, which do you believe are the most relevant ones for autonomous driving / HCT / smart roads / smart parking? Would you like to add some information attributes that you think are missing in the list?

Information attributes HCT:

- Road Hauliers: Weight, Length, Turning radius, Axle configuration
- Smart roads, Highways: Traffic info, Weather info, Accident info, PBS, Bridge loading
- Smart parking: Parking status, Charging status, Extra long truck allowed, Reservable, Trailer drop of, Security cameras, Opening hours
- Smart roads, cities: Weight, Length, Turning radius, Axle configuration, PBS, Bridge loading
- Ports and terminals: ETA, Type of load, Extra long truck allowed, Vehicle ID, Load status, Queuing status, Opening hours
-

Information attributes AV:

- Road Hauliers: Real-time vehicle monitoring, Degree of autonomous driving
- Smart roads, Highways: Traffic info, Weather info, Accident info, Visible guiding lines
- Smart parking: Parking status, Charging status, Reservable, Trailer drop of, Security cameras, Opening hours
- Smart roads, cities: Traffic info, Weather info, Accident info, Visible guiding lines
- Ports and terminals: ETA, Type of load, Access into port, Vehicle ID, Load status, Queuing status, Opening hours

3. How do you see these frameworks evolving in the next 5-10 years? Any new ones?
4. Are there specific innovations or research areas that you believe will significantly impact future developments?
5. What are the key factors for successful implementation of these frameworks in real-world road freight transport and terminal-port logistics operations?

RQ3: How can these contemporary and future frameworks affect intelligent access in road freight transport and port- and terminal logistics

1. In what ways can (the identified framework of) autonomous driving, smart roads, smart parking and HCT enhance intelligent access to road freight transport and port- and terminal logistics?

2. From the list of potential effects of IA, which of them do you think would be affected by the contemporary and the future frameworks, respectively?

- Better use of existing infrastructure with traffic management based on time and place;
- Less degradation of road infrastructure through improved management of weight, speed and routing of heavy vehicles;
- Realizing climate objectives by reducing congestion and prioritizing climate-friendly vehicles, for example management of low emission zones, and this will give more transparent and greener logistics;
- Increasing road safety through, for example, less overloading or improved insight into where safety incidents arise on the road network;
- Creation of a level playing field between different haulers/carriers, improving compliance by haulers/carriers with regulations as set out by NRAs; Improved control of the transport of abnormal loads and dangerous goods;
- Controlled introduction of High Capacity Vehicles; Faster and more unified and controlled processing of transport documents in cross-border transport through digitalization.

Others:

1. In your opinion, what are the biggest challenges to achieve IA in road freight transport and port-terminal logistics?

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