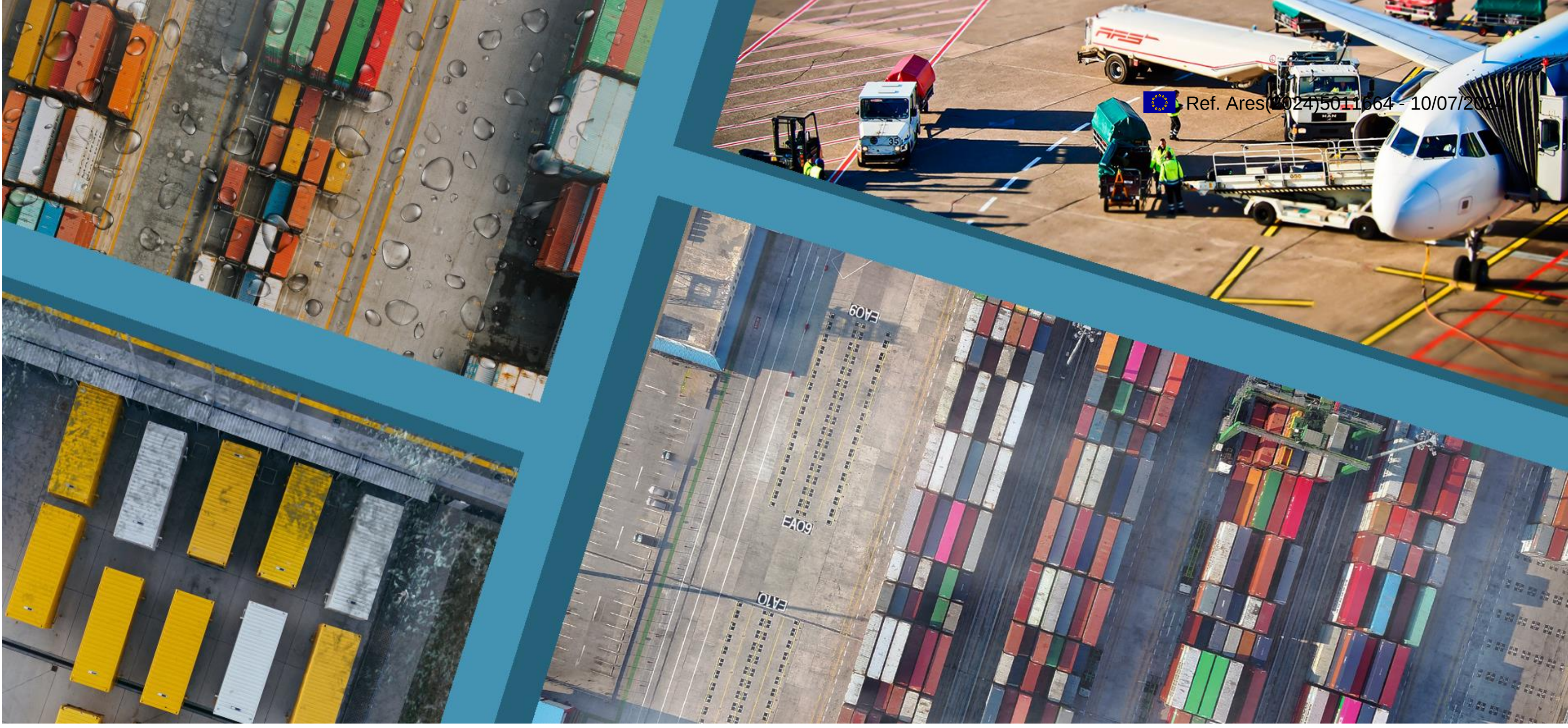

AWARD
Scaling autonomous logistics

D7.3
Impact Assessment and User Survey Results

Lead: ENIDE

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List of acronyms

ADS	Autonomous Driving System
AGTS	Automated Ground Transport Systems
AGV	Automated Guided Vehicle
AQI	Air Quality Index
AV	Autonomous Vehicle
C2C	Cradle-to-Cradle
CNEL	Community Noise Equivalent Level
CO2	Carbon dioxide
EASA	European Union Aviation Safety Agency
EU	European Union
EPDs	Environmental Product Declarations
FMS	Fleet Management System
GHG	Greenhouse Gas
GWP	Global Warming Potential
HDV	Heavy-Duty Vehicles
IPPC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
MTBF	Mean-Time Between Failure
MTBO	Mean-Time Between Overtakes
MTBS	Mean-Time Between Stops
NAAQS	National Ambient Air Quality Standards
NOx	Nitrogen Oxides
PM	Particulate Matter
SEL	Sound Exposure Level
TTW	Tank-to-Wheel
WTW	Well-to-Wheel

Executive Summary

The Deliverable D7.3 serves as an impact assessment report, offering a comprehensive cross-sector and cross-pilot evaluation within the AWARD project, encompassing data collection, analysis of results achieved by pilots, and considerations for scaling up similar operations with a larger fleet of automated vehicles. This executive summary provides an overview of the key aspects that will be analyzed and reported in detail within D7.3.

The AWARD project has made significant progress in testing and implementing autonomous vehicles (AVs) across diverse use cases, including airports, ports, and industrial settings. The primary objective of Work Package 7 (WP7) is to evaluate the impact of autonomous systems on safety, efficiency, environmental considerations, and socio-economic factors, from a user and stakeholders' perspective.

Safety assessments indicate a notable reduction in accidents and incidents attributed to human factors with the deployment of autonomous vehicles, averaging around 30% at ports and airport sites. Similarly, in forklift operations, automation is expected to eliminate major accident types, such as vehicles tipping over in tight turns. However, these benefits are likely to be diminished by an increase in overtaking incidents, as we observed frequent overtaking maneuvers which could eventually lead to accidents. In hub-to-hub operations, a significant reduction is also anticipated in factory areas, but public road segments remain more complex to evaluate due to current technical limitations. The primary safety benefits of automation involve reducing minor collisions and small dents in vehicles through collision avoidance systems. Nevertheless, human intervention remains crucial in challenging operational conditions, with FMS providing supportive assistance.

Efficiency gains are observed in various operational aspects, such as fleet management and time savings. While automation may not always be faster than manual vehicles, it generally meets existing requirements. Additionally, automation frees up resources by reducing the need for human labor. For example, the use of autonomous forklifts in supermarkets allows workers to keep their core responsibilities uninterrupted and not focus on unloading tasks. At airports, autonomous baggage tractors are expected leading to an estimated overall operational cost reduction, particularly for large fleets. This can offer significant cost savings by reducing the need for human drivers, potentially cutting costs by up to 85% in a fleet of 30 vehicles after installation. However, this presents another challenge: in cases involving only one vehicle, innovative business or process ideas are essential to maximize the benefits of automation. It is crucial to consider how the driver could utilize the freed-up time effectively.

For environmental impact assessments, no change in fuel consumption was observed; in fact, fuel usage could potentially increase if the autonomous vehicle frequently stops for safety reasons. However, this is expected to improve in the future as the vehicle becomes more specialized in route travel. Notably, fleet optimization, particularly at airports, is expected to result in significant fuel savings.

Socio-economic considerations explore job creation and evolution, cost reduction implications, and revenue generation opportunities. The transition to autonomous systems is projected to significantly reduce operational costs, encompassing machine costs, Hubs &

Warehouses, fuel expenses, and insurance. Increased operational days and reduced idle time contribute to revenue generation opportunities.

In the same line, from a stakeholder perspective this represents a room for possibilities in order to improve current state. Stakeholders emphasized the need to promptly address several challenges for successful integration into society, such as improving human-machine interfaces (HMI), upgrading infrastructure cameras, and implementing intelligent traffic lights.

In conclusion, the findings within D7.3 underscore the positive impact of autonomous vehicles across sectors, providing a thorough analysis of safety, efficiency, environmental considerations, and socio-economic factors. The subsequent sections of this deliverable will delve into detailed assessments, methodologies, and specific use case evaluations that contribute to these overarching conclusions. The report also addresses scaling up considerations and social and industrial projections, drawing from available EU and national statistics.

1. Introduction

1.1. AWARD project scope

The goal of AWARD is to develop and enable the deployment of a safe autonomous transportation system in a wide range of real-life use cases in a variety of different scenarios. This encompasses the development of an autonomous driving system (ADS) capable of handling adverse weather conditions such as heavy rain, snowfall, fog. The ADS solution will be based on multiple sensor modalities to address 24/7 availability. The ADS will then be integrated into multiple vehicle types used at low speed, mostly in confined areas. Finally, these vehicles will be demonstrated in a variety of real-life use cases to validate their value in the application and identify any limitations. Logistics operations will be optimized thanks to a new fleet management system that will act as a control tower, gathering all information from subsystems (vehicles, road sensors, etc.) to coordinate the operations and protect vulnerable road users. This work should then enable commercial exploitation of the technology and policy recommendations for certifications processes.

1.2. Overall methodology for impact assessment

The AWARD project adopts a comprehensive testing and evaluation methodology based on the FESTA Handbook [1], initially developed by the FESTA support action in 2008. This handbook was designed to guide field operational tests in the automotive sector and has undergone iterative updates through subsequent networking projects such as FOT-Net, CARTRE, and ARCADE. The continued refinement of the FESTA methodology incorporates valuable lessons learned and adapts to diverse testing scenarios.

Aligned with the FESTA methodology, the AWARD project places significant emphasis on scientific rigor, employing a structured approach that has demonstrated its efficacy. The methodology serves as a reliable framework for planning and executing tests, ensuring the validity and comparability of results. Originally tailored for large-scale user tests, the FESTA methodology has proven adaptable to various testing campaigns, including smaller-scale initiatives.

In the initial phases of the AWARD project, echoing the FESTA approach, careful consideration is given to scoping research questions and delineating a focused strategy for data collection. The planning of tests and data collection is meticulously orchestrated to align with statistical evaluation requirements, emphasizing the acquisition of sufficient data both in the presence and absence of the autonomous systems under scrutiny. This scientific approach serves as the cornerstone for robust statistical analysis, reinforcing the credibility and reliability of the impact assessment results within the AWARD project.

As the AWARD project applies FESTA to industrial field operational tests, the main differences compared to other automotive tests include data collection about industrial process KPIs. These could encompass time requirements for luggage delivery, savings related to faster ship loading, new tasks drivers might undertake when freed from driving, and potential changes in the overall industrial process at the fleet management level.

1.3. Scope of the deliverable

The objective of the present deliverable D7.3: Impact assessment and user survey results, is to provide cross-sectoral and cross-pilot evaluation, together with an analysis of the data collected from the results of pilots. Scaling up takes into account identical operations but with a larger fleet of automated vehicles. This impact assessment's social and industrial estimates will also be included, limited to data available from the EU and national statistics.

1.4. Target Audience

This report is a public document that will be available for all interested public. It is foreseen that the target audience of this deliverable are end users and stakeholders involved in pilots. Evaluation experts may view this deliverable as one of the first examples of assessing impacts of automated industrial trucks in short-distance outdoor logistics. In addition, the research community on automation, partners to the AWARD solutions, as well as logistic operators, AV's manufacturers, and fleet managers can benefit from the information in this deliverable.

1.5. Relationship with other tasks and deliverables

As part of T7.3: User and stakeholder evaluation, D7.3 is directly connected to results and data coming out of the pilots from WP6 and is feeding WP8 for the different studies of socio-economic outcomes.

1.6. Structure of the deliverable

The present deliverable is structured as follows:

- Chapter 1 introduces the deliverable
- Chapter 2 assesses the impact on the port use case
- Chapter 3 analyses the impact on the airport use case
- Chapter 4 evaluates the Hub2Hub impact
- Chapter 5 provides the forklift impact assessment
- Chapter 6 concludes the document
- Chapter 8 – Annex I aims to explain to the reader the methodology implemented for evaluating the impact of the project in different areas: safety, efficiency, environmental and stakeholders and users impact assessment. This includes concepts, used methods, research questions and KPIs and how to scale up.

2. Port impact assessment

2.1. Test site introduction and routes

The port demonstrations took place at DFDS's Rotterdam (Vlaardingen) terminal in the Netherlands, utilizing an automated Terberg EZTug vehicle for trailer movement within the terminal premises. The routes included gate transits to and from the public road, as well as loading and unloading operations on a ship. The Rotterdam terminal, a bustling Roll-on/Roll-off (RoRo) terminal with ferry routes to the UK, handling over 150,000 trailers annually and operating 32 tugs like the Terberg truck, showcasing autonomous capabilities.
The operations of the use-case deployed were divided into three phases:

- Phase 1: Moving trailers within the terminal, concluded in November 2023.
- Phase 2: Last-mile delivery from the terminal to the public road.
- Phase 3: Ship loading/unloading.

Each phase involved tasks such as parking trailers, navigating gate processes, and driving onto ships. The trials aimed to demonstrate the EZTug's versatility in real-world port scenarios.
The EZTug, equipped with an Automated Driving System (ADS) and integrated with the Applied Autonomy Fleet Management System, enhanced operational efficiency and enabled secure, automated movements within and outside the terminal. This system allowed seamless communication with DFDS's systems, facilitating work order exchange and reducing the need for a safety driver, thus lowering container unloading times and CO2 emissions.

2.2. Timeline

The baseline data collection was tested during 2022, while preparations for pre-testing the automated vehicle started in March 2023. In September and October 2023, the EZTug demonstrated its capabilities at the Rotterdam terminal, efficiently maneuvering trailers in the port's complex operations.

Table 1: Timeline of port use case

Phase	Start month	End month
Pre-testing	27	31
First baseline data sample for evaluation		Summer 2022
Operations and interviews	29	36
Dataset finalization		34
Evaluation and reporting	32	42

2.3. Performance goals and pre-existing indicators/statistics

The anticipated benefits of automating trailer tugs include precise location tracking and increased efficiency through autonomous trailer rearrangement during off-peak hours. This results in better-prepared loading and unloading operations and quicker turnaround times. Currently, manual processes track fuel consumption and operating hours of tugs. The demonstration aims to assess the performance of automated electric tugs compared to diesel-driven ones, exploring the potential for full automation of tug operations. Additionally, the study will evaluate the training time required for conventional tug drivers versus the training for new automated vehicles and routes.

2.4. Description of automated vehicle functionalities

The EZTug, shown in Figure 1, is an autonomous yard truck designed to optimize port operations and logistics. It operates autonomously using a sophisticated technological framework that includes a full range of sensors for safe and precise operation. These sensors enable accurate navigation and interaction within the operational environment. The EZTug's teleoperation capabilities allow for remote control, enhancing flexibility and control over the vehicle's movements and eliminating logistical challenges for seamless operations.

The EZTug can perform automated handshakes[1] with container handling equipment, streamlining the interaction process for secure and efficient movements within and outside the port terminal. Its advanced perception systems and complex algorithms allow it to navigate rugged weather conditions and maintain continuous operation, extending the Operational Design Domain (ODD) validation and qualifications.

Integration with the Fleet Management System (FMS) developed by Applied Autonomy ensures constant communication with DFDS' systems. This seamless exchange of crucial information about the vehicle and work orders allows for secure entry and exit from the terminal without human intervention, streamlining port terminal operations.

Figure 1: The EZTug

[1] In computing, the term handshake refers to a signal exchanged between two devices or programs to establish communication rules before full communication begins. For instance, when a computer communicates with a modem, they signal each other that they're ready to work and agree on protocols to use.

2.5. Affected other operations

The automated Terberg Tug (EZTug) coordinates its tasks with both fellow tug drivers and external drivers entering the port. The primary impact will be on dispatch operators responsible for planning ship loading and unloading. Future operational scenarios are expected to notably influence maintenance operations.

2.6. Infrastructure modifications

To support the EZTug's autonomous operations, dedicated lanes and gates were implemented within the port to streamline movements and reduce interactions with other vehicles. These lanes and gates were marked to guide the EZTug during its tasks, ensuring safer and more efficient operation. The dedicated paths allowed the EZTug to navigate the port with minimal disruption to other activities, facilitating smoother and quicker trailer movements. This setup was crucial in demonstrating the potential for integrating autonomous vehicles into existing port infrastructure while maintaining operational flow and safety.

2.7. Data logging

2.7.1. Baseline data collection

Baseline data collection in 2022 provided control metrics for manual operations. The automated vehicle managed most data collection tasks, with occasional manual operations to ensure a thorough dataset. During manual mode, baseline data indicated efficient trailer handling with minimal human intervention. The average manual driving speed was 14.4 km/h. Manual mode required continuous human supervision, resulting in higher personnel costs. For Phases 1 and 2, out of 25 hours of total driving, 16.5 hours were manual driving (25 hours total minus 8.5 hours automated).

location_id	Driving Time (min)	Manual Driving Time (min)	%_manual_driving
⊞ NL_VLA_1	481,17	140,15	29,13 %
⊞ NL_VLA_2	123,80	16,65	13,45 %
Total	**604,97**	**156,80**	**25,92 %**

Figure 2: Vlaardingen – Percentage of manual driving where percentage of automated driving > 40%

2.7.2. AV data collection

Automated vehicle data collection utilized EasyMile's software stack, recording vehicle status, position, and mode at 2 Hz. The fleet management API supplied additional data, such as vehicle location, emergency stops, battery level, traveled distances, dispatch durations, and error logs during automated driving. The vehicle also featured a front-facing camera for video recording, subject to spatial constraints. In Phases 1 and 2 (September 2023), there were 25 hours of driving with 8.5 hours automated. In Phase 3 (October 2023), 2 hours of testing were conducted.

2.7.3. Access to log data

The test site leader controlled and owned the data, making it available to named evaluation partners as a confidential dataset, ensuring secure and controlled access for analysis.

2.8. Results

2.8.1. Technical evaluation

This section provides a summary of the technical evaluation report D7.2. Roll-on/Roll-off (RoRo) ports, also known as trailer ports, handle unstandardized cargo with varied interfaces and connections, serving short sea shipping routes with frequent sailings and quick turnaround times. Unlike container ports, RoRo operations face automation challenges due to the complex nature of trailers and their cargo, requiring advanced security measures such as extensive lashing.

Figure 3: Terberg test vehicle on route in DFDS Rotterdam port

The maximum automated speed on straight segments was constrained by bumpy asphalt, which caused sensor ground filtering issues. As a result, speeds were limited to 15 km/h (Figure 4, dark blue) and 20 km/h (Figure 4, purple) on some segments. A busy intersection along the route always required safety driver assistance. However, this crossing would be unnecessary when only performing trailer rearrangement. Additionally, the port's chaotic traffic mandated that AV operations occur during off-peak hours to minimize interference.

The primary challenge was automating the connection of pneumatic and electric wires between trucks and trailers, which can take up to two minutes for human drivers (Figure 5). Robotic arms and adapters were considered but faced complexities. The final testing phase focused on moving trailers onto ships, complicated by interactions with other drivers, high power needs for heavy loads, and changing ramp slopes due to tides.

DFDS Rotterdam Terminal Tests revealed that automation can expedite trailer rearrangement for faster ship loading. However, navigating AVs inside ships remains impractical due to the need for safety zones. The average automated driving speed was 8.6 km/h compared to 14.4 km/h for manual driving. The vehicle drove slower due to bumpy conditions, and 29% of automated driving required manual support, equating to 17 minutes per hour. Energy consumption differences between manual and automated modes were minimal, about ±2%. Frequent overtaking during busy hours limited AV operations to off-peak times. Issues like automatic trailer connection must be resolved before full operational use. The lowest hanging lidars need to be placed higher to avoid problems when driving in/out of ships. Safety drivers handled the busy intersection by forming eye contact with other drivers and occasionally waving their hands to signal who moves first. This shows a fundamental problem in heavy mixed traffic.

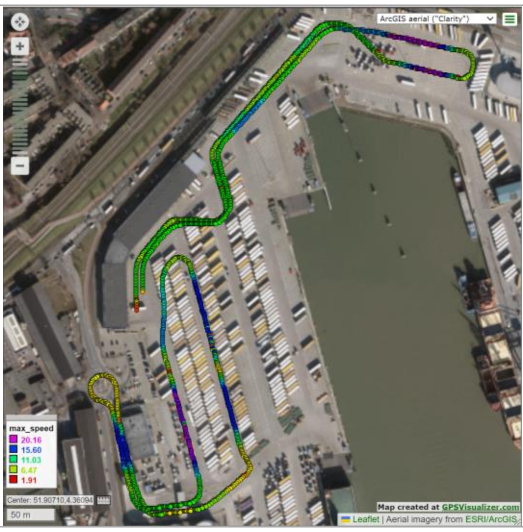

Figure 4: Maximum automated driving speed in different parts of the operative route

Figure 5: Pneumatic and electric connectors between a truck and trailer

2.8.2. Safety evaluation

Manual intervention and emergency stop statistics

Based on fleet management system assignments, there were 506 minutes of automated driving, including periods when the vehicle was on a job. During these assignments, there were 90 manual mode activations, equating to one every 5.6 minutes.

Safety driver reports, using a mobile phone app, provide insights into manual interventions and emergency stops. The operator documented 32 cases, with other vehicles causing 11 stops. Although there were no close-call emergencies, 6 cases were marked as hard stops. The driver categorized the stops as follows:

Table 2: Safety stops

Stop category	Number of cases
Obstacle emergency	4
Vehicle emergency	2
Soft vehicle-related stops	9 (3 by system, 6 by operator)
Safety stop	7
Operator had to overtake or make U-turn	7

Loss of localization	3

Observations and SOTIF proving ground test lessons

The EZTug operated safely in both dry and moderate rain conditions, avoiding hazardous situations by safely interacting with surrounding traffic. It slowed down when detecting objects within predefined safety zones, ensuring no critical incidents occurred.

Given these were initial tests in a busy area, extra caution was exercised, relying more on human support, including manual validation by a safety driver at two intersections. One of these intersections might be automated in the future, while the other, leading to a maintenance area, poses significant challenges for autonomous navigation.

In busy/chaotic intersections, even human drivers need to negotiate who goes first. Such testing means establishing eye contact, making it difficult to get realistic data on interaction between automated and human drivers. While traffic lights could mitigate these issues, industrial sites might avoid such installations due to performance considerations or site layout constraints.

The main safety concern was other drivers frequently overtaking the vehicle, which mostly drove at speeds between 10 and 20 km/h. This leads to considering operational areas and hours: the vehicle would mainly rearrange or transfer trailers outside peak hours.

While the port's driving environment is chaotic, the terminal area is clean and obstacle-free. Access is strictly restricted, with occasional appearances of pedestrians and cyclists. The primary concern for the automated driving system remains other vehicles and occasional careless pedestrians.

In the SOTIF proving ground safety tests, the main development point was lateral safety and improvements in object tracking to prevent collisions with fast-moving road users.

Impacts on accident types and EU statistics

Over the past 2.5 years, DFDS's Rotterdam port has recorded numerous damage reports. The port manages about four ships and over a thousand trailers or other cargo units daily, with up to 30 drivers working at peak times.

Despite maintenance contracts, 57% of damage reports focus on trailer conditions upon arrival at the terminal, identifying issues like cuts, tears, leaks, and broken connectors. Over a thousand trailer damages and about 150 cases of equipment failures have been documented.

Damage reports primarily cover material damage, with no fatalities reported. Approximately 10 injuries are reported annually. Since driving speeds at the port are low, the frequency and severity of driving-related injuries and damages are relatively low.

Regarding tug damages, 26% occurred onboard ships and 74% on the terminal side. Accidents during trailer transfer operations are split between ships and the terminal. The work involves connecting, disconnecting, lashing, and parking trailers in tight ship environments, where small dents are unavoidable without automation.

The cargo on ships is diverse, and incidents often involve moving, lifting, and arranging oversized trailers or machinery. Special transports are not easily automated. Securing loads also involves equipment, with accidents related to tool breakage or improper support.

There were 11 damage reports where extreme weather conditions would have been too much for automation. Slippery surfaces on deck led to drivers losing control or slipping, causing collisions. Solutions suggested the inclusion of reduced speed in turns, caution in wet conditions, and installing anti-slip materials.

Tight spaces for trailer management involve a whistler, a support person, to aid drivers. Accidents might be avoided with future trucks and their collision avoidance systems.

Despite the port's cleanliness, 196 tire puncture accidents have been documented due to sharp objects, loose materials, and poor maintenance.

Approximately 190 reports involved third-party drivers causing damage. These incidents might be preventable with automated tugs equipped with collision avoidance systems. Further miscellaneous cases unrelated to automated driving included ship navigation, hydraulic leaks, suspension failures, driver slips, machinery operation, and steel plates shifting. Our analysis focused on accident reports where automation could enhance safety.

We identified 424 cases where automation could potentially reduce incidents, amounting to 29% of all damage reports, excluding trailers that already arrive damaged.

Table 3: Accident types potentially avoidable with automated trucking

Accident type	Comment	Count of reports
Collisions with infrastructure/vessel	Scratches in tight spaces	99
Collisions with other vehicles/machines	Rather dents than more severe	73
Collisions with objects/obstacles	Miscellaneous collision reports, not all could be avoided	62
General negligence	Driver forgetting e.g. connectors or legs	52
Accidents related to parking or starting movement	Difficulties to assess free space	50
Communication errors	Mainly with a whistler who helps drivers to park or warns them	27
Collisions with trailers while driving	Occasional hits also while driving and not just parking	25
Vehicle damage noticed at the start of a shift	Some scratches were reported later	25
Challenging environmental conditions	Slipping, low friction, driver using too high speed	6
Broken windows	Automated vehicles might not need a cockpit	5

It is challenging to estimate the financial safety potential of automated driving due to the varying severity of reported accidents. Automation is still in the research phase, and its impact on industrial accidents is not straightforward to assess. This categorization is likely one of the first based on Ro-Ro port accident data.

2.8.3. Efficiency

The efficiency impact assessment aimed to evaluate how the AWARD ADS influences economic, operational, and quality indicators in forklift operations. The research was guided by three primary questions:

- How does the ADS influence economic indicators?
- How does it affect operational indicators?
- And how does it impact the quality indicators in logistics operations?

To address these questions, we formulated several hypotheses and analyzed various performance metrics. The analysis involved segmenting the logs by session to represent each movement, allowing comparisons of manual versus autonomous operations. This approach helped isolate key performance indicators and apply mathematical analysis to draw meaningful insights. Some of the main findings are presented in Table 4.

Table 4: Efficiency hypothesis and main findings of the port use case

Hypothesis	Findings
The ADS supports reducing personnel costs.	The analysis of the personnel time to support the vehicle reveals that for the driving task itself, the port test data indicate savings between 86.55% and 70.87% of personnel time through automating the driving task. These savings could also be reflected in personnel costs savings in deployments where no safety driver is required. Since the port of Vlaardingen did not permit to drive without a safety driver, a reduction of personnel costs could not be realized within the tests. However, future applications of automated freight transport vehicles in combination with teleoperation could contribute to reducing personnel costs as well as mitigating driver shortages on the long run.
The ADS reduces net transfer time.	The assignment duration is predominantly in automatic mode longer on average than those in manual mode.
The ADS decreases personnel time to support the vehicle while driving.	Regarding the driving task itself, the Vlaardingen port test data reveals the following. In phase 1 and 2 (Port dataset 1) the amount of manual driving to support automated driving trips was 29%. 13% of all driving was manual in Phase 3 at the port of Vlaardingen (Port dataset 2). Within the initial two test phases at the trailer yard of the port, the median MTBO was 7.55 minutes. The MTBO ranges from a minimum of 5.54 minutes to a maximum of 18.42 minutes. In case such overtakes may be resolved via teleoperation solutions the personnel time to support a transport vehicle might be reduced significantly.
The ADS reduces fuel consumption.	Port dataset 1 • Fuel consumption is higher in sessions where automatic mode predominates, both in absolute terms and per minute. • Fuel Efficiency: Although fuel consumption is higher in automatic mode, efficiency per kilometer appears to be similar in both modes. Port dataset 2 • Fuel Consumption and Efficiency: Fuel consumption is notable, and fuel efficiency per minute is slightly lower compared to port dataset 1. The data collected does not allow clear conclusions to be drawn regarding efficiency due to the absence of mileage.
The ADS decreases vehicle speed.	Port dataset 1 • Operating Speed: The average speed is slightly lower in automatic mode. Port dataset 2 • Operating Speed: The average speed is similar to that observed in Phases 1 and 2 (port dataset 1). The data collected does not allow clear conclusions to be drawn regarding efficiency due to the absence of mileage.

The operational availability of the ADS is lower than that of a manually operated vehicle.	The general availability of automated vehicles will be similar in case driver is available and vehicle still can be operated manually. Regarding the L4-function availability, potential operational hours could be improved from 5,975(68% of possible hours) to 8,547 (97.5% of possible hours) through the AWARD ODD extension with respect to the 2023 Rotterdam weather data.

Subsequently, a more detailed analysis for the port use case with respect to the efficiency assessment within the different phases is given.

Personnel Time and Operational Efficiency

One indicator to assess the personnel time to support the transport vehicle was an adoption of the mean-time between failure. In general, the **M**ean-**T**ime **B**etween **F**ailure (MTBF) is a measure used for making decisions and predicting lifecycles of equipment. MTBF values are often quoted without defining what constitutes a failure, which is misleading and useless. There are two basic definitions of failure:

1. the termination of the ability of the product to perform its required function, or
2. the termination of the ability of an individual component to perform its required function, but not the termination of the ability of the product to perform.

The latter understanding is referred to within the AWARD project. When a human needs to support/overtake an L4 vehicle, a failure of the L4-system function occurs.

MTBF affects both reliability and availability, which are different concepts. Reliability is the ability of a system or component to perform its functions without failure for a specified time, while availability is the degree to which a system or component is operational and accessible when needed. Subsequently, the **M**ean-**T**ime **B**etween **S**tops (MTBS) and the **M**ean-**T**ime **B**etween **O**vertakes (MTBO) are visualized for the port dataset 1 and 2. Stops may either be triggered and resolved by the driving system itself or by a human safety operator. Overtakes are logged points in time while performing a transport assignment, where a human safety operator needs to intervene.

Port dataset 1 (Logs from phase 1 and 2 mixed from 25/09/2023 to 28/09/2023)

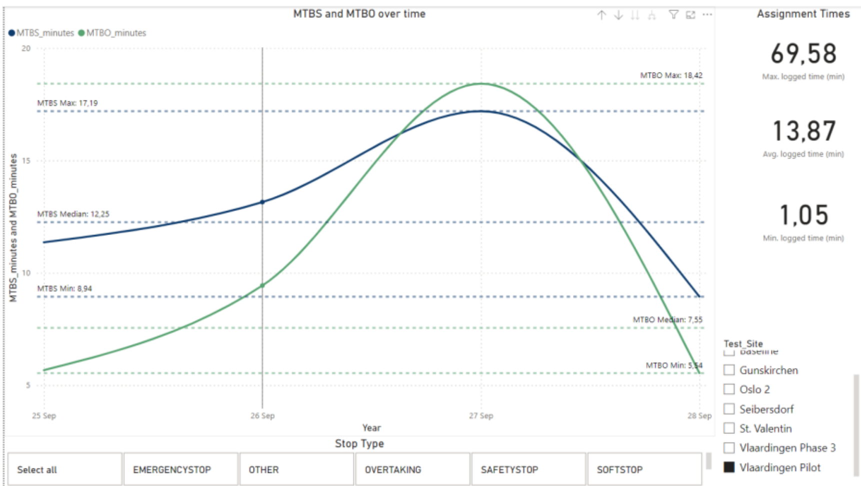

Figure 6: MTBS, MTBO - port dataset 1

Within the initial two test phases at the trailer yard of the port, the median MTBO was 7.55 minutes. The MTBO ranges from a minimum of 5.54 minutes to a maximum of 18.42 minutes.

Compared to the MTBO, the median MTBS is 12.25 minutes. Moreover, the logged MTBS reveals a minimum at 8.94 minutes and a maximum of 17.19 minutes.

Port dataset 2 (Logs from phase 3 on 9/10/2023)

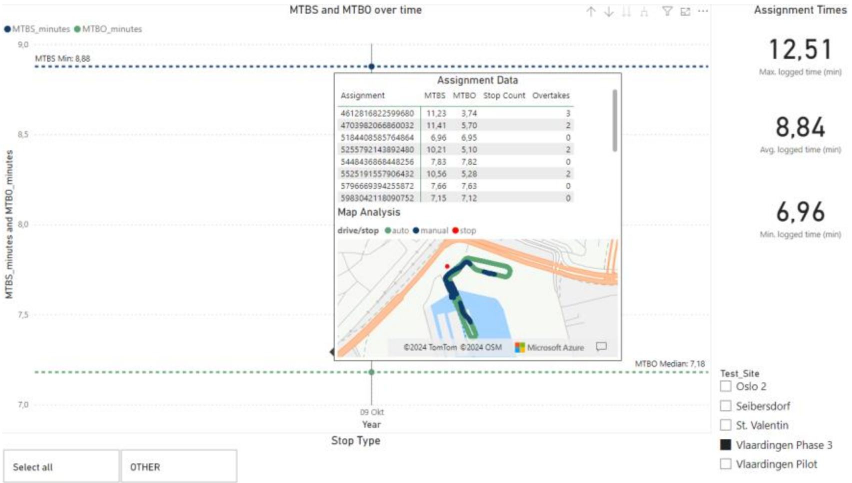

Figure 7: MTBS, MTBO - port dataset 2

Across the port testing phases 1 and 2, 29% of automated driving was supported by a safety driver. That means the safety driver was active 17 minutes per hour. Much of this is explained by long manual intervention times at the busy intersection. The distribution of manual activations shows that most times the driver managed to handle everything within 30 seconds, whereas the busy intersection required him to occasionally wait longer.

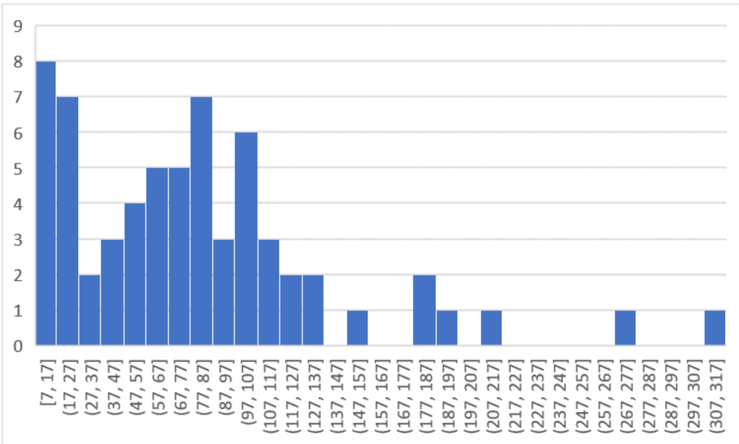

Figure 8: Histogram of manual mode activations, where the number of cases is plotted for every time period of activity in seconds.

The main indicators for efficiency in these tests were average driving speed and the amount of human support necessary, in minutes. The routes were performed by a human driver as a comparison, but for example no actual comparable rearrangement of trailers was possible in these first tests. The task of rearranging trailers, and port-wide comparison of human versus automated driving was later simulated using the key measured speeds and delays.

Vehicle Speed Analysis

As a main comparison, the average automated driving speed over all assignments was **8.6 km/h.** A human test driver drove the same routes using an average speed of **14.4 km/h.** This calculation disregarded the stopping periods and calculated average during moving, only. If stops were counted in, averages were **6.4 km/h** for automation and **7.8 km/h** for human.

Naturally, such later averages are affected by how much waiting time the assignment includes – here the human driver part has not been as accurately cut to driving and we prefer the first comparison.

In the ship loading test, the automated driving speeds were: 6.8 km/h (when speed > 0) and 5.4 km/h for the whole duration. There was no human comparison available.

Port dataset 1 (Logs from phase 1 and 2 mixed from 25/09/2023 to 28/09/2023)

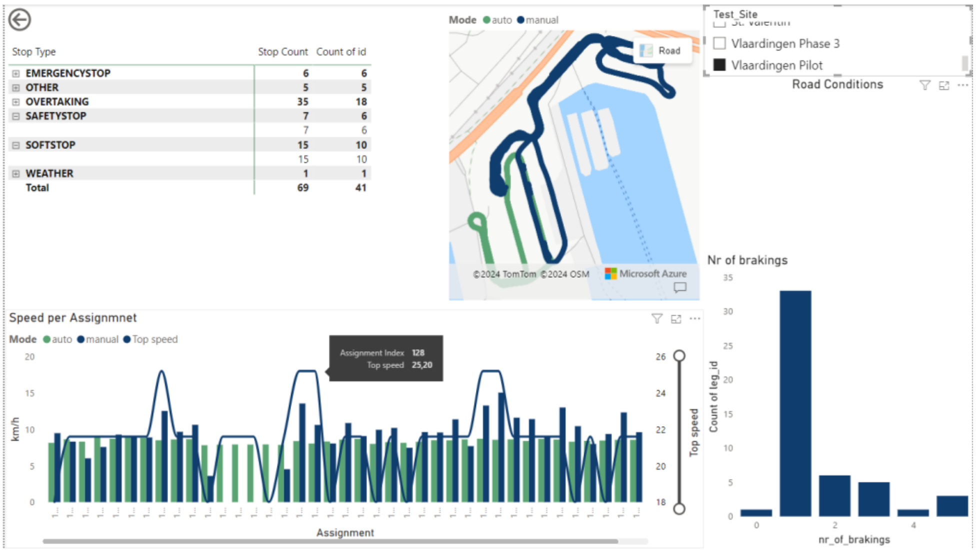

Figure 9: Speed par assignment - port dataset 1

Port dataset 2 (Logs from phase 3 on 9/10/2023)

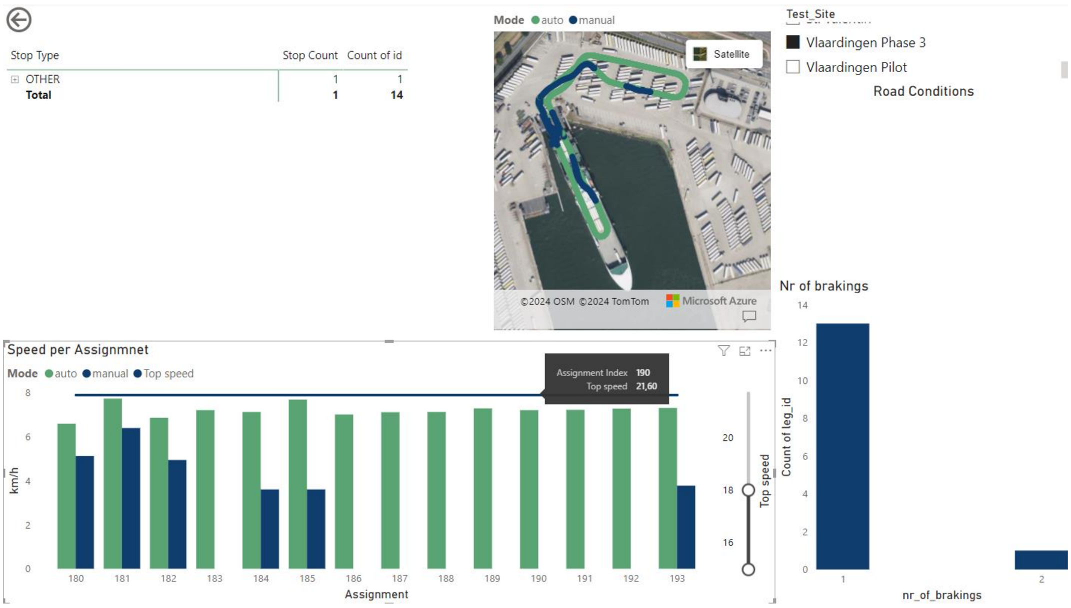

Figure 10: Speed per assignment - port dataset 2

Operational Availability

Since the L4-transport vehicle in the port use case could either be operated in manual or automated mode, the general operational availability of the automated versus the manual vehicle would be similar. However, the interesting aspect for port operators is the potential availability of the L4 automated driving function. With respect to the operational availability of the ADS, especially weather conditions have been investigated. In the port use case OGIMET weather data for 2023 measured on a 60min interval were used.

Given such weather data different scenarios may be evaluated. The following table illustrates days and hours in which an automated L4-vehicle might face difficulties due to harsh weather conditions at the port of Vlaardingen. The restrictions (Temp < -10°C, or Rain > 10mm, etc.) are given in the table header.

Table 5: Days and hours in which an automated L4-vehicle might face difficulties due to harsh weather conditions at the port of Vlaardingen

Location	Difficult Hours	Difficult Days	Temp < -10°C Hours (Days)	Rain > 10 mm Hours	Visibility below 200 m (rainy)	Visibility below 200 m (non-rainy)	Heavy Rain Hours	Heavy Snowfall Hours	Thick Fog Hours	Hours of Dust and Sand	Hours of Thunder storms	Of year (%)
Rotterdam	162	73	0 (0)	1	3	66	34	3	0	122	0	**1.8**

An additional dashboard for investigating the potential availability of a L4-vehicle based on weather data and the vehicle ODD has been developed. The dashboard allows to select harsh weather conditions under which the vehicle is able to operate, working hours per day and the timeframe (start/end date) for which possible working hours are calculated. Based on the configured ODD the potential availability of the L4-function is the given in working hours. Figure 11 depicts the dashboard and illustrates the difference between EasyMile's L4 vehicle ODD before the AWARD project and the potential improvement after the project with the AWARD sensors set. Figure 11 illustrates that the potential operational hours could be improved from 5,975 (68% of possible hours) to 8,547 (97.5% of possible hours) through the AWARD ODD extension with respect to the 2023 Rotterdam weather data. This corresponds to a potential improvement of 29.5%. The working hours are calculated for a 24/7 port operation for 365 days in 2023.

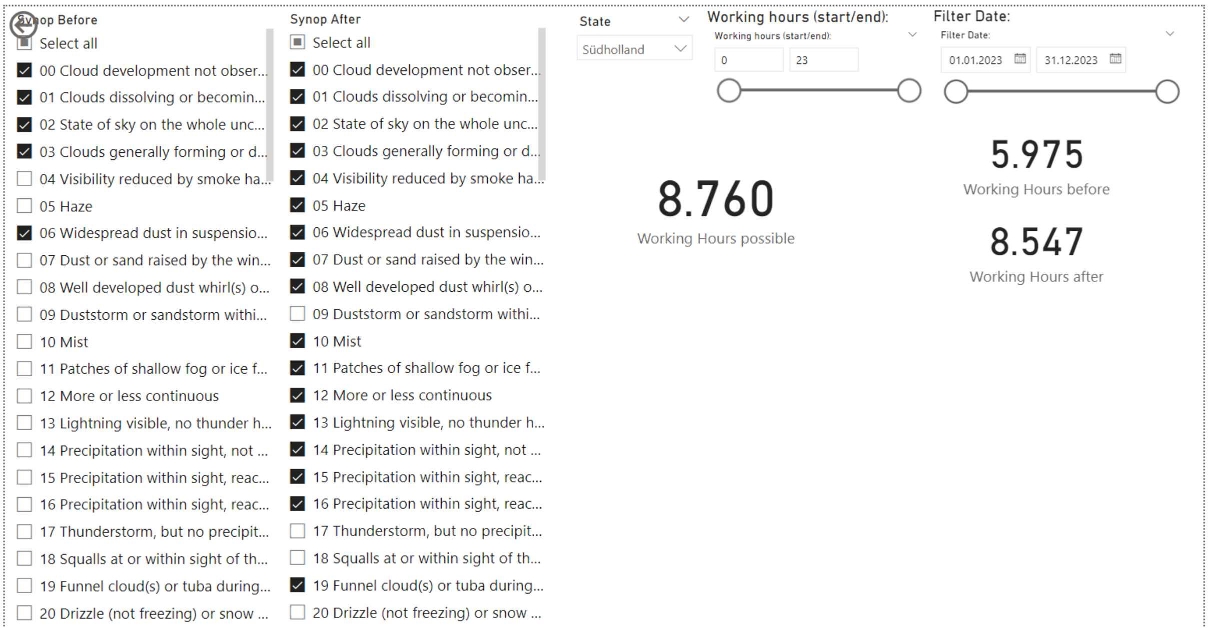

Figure 11: Weather ODD analysis for Rotterdam 2023

Timeliness and Reliability of Transport Orders

The log data of the FMS provide insights into planned and actual times for start and end times of dispatch assignments. The standard deviation of the difference between actual and planned execution times in the port dataset 1 is rather high within the test data with a value of 36 minutes. However, the median difference of the actual/planned execution time is around 1 minute. Also, the median difference between the actual/planned execution time within the ship loading operations (port dataset 2) is rather low with a value of 1.89 minutes.

Port dataset 1 (Logs from phase 1 and 2 mixed from 25/09/2023 to 28/09/2023)

Standard deviation for dispatch assignments	Median for dispatch assignments:
• Diff. actual/planned start time = 10 947.44 sec -> ~182 min • Diff. actual/planned finish time = 11 036.63 sec -> ~184 min • Diff. actual/planned execution time = 2 207.54 sec -> 36,79 min	• Diff. actual/planned start time = 235 sec -> ~4 min • Diff. actual/planned finish time = 359 sec -> ~6 min • Diff. actual/planned execution time = 58 sec -> ~1 min

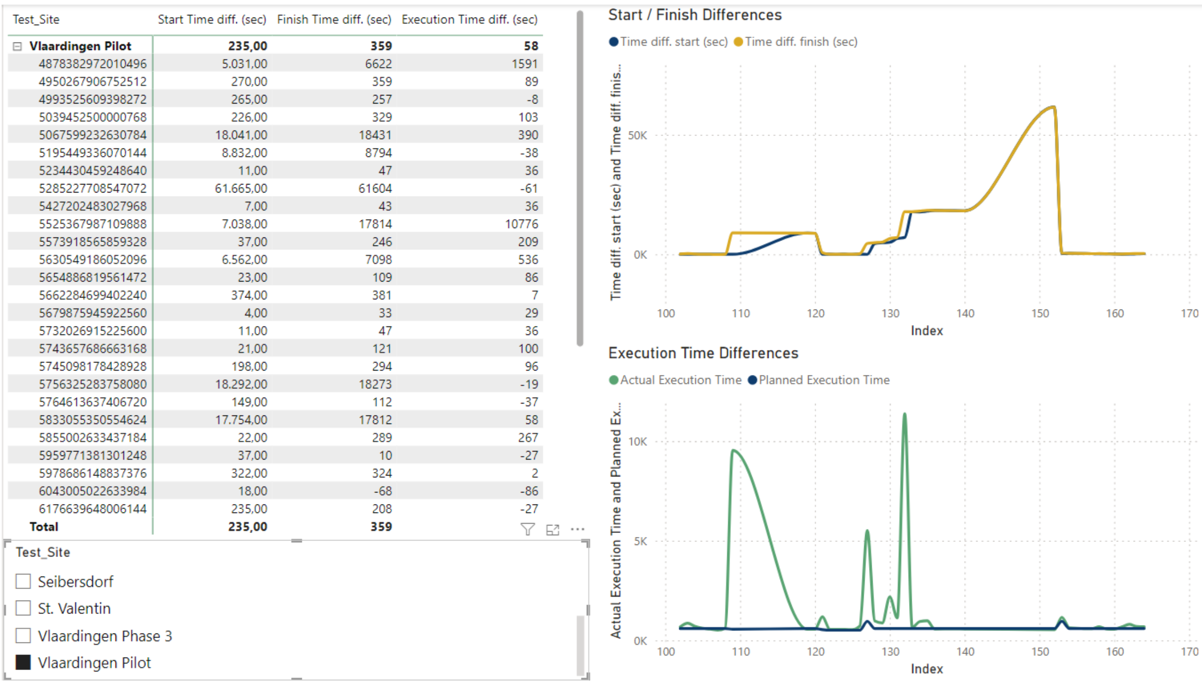

Figure 12: Dispatch assignment - timeliness analysis – port dataset 1

Port dataset 2 (Logs from phase 3 on 9/10/2023)

Standard deviation for dispatch assignments	Median for dispatch assignments:
• Diff. actual/planned start time = 136.75 sec -> ~2.28 min • Diff. actual/planned finish time = 186.32 sec ->~3.1 min • Diff. actual/planned execution time = 113.39 sec -> ~1.89min	• Diff. actual/planned start time = 41.5 sec -> ~0.69 min • Diff. actual/planned finish time = 258 sec -> ~4.32 min • Diff. actual/planned execution time = 51 sec -> ~ 0.85 min

Test_Site	Start Time diff. (sec)	Finish Time diff. (sec)	Execution Time diff. (sec)
Vlaardingen Phase 3	**41,50**	**258**	**51**
4612816822599680	19,00	274	255
4703982066860032	203,00	469	266
5184408585764864	64,00	63	-1
5255792143892480	324,00	518	194
5448436868448256	190,00	242	52
5525191557906432	291,00	506	215
5796669394255872	341,00	381	40
5983042118090752	9,00	19	10
6036503790616576	7,00	36	29
6100848708943872	5,00	55	50
6108376310218752	17,00	372	355
6139437715030016	328,00	368	40
6215464407531520	9,00	89	80
6301666682863616	3,00	12	9
Total	**41,50**	**258**	**51**

Test_Site

- [ ] Seibersdorf
- [ ] St. Valentin
- [x] Vlaardingen Phase 3
- [ ] Vlaardingen Pilot

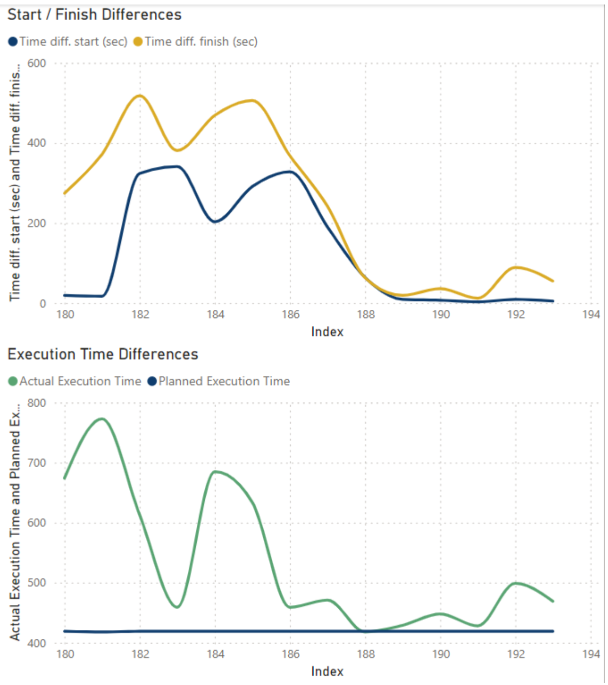

Figure 13: Dispatch assignment - timeliness analysis – port dataset 2

Main findings timeliness and reliability analysis

- Analyzing the timeliness of dispatch assignments performed in Vlaardingen reveals that the majority of the assignments took longer than planned by the FMS.
- However, the median difference of the actual/planned execution time is around 1 minute. Also, the median difference between the actual/planned execution time within the ship loading operations (port dataset 2) is rather low with a value of 1.89 minutes.
- Transport reliability is defined as the certainty that a transport order may be conducted within the expected time frame (schedule).
- In Vlaardingen 41 assignments were performed in phase 1 and 2 (Port dataset 1). Out of these 41 assignments 11 (27%) lasted shorter than planned. The remaining 30 assignments (73%) took longer than planned.
- In Phase 3 (Port dataset 2) related to ship loading operations, overall, 14 assignments were performed. Only one of these could be finished in time (7%), the other took longer (93%).

2.8.4. Environmental evaluation

Energy consumption differences between manual and automated mode were difficult to estimate accurately, as the driven kilometers were small. Longer experiments would be necessary. The following data should be considered as indicative, as it only covers first tests. As automated driving becomes more fluent in an area thanks to further optimizations, energy consumption can drop.

When we split recorded driving data by changes in battery level percentages to see how far a vehicle travelled with one percentage of a full battery, we get the following results. These are summed values over all such 1% periods, filtering out periods where no or very little driving took place:

- Manual mode driving distance total 50.7 kilometers with total 17% change in battery

- Automated mode: 59.9 kilometers, 25% change in battery (requiring minimally 30% automated driving during the period)
- Automated mode: 36.1 km, 15% change in battery (requiring >50% automated driving during the period).

From these numbers we get that the vehicle was able to drive:

- ⇨ 2.981 km per battery change in manual
- ⇨ 2.396–2.404 km in automated mode.

Automation used about 24% more energy in these samples. EZTug has battery size of 222 kWh.

As the data can be split in many ways, another comparison of a consecutive 4-hour manual driving versus a 2-hour sample of automated driving showed an increase of 16%. Therefore, we conclude that the increase was around 20%. The performance difference could drop, if the amount of unnecessary hard stops in automation mode can be reduced.

Braking event analysis

The automated vehicle braked much more often than a human-driven one: 2.5 times more frequently. It used soft braking much more frequently than the human test driver and occasionally performed medium-level emergency braking, which is rare for human drivers.

If we normalize braking deceleration by count, we see that a human breaks a bit harder on average. However, the human driver did not have to use emergency braking (happened twice during 8-hour data).

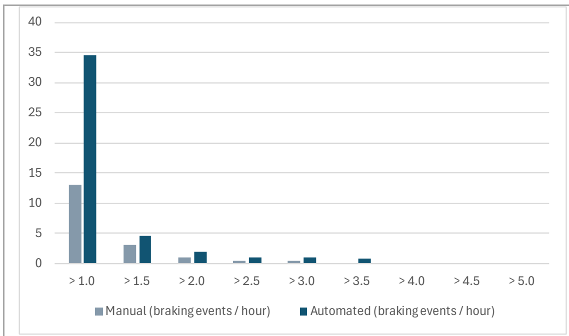

Figure 14: Comparison of the frequency and intensity of braking between human and automated driving.

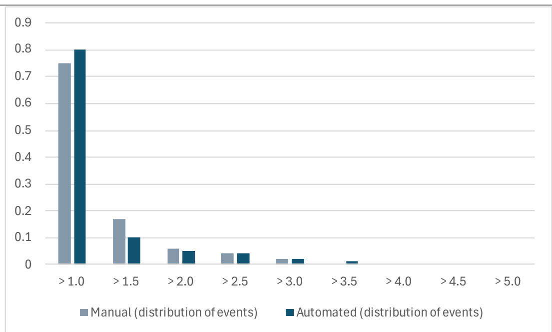

Figure 15: Normalized distribution of braking decelerations, providing averages for all braking events.

The softer braking (more fluent driving) by automation might help to compensate a bit for the number of braking events. However, as the automated vehicle brakes 2.5 times more often, and every time a heavy vehicle must accelerate again, it is understandable that its driving style consumes more battery than a human driver would.

2.8.5. Stakeholders and users' evaluation

The main results from interviews (n=7) with port stakeholders are summarized below, highlighting the 12 most relevant codes. Figure 16 represents a word cloud of frequently recurring terms from the interviews. The questionnaire responses did not yield significant results or clear trends.

Figure 16: Word cloud representing frequency of terms (port interviews)

Efficiency (n=36): Participants noted that autonomous machines are generally more predictable and reliable than humans. Remote control can enhance decision-making, efficiency, and safety, enabling managers to oversee multiple vehicles for longer periods. This should result in fewer accidents, better maintenance planning, and cost savings. However, flexibility will be limited, requiring constant human presence, and operations may be slower due to high safety standards. Some processes still need optimization, like having one system for all logistics operators.

Time Frame, Technological Readiness (n=35-19): Initially, costs will increase, and transitioning to advanced technologies will add complexity. Over time, operations will become cheaper, systems more user-friendly, and people will adapt to new workflows. Legislation and labor conditions need to align with technological advancements to prevent layoffs due to automation. Some participants felt the systems won't be fully mature soon, potentially causing issues like slowness and accidents, while others believed new technologies wouldn't be marketed unless ready to a certain extent.

FMS Design Improvement (n=31): Participants suggested improvements like more detailed information about operations and vehicles, better notifications (e.g., different colors for critical issues), real-time camera views, and more weather data. The system should avoid overwhelming operators with too much information, particularly as fleets grow. It should handle issues autonomously, requiring operators only to oversee and confirm actions.

Human-Machine Compatibility (n=31): Concerns were raised about increasing complexity making it hard for operators to understand or intervene. Some linked this to growing dependency on automation, while others thought the workflow wouldn't change much. Reducing human presence on docks was seen as beneficial for safety and efficiency, provided real-time remote monitoring matches on-site events accurately. Introducing automation in human-designed environments may be challenging, and mixed technologies (manual and autonomous) might not offer the same benefits as full automation, potentially causing issues like unpredictable manual drivers.

AVs (n=28): Initially, AVs may perform only simple tasks and move slowly, stopping at minor obstacles. However, significant investments have made AVs quite advanced. Further funding should ensure AVs have state-of-the-art sensors and communication equipment. Managers could control multiple vehicles, but there are concerns about job losses to AVs, more so than to FMSs. Each vehicle should have standardized planning through the FMS, with all relevant information (e.g., cameras, battery status) readily available.

Acceptance (n=26): Acceptance varied, with some people resistant to change and negative aspects of automation emphasized by media and detractors. There is fear of job losses, with some believing company owners might resist paying more for remote work or hire fewer people to control more operations. Changes in labor law were seen as necessary. Some thought working as a remote operator might become boring, while others reported high acceptance among port employees, believing these technologies will eventually become commonly used and accepted.

Communication/Connectedness (n=21): Concerns were raised about the risk of digital communication leaks or interceptions, with greater system complexity increasing these risks. Bad weather was also seen as a potential hindrance. Reliable sensors, real-time cameras, and low latency are crucial for maintaining contact with AVs.

Personal Experience, Location, Weather (n=20-16-10): Reactions to the technologies varied, with some reporting resistance from employees while others found positive reception. Northern European countries were perceived as quicker and more efficient in adopting new technologies. Participants generally felt that safety, security, and reliability would be ensured. Rough port dock conditions were seen as challenging for hardware, and current vessels and terminals not being designed for automation were noted as potential problems. Big ports pose scalability questions for technological solutions. Real-time weather information is crucial for job scheduling, especially in strong wind conditions on docks.

2.9. Integration and next steps

The port demonstration was about testing and proving whether an automated vehicle can confidently drive in the port area. When the automated vehicle is used for rearranging trailers outside the main rush hours of loading or unloading a ship, or working more in its own area, it is basically easy to see the future possibilities. Driving on the busier routes in mixed chaotic traffic with human drivers, is still rather a topic for R&D than forming the first actual opportunities.

Loading a ship and driving between different decks is also rather a research topic. Electric trucks, in their current first versions, do not even possess the raw power to pull all trailers up the ship. On the ship, humans are finally needed for lashing and securing the trailers before the shipping – although, these tasks could become separate from driving a truck.

The main obvious hurdle that has to be solved before take-up of automated rearrangement of trailers is the way to automate connecting and disconnecting the trailers. Any improvements in automated connecting would also speed up human driver work considerably. Currently, they might need two minutes to connect a trailer. This is even though the connectors are standardized – their locations aren't. There are two pneumatic hoses and one electric to connect, and trailer legs to operate. During the project several future options were discussed, but a trivial solution is not available. Instead, developing some adaptor to be installed on the trailers – or installing a robotic arm would likely be necessary. Further standardization is one option. With standardization, however, one has to consider how to update the current trailers. Adaptors might be easier to get going within one shipping company, being installed on a trailer as it is received and removed before the trailer is released, at another port, after shipping it. However, an adaptor design does not seem simple, either.

DFDS and EasyMile plan to continue development activities. The driving part was the first demonstration, and the follow-up phases would focus more on integration possibilities.

2.10. Simulations and modelling of automated operations

The Port simulation primarily focused on the process of rearranging trailers within the port area. The main goal of this rearrangement is to expedite ship loading, leading to significant cost savings. According to information from port personnel, every 15-minute reduction in ship loading time results in approximately €2500 in savings. The simulation's objective was to compare the costs of trailer rearrangement against these potential savings and determine the cost-effectiveness of automated operations.

A list of trailer transfers was randomly generated for the simulation, with the aim of repositioning trailers closer to an upcoming ship. For a visual representation, please refer to Figure 17 and Figure 18, which depict the port map. In Figure 17, red lines indicate the routes taken, green dots represent incorrect placements, and blue dots signify the correct locations.

At the port, there are two field support employees in the simulated case of automated vehicles. The employees connect trailers to vehicles and support the operation of the vehicles. There is no need for these additional workers for human-operated vehicles; the drivers handle the connection themselves. Various assumptions are presented in Table 6.

The simulation was conducted for both scenarios: one where human labor is necessary for connecting trailers to trucks (the current practice) and one where it is not required (as envisioned for the future). The results provide detailed information on labor costs associated with trailer switching and potential savings if this process were to be automated.

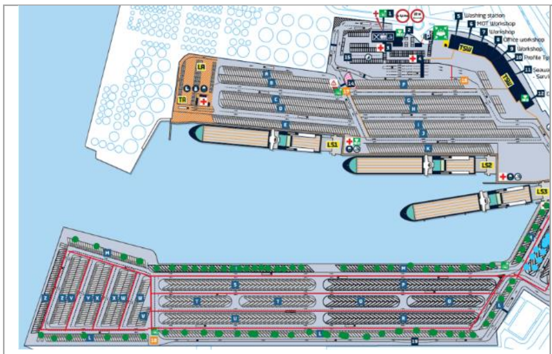

Figure 17: Port map of the simulation (source: Port presentation 2023-05-04)

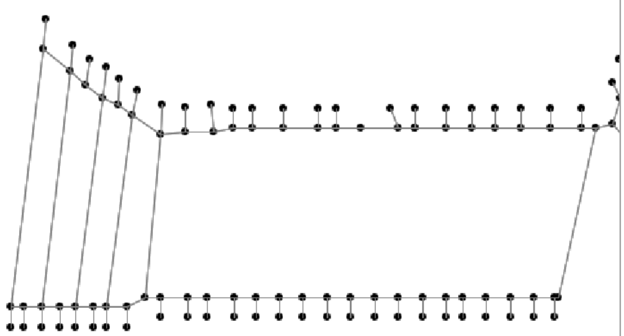

Figure 18: Port simulation map

Table 6: Assumptions of the port simulation

Assumptions of the port simulation
Average speed based on actual driving data: 14.4 km/h for human vehicle and 8.6 km/h for automated vehicle.
Breaks for human drivers: two breaks of 25 minutes each, one break of 1 hour
Time required to connect a trailer per vehicle: 2.5 minutes.
Time required to disconnect a trailer per vehicle: 1 minute.
Cost of human labor: €50 per hour
Cost per kilometer: €1
Human employees take break when there is free time
Absence of traffic congestion
5 minutes of human teleoperation work per operated hour
Organizing all trailers saved 15 minutes in ship loading
The 15-minute time savings in faster loading leads to a cost savings of €2500.
Two employees were responsible for connecting trailers to automated vehicles.

The tables break down the costs of remote operation, maintenance staff and vehicles (costs per kilometer), and the money saved is the amount of money saved by moving trailers. Simulation results are shown in following tables:

Table 7: The first port simulation results, with 2 persons to support trailer connecting/disconnecting.

	Human vehicle	Automated vehicle
Number of vehicles	5	5
Working time period (h)	3.0	3.0
Kilometers travelled	113.29	84.82
Transported trailers	120/251	87/251
Human support costs (€)	0	300
Human teleoperation costs (€)	0	41.02
Vehicle operation costs (€)	113.29	84.82
Vehicle ownership costs (€)	8.56	17.12
Total costs (€)	871.85	442.95
Savings from rearrangement (€)	1195.22	866.53
Saved money after costs:	323.37	423.58
Average vehicle utilization (%)	52.19	65.62
Human drive/support time (h)	7.83	6.82

Table 8: The second port simulation results, without 2 persons to support trailer connecting/disconnecting.

	Human vehicle	Automated vehicle
Number of vehicles	5	5
Working time period (h)	3.0	3.0
Kilometers travelled	113.29	84.82
Transported trailers	120/251	87/251
Human support costs (€)	0	0
Human teleoperation costs (€)	0	41.02
Vehicle operation costs (€)	113.29	84.82
Vehicle ownership costs (€)	8.56	17.12
Total costs (€)	871.85	142.95
Savings from rearrangement (€)	1195.22	866.53
Saved money after costs:	323.37	723.58
Average vehicle utilization (%)	52.19	65.62
Human drive/support time (h)	7.83	0.82

In the port simulation, the number of sorted boxes changes in proportion to the time and money saved. The savings come from speeding up the ship's visit to the port. The amount of savings is estimated using a factor from the data provided, so as the number of trailers sorted increases, so does the amount of savings. The savings with different levels of human support are shown in Figure 19.

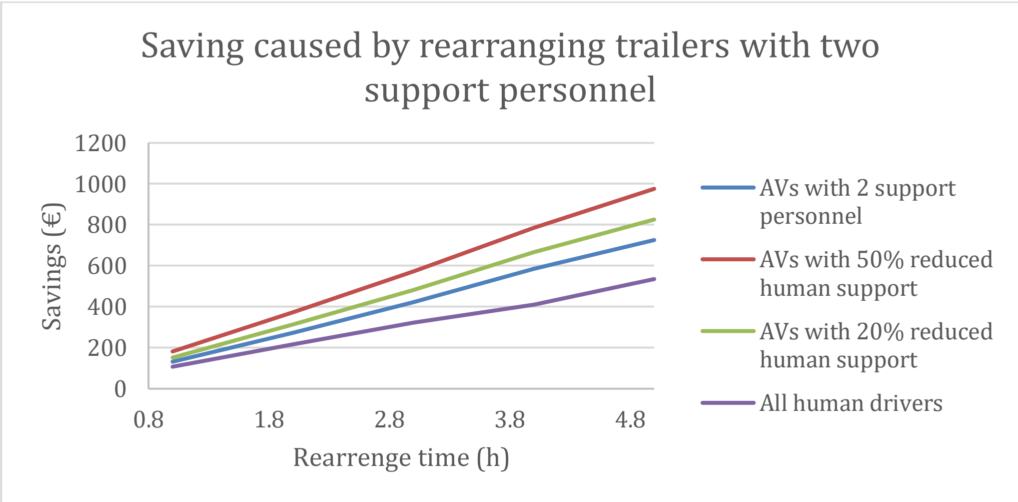

Figure 19: Money savings as a function of working time (5 vehicles).

With five vehicles and three hours of work, the benefits range from €320 to €570, depending on factors such as the number of supported individuals and the vehicle type. Figure 19 shows that by decreasing the need for human support, the advantages of automation can be increased. While human-operated vehicles may move faster and handle more trailers, automation still holds a distinct advantage. Given the high cost of human labor, automation emerges as the more profitable choice compared to relying solely on human-operated vehicles. The benefits produced by the arrangement depend almost linearly on the arrangement time, which is why the number of benefits can be increased by maximizing the arrangement time. However, this is not always possible, as the available time depends on the time of arrival of the ship.

Main findings

- It is worthwhile rearranging trailers using automated and human-operated vehicles, as the savings in terms of time spent are significant.
    - For 5 automated vehicles, costs would be 49% lower than for human-operated vehicles, including 2 support persons in the field and a teleoperation service, and 83% lower than for human-operated vehicles without 2 support persons in the field.
- If the process of connecting trailers to vehicles can be fully automated, it has the potential to reduce automated vehicle total costs by roughly 68% in the case of 5 automated vehicles and 3 working hours. The extent of savings would depend on the number of vehicles and working hours.
- Increasing the number of organizing vehicles is preferable to extending the working hours, if possible. This seems to be due to the long time it takes to connect trailers.

2.11. Implications on a larger scale

To understand the specific approach to scaling in this context, please refer to Annex I, section A6. This applies similarly to sections 3.11, 4.11, and 5.11 of the other use cases.

To scale the results to a regional level, we start by segregating the scenario into the different measures of interest.

The first step is to obtain Roll-on/Roll-off (Ro-Ro) details. Roll-on/Roll-off (Ro-Ro) is a method used to load and unload vehicles and other wheeled cargo on ships, ferries and other transport vessels. This process involves bringing cargo directly onto the vessel on its own wheels or using a flatbed vehicle, such as a trailer or dolly. Ro-Ro vessels are specifically designed for this purpose and have built-in ramps or doors that facilitate the movement of cargo.

The following table shows the gross weight of goods handled in the main ports, in particular, it is of interest to focus on the ro-ro ports for trailers in the EU.

Table 9: Gross weight of goods handled in the main European ports

CARGO (Labels)	2022 TOTAL	CARGO (Labels)
Liquid bulk goods	1,269,052	36.98%
Dry bulk goods	786,409	22.92%
Large containers	780,771	22.75%
Ro-Ro – mobile self-propelled and non-self-propelled units	409,381	11.93%
Other cargo not elsewhere specified	185,767	5.41%
Unknown	-	
Total	**3,431,381**	

In 2022, 11.9% of the freight traffic of the main European ports was transported in Ro-Ro units. The major ports cover 3,431,381,000 t / 3,480,872,000 t~98-99% of the total EU27 cargo tons in 2022.

Based on cargo tons only, we could estimate the total Ro-Ro ports by taking the total number of ports as a starting point, this value is ~ 1200 ports. The calculation consists of 0.119 * 1200, which gives us 143, i.e. there are approximately 150 Ro-Ro ports in Europe.

Then the gross weight of goods transported to/from the main ports is analyzed (23 EU countries are considered). Data was taken from Eurostat and the following was obtained:

- Temporal Frequency Annual (2013 to 2022)
- Direction of flow Outbound
- Type of cargo Ro-Ro
- Self-propelled mobile units
- Nationality of registration of vehicle
- Unit of measure Thousands of tons

After cleaning the data, it was obtained that 255 ports have had outbound ro-ro activity in 2013-2022 (self-propelled mobile units). To this, the average gross tonnage (2013-2022) was calculated, and ports were classified by size as follows:

Table 10: Number of European ports by amount of goods handled

	All ro-ro ports with outward activity	AVG > 10 thousand tons	AVG > 50 thousand tons	AVG > 100 thousand tons	AVG > 500 thousand tons	AVG > 1000 thousand tons
Number of ports in EU by average annual gross weight of goods transported from port (outward) in 2013-2022.	255	187	149	125	72	40

With the above, there are 255 ports with annual outbound ro-ro departures in the EU. There are 187 ports with more than 10,000 tons of annual outbound ro-ro departures and 40 significant ro-ro ports with more than 1,000,000 tons of the same activity.

The next step is to identify how many ro-ro departures there are in the EU. Following a discussion with DFDS it was identified that there are 4 ship departures per day.

Port activity data from Portnet 2022 (Traficom, Lipasto VTT), indicates that there are a total of 24,656 port calls per year in the 15 main ports of Finland (2022), 24,656 / 15 = 1643 vessels per year per port ~ 4.5 vessels per day per port.

Finally, the volume of vessels in the main ports is analyzed by vessel type and size (based on entry declarations). The following table shows the results:

Table 11: Volume of vessels by type

Vessel category	Number of vessels	Share%
Cargo, non-specialized	1,552,950	68,85 %
Passenger (excl. cruise)	316,794	14,05 %
Cruise passenger	141,867	6,29 %
Liquid bulk	79,945	3,54 %
Container	63,948	2,84 %
Dry bulk	37,711	1,67 %
Cargo, specialized	16,008	0,71 %
Other	23,131	1,03 %
Other	20,198	0,90 %
Offshore activities	2,933	0,13 %
Total	**2,255,485**	

Thus, based on the ~1200 ports in Europe, the average number of ships departing is 2,255 485 / 1200 = 1879 per year per port, which means 5.1 ships per day.

The category "Cargo, non-specialized" includes ro-ro vessels. Assuming 3/4 of them are ro-ro vessels, this would be 5.1 (all vessels per day) * 0.6885 (cargo, non-specialized share) * 0.75 (assumed share of ro-ro vessels) = 2.7 ro-ro vessels per day per port covering the 1200 major ports.

If we use only the number of ro-ro ports from the tables above: 255 ro-ro ports with activity 2013-2022, and again, if ro-ro vessels cover ¾ of the category "Cargo, non-specialized", it would be 3/4 * 1,552,950 vessels = 1,164,712.5 assumed ro-ro vessels. Divided by 255 ports

-> 4567.5 ro-ro vessels per port. This would mean an average of 12 ro-ro vessels per day in the 255 ports mentioned.

Finally, the number of total trailers that can be carried by a Ro-Ro vessel must be determined. This indicator will depend on the size and characteristics of the vessel, as well as the trailer, but, in general, a Ro-Ro vessel with a capacity of 5,000 lane meters can carry approximately 250 standard 12-meter trailers. For the purposes of this analysis this value will be assumed.

Considering the above, we proceed to estimate the need for this type of vehicle and the impact on cost savings from the results obtained from the simulation.

From the simulation it was obtained that the use of automated vehicles generates significant time savings. If 5 autonomous vehicles are used, the costs are 49% lower than those of manual vehicles (this when 2 field support personnel and a teleoperation service are included) and 83% lower (if these support personnel are excluded) with respect to manual vehicles.

To extrapolate the results, it is assumed that each vessel requires the reordering of 250 trailers, this leads to an estimate of 250*12=3000 trailers per day per port. To simplify, if 5 automated vehicles can handle these trailers efficiently, the cost savings become significant. Assuming that the daily cost of a fully human operated vehicle is 168 € (considering the cost of 32 € per hour), the total cost of operating 5 manual vehicles would be 5×168=840 € per day. Now, regarding autonomous vehicles and the savings from using them, it was obtained that, with 5 automated vehicles and 2 support persons, the costs are 49% lower than manual vehicles, which means ~ €428 (0.51 x 840=411.6), while without support persons the cost is ~ €143.

3. Airport impact assessment

3.1. Test site introduction and routes

The automated baggage transport testing at Oslo Airport, Norway, comprised four phases aimed at evaluating and advancing the use of an automated baggage tractor.

- **Phase 0 and Phase 1:** These initial phases focused on validating the vehicle's safety and basic functionality. Continuous testing was conducted throughout the AWARD project to ensure reliability and performance.
- **Phase 2 (April to June 2022):** This phase increased the complexity of missions, including performance comparisons with human-driven vehicles. Preparatory work involved training ground handlers, assessing risks for new routes, and resolving data collection issues. The missions included driving from the EZTow waiting mission point to the airplane stand, picking up filled carts, transporting them to the PMZ Arrival for manual unloading, returning to intermediate storage, and driving back to another gate or the EZTow waiting mission point. Another route involved collecting empty carts from intermediate storage and transporting them to cart storage before returning to the waiting mission point or storage for subsequent trips.

  The missions in Phase 2 included various segments aimed at comprehensively assessing the vehicle's capabilities, which are listed below, with the route depicted in Figure 20.

  1. EZTow waiting mission point
  2. Drive to airplane stand
  3. Pick-up filled carts and bring them to PMZ Arrival
  4. Manual unloading of baggage
  5. Return to intermediate storage
  6. Drive back to another gate or to EZTow waiting mission point.

  The segments of the second route (illustrated in Figure 21) include:

  1. EZTow waiting mission point
  2. Drive to intermediate storage for carts
  3. Collect empty carts and transport them to carts' storage
  4. Return to the waiting mission point or to intermediate storage for subsequent trips.

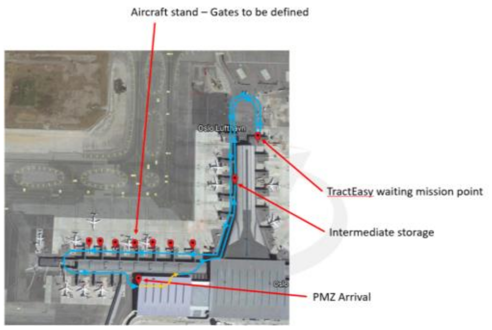

Figure 20: Phase 2, planned mission 1

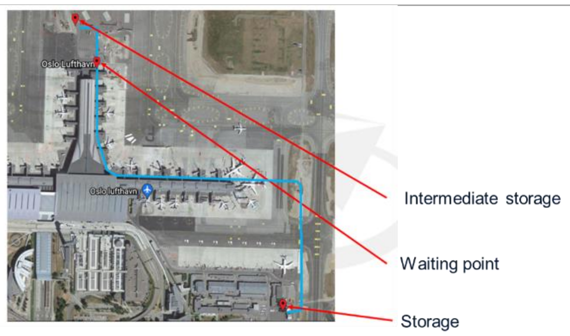

Figure 21: Phase 2, planned mission 2

- **Phase 3 (21 September 2023 to 1 February 2024):** Building on the insights from Phase 2, this phase focused on driverless operations assisted by an escort car. It aimed to tackle more challenging weather conditions, complex routes, and nighttime operations, thus examining the broader feasibility of automated baggage tractor operations. The wintertime tests conducted during this phase provided valuable data on the vehicle's performance under harsh winter conditions, including snow and cold weather impacts on sensor functionality.

Figure 22: TLD automated baggage tractor

Significant progress was made in 2023, particularly in adapting to snow conditions. The team conducted on-site tests at the Oslo tarmac, making strategic hardware and software modifications. These efforts culminate in final testing scheduled for January 2024, aiming to simulate the operational intricacies of the EZTow within the airport environment. This marks a pivotal step toward integrating autonomous driving systems into future logistic operations.

3.2. Timeline

Below you can see the timeline of phase 2.

Table 12: Timeline of Phase 2

Phase 2	Start month	End month
Pre-testing	16	16
Baseline data collection	16	18
Operations and interviews	17	18
Dataset finalization		19
Evaluation and reporting	20	23

In Phase 3, there were consecutive 2-month periods dedicated to testing novel missions and routes, employing the same configuration as Phase 2 (refer to Table 13). Phase 3 specifically involved trials of driverless operations with an accompanying escort car, addressing intricate missions and routes, adverse weather conditions, nighttime operations, and challenging localization scenarios (Oslo tarmac).

Table 13: Timeline of Phase 3

Phase 3	Start month	End month
Operations and interviews	Autumn 2022	
Strategic testing	2023	
Final testing	January 2024	January 2024

3.3. Performance goals and pre-existing indicators/statistics

As outlined in D7.4, the long-term benefits of automating luggage tractors encompass a reduction in the number of drivers, safety enhancements, improved utilization of luggage tractor capacity, reduced driving through better planning of automated vehicle trips, streamlined manual planning with enhanced fleet management, and optimized cart and container capacity utilization. It is anticipated that there won't be significant changes in driven routes, as the airport has limited alternatives. Delays and luggage damage are not expected to be greatly affected, given the comparable automated driving speed to human drivers. Currently, energy consumption and operational hours data are maintained by various ground handling companies, and collecting baseline data directly using a data logger is deemed more efficient. While other automated operations at the airport are limited to vehicles following a lead car during snow cleaning, no immediate plans exist beyond baggage transport. Systematic collection of airport accident data is in place, and similar data is accessible from various countries.

3.4. Description of automated vehicle functionalities

The trials utilize a TLD baggage tractor equipped with sensors (see Figure 23). TLD, a prominent airport equipment provider, supplies the vehicle, which will be outfitted with instrumentation by project collaborators and utilizes EasyMile's navigation software.

Figure 23: Automated baggage tractor

This electric vehicle aligns with Oslo Gardermoen airport's existing use of electric vehicles for both indoor and outdoor luggage transport. While the vehicle will autonomously drive, the manual operation of unhooking and hooking carts will persist throughout the project timeline.

Fleet management will necessitate signaling completion of these operations for the vehicle to proceed. With a maximum speed of 30 km/h, the automated vehicle aims for a speed comparable to human-driven counterparts. Notably, the vehicle is slightly wider, around 40 cm, due to sensor instrumentation. Safety measures include the presence of a safety operator inside the vehicle during all tests.

3.5. Affected other operations

The automated vehicle will engage with luggage handlers and various apron activities, including refueling, catering, and cleaning operations during the turnaround process. Currently, there is no direct monitoring of baggage tractor-related timings or delays. Delays are typically marked only if an airplane is delayed, with the primary cause noted. If a ground handling issue, particularly a baggage tractor malfunction, is identified as the reason for a delay, relevant notes would be made. In the event of a problem with the automated vehicle, a manually driven vehicle might be requested as a replacement. However, the arrival of a manual vehicle could potentially lead to delays in the airplane departure, impacting turnaround times of 20–30 minutes, which may result in declared penalties based on operational agreements.

3.6. Infrastructure modifications

During the testing phases at Oslo Airport, several infrastructure modifications were necessary to accommodate the automated baggage tractor. One significant change was the need for consistent and effective road maintenance, especially during the winter tests, to ensure the vehicle's sensors could function properly despite snow accumulation. The vehicle's sensors required protection from snow and ice buildup, leading to modifications in their placement and occasional manual cleaning. Additionally, summer tires were replaced with winter tires to improve traction on icy surfaces, although studs were not used to allow the vehicle to drive indoors. Some road segments had to be shifted to avoid snowbanks and ensure the vehicle could navigate its routes without obstruction. These modifications were crucial for maintaining the vehicle's operational efficiency and safety in varying weather conditions.

3.7. Data logging

3.7.1. Baseline data collection

The baseline data collection for manual driving was a critical component of both the summertime and wintertime tests, providing insights into the extent and nature of human intervention required during automated operations. During the summertime tests, conducted from 13 April 2022 to 17 June 2022 (Phase 2), data was meticulously recorded to capture instances where manual driving was necessary to support the automated vehicle. This period involved extensive documentation of driving hours, including when and why manual interventions occurred. Similarly, the wintertime tests, carried out from 21 September 2023 to 1 February 2024 (Phase 3), focused on understanding the challenges posed by harsh winter conditions. Data collected during these tests included detailed logs of manual driving time, conditions prompting manual control, and the nature of support provided. This baseline data is essential for benchmarking the current capabilities of automated systems and identifying areas where manual intervention is still critical.

location_id	Driving Time (min)	Manual Driving Time (min)	%_manual_driving
NO_OSL_2	550,11	132,07	24,01 %

Figure 24: Percentage of manual driving where percentage of automated driving > 40%

3.7.2. AV data collection

The automated driving data collected during the testing phases was integral to evaluating the performance and reliability of the automated baggage tractor. During the summertime tests from 13 April 2022 to 17 June 2022 (Phase 2), comprehensive data was gathered on the vehicle's automated operations. This included high-frequency logging of vehicle status, such as position, mode, emergency stops, battery level, and traveled distances. The focus was on capturing the vehicle's behavior in various operational scenarios and understanding its performance in favorable weather conditions. The wintertime tests, conducted from 21 September 2023 to 1 February 2024 (Phase 3), extended this data collection to include operations under challenging winter conditions. Detailed records were kept on the vehicle's automated driving performance, including the impact of snow and cold weather on sensor functionality and overall system reliability. This data is crucial for assessing the robustness of the automated systems and guiding improvements for future deployments.

3.7.3. Access to log data

Test site partners oversaw dataset management, and the collected data was uploaded to an FTP server, accessible to designated evaluation partners with confidentiality protocols in place.

3.8. Results

3.8.1. Technical evaluation

The technical evaluation at Oslo Airport focused on operations under Nordic winter conditions, specifically addressing positioning accuracy and the challenges posed by winter weather. Oslo served as a key research location for sensor data fusion with the AWARD project sensor set.

Initial winter tests revealed several difficulties, such as sensors accumulating snow, which impaired functionality (Figure 25). The vehicle was initially equipped with summer tires, which were inadequate and subsequently replaced with winter tires. Studded tires were not permitted as the vehicles sometimes drive indoors. These tests highlighted the importance of effective road maintenance to ensure AV performance.

Figure 25: Snow blocking a sensor

Snowbanks impacted map-based positioning, causing lateral driving deviations of +/- 15 cm from the planned route, compared to summertime errors within 6 cm. Snow accumulation occasionally narrowed lanes, despite active maintenance efforts aimed at keeping full lane width. During severe weather, landing lanes were prioritized, making ground handling routes secondary. One road segment had to be shifted to avoid snowbanks.
During heavy snowfall (Figure 27), the vehicle required manual operation. Light snowfall (Figure 26) allowed for continued automated testing, although there were occasional emergency stops due to lidar obstructions.

Figure 26: Light snowfall, during which testing was possible

Figure 27: Heavy snowfall stopping tests

When the snow started to melt, the vehicle handled well in deep puddles, which could have posed issues due to lidar reflections, but this was not a problem in practice.

Figure 28: Wintertime tests, snowbanks and puddles.

Figure 29: Maximum automated speed and route in Oslo winter tests

Figure 28 shows that maximum route speeds during winter testing matched summer speeds, thanks to good road maintenance, with reductions only during snowfall. Certain segments required manual intervention due to visibility issues and traffic conditions, such as turning left at a busy intersection, ensuring safety through a conservative approach.

At Oslo Airport, key findings from the automated baggage tractor tests include:

- Manual driving time: ~7 minutes per trip.
- Automated driving time: ~10 minutes per trip, both acceptable for luggage delivery and plane turnaround.
- Maximum automated speed: 15 km/h (vs. 20–30 km/h for human-driven), leading to frequent but manageable overtaking on long straights.
- Operators felt safe, with no critical situations.

In June 2022, 50 hours of driving were logged, with 36 automated hours over 12 days. About 12% of automated operations needed manual support for documentation and garage transport, averaging 30 meters and 30–40 seconds per intervention. Approximately 5 minutes of human support per operational hour is realistic, with one or two teleoperators potentially overseeing 12 vehicles. Clearer turnaround locations could reduce the need for teleoperation.

3.8.2. Safety evaluation

Emergency stop statistics

Operators felt safe in the automated vehicle, and no critical situations occurred during testing. There were many instances where another vehicle overtook and cut in too closely. The hardest braking during the summer tests was at 3.5 m/s² due to a perceived obstacle, despite object tracking capabilities not yet being active in production.

Figure 30: Another vehicle cutting in

Figure 31: Crowded route endpoint

Manual intervention was needed in crowded areas, like trolley storage, to navigate, highlighting the need for better separation of manual and automated operations. During the summer tests, 36 hours of automated operations out of 50 hours of driving recorded 306 safety stops with no near-misses or incidents. Most common reasons for safety stops (including both automated and manual continuation) were:

- no obstacle (70)
- overtaking vehicles (55)
- blocked by a trolley (about 50) – could be improved!
- vehicles otherwise (47)
- uneven road (about 30)

Of those that required manual work, no obstacle 58, overtaking 13 (changes), blocked 52, vehicles 28 (changes), uneven road 15 (changes).

Winter tests showed issues with localization and dirty sensors, leading to frequent stops. Manual pauses happened every 6 minutes, and localization issues every 25 minutes. Placing sensors higher could reduce warnings related to dirty sensors. Localization errors mostly occurred near gates, possibly due to a dynamically changing environment or GPS difficulties.

Some of the error messages are repetitive, but by filtering the messages within a few seconds, the distribution shows that localization and dirty sensor problems start to climb near the number of cases of obstacles on route:

- 110 paused by operator
- 27 blocked (and not merely paused) by obstacle stops
- 27 localizations lost
- 22 times sensor cleaning would be required by the vehicle due to lidar errors.

Operator wishing to pause the navigation so often indicates being extra careful and requiring further development work on fluent interaction with other traffic at the site.

The EZTow vehicle performed well in safety tests, handling dark and moderate rain but struggling with heavy rain or snowfall. It had an impressive reaction time of 0.3 seconds. Fast reaction times and slow speeds made it safe, though it recommended increasing braking deceleration to avoid collisions with fast-moving pedestrians. The main safety concern was overtaking by other drivers, which could become a problem in long operations.

Human drivers often sped near luggage halls, leading to minor dents and occasional notable collisions, typically not documented unless an aircraft was involved.

Figure 32: Localization error stops on aerial view – most happen near gates

Observations and SOTIF proving ground test lessons

Among the AVs used within AWARD's use cases, the EZTow vehicle is the closest to a working product. In the safety tests all test scenarios were completed satisfactorily. Also, during the operational tests, there was no threat to other road users. The vehicle is able to operate in dark environments and moderate rain, but heavy rain or heavy snowfall stop it with the lidar sensor set, mainly due to accumulation of water or snow near the sensors than software limitations.

The vehicle was tested to have an impressive reaction time of 0.3 seconds, measured from an obstacle appearing in emergency zone and vehicle speed starting to drop.

Fast reaction times combined with slow speed make the vehicle very safe. Especially it handles well objects in the front. In safety tests it was still possible, timing fast pedestrian movement coming from the side exactly right, collide with the vehicle before it was able to fully stop. Based on the tests, it was recommended to increase breaking deceleration from a maximal value of 3.5 m/s2 to 5.6 m/s2 or higher to avoid such cases. Friction limits are approximately 10 m/s2. Also, ongoing object tracking development will provide better responsiveness in the future to fast-approaching lateral road users.

The main safety concerns that this vehicle introduces are rather the numerous overtaking cases by other drivers. At the airport, however, the visibility is mainly good on long straights, and overtaking doesn't cause immediate danger. In long operations, an overtaking accident becomes a possibility.

Currently, the human drivers of luggage tractors often come fast from luggage halls, expecting other drivers to drive extra carefully near these doors. This has occasionally come as a surprise for new workers. The accidents, however, have been small dents in vehicles. The vehicles rarely undergo repairs for such dents. Leaving them on the side, notable collisions between ground vehicles rather happen once a month, but they are usually not documented in detail unless an aircraft was considered to be involved in the incident.

Impacts on accident types and EU statistics

In early 2000s there was circa one ground handling incident with resulting aircraft damage per 5000 flights [2]. The incidents take place mostly when the AC is parked and majority of them occur when establishing an interface between aircraft and ground equipment. Actors cause most damage when attaching vehicles to aircraft doors.

Ground handling damage is mainly reported when an aircraft suffers or when flights are delayed for ground handling reasons. The report by Balk estimates that there are approximately 28 times more ground handling incidents, without AC damage. This creates a difficulty, when assessing, based on current accident statistics, the safety potential of automated ground vehicles.

According to existing statistics and project interviews, ground handling accidents leading to human injuries are rare. There were 7 fatal accidents, 448 non-fatal accidents and 104 serious incidents during 2009–2018 in aerodrome and ground handling operations at EASA (European Union Aviation Safety Agency) member state airports [3]. According to these figures and EASA flight statistics (average 9 095 146 flights/year in 2008–2017), we can estimate there are 0.08 fatal and 5 non-fatal ground handling accidents per million flights in EU airports. The latest figures over 2012–2021, in total, are 3 fatal accidents, 228 non-fatal accidents and 100 serious incidents.

Safety potential – analysis on ground vehicle occurrences in EU airports 2015–2021:

VTT analyzed 189 ground operation occurrence reports from airports in EU countries. The data was received from Finnish Transport and Communications Agency Traficom [4], and it covered German, English and Finnish ground operation occurrence reports from airports in EU countries from years 2015–2021. All of the reports were from situations with aircraft vicinity, so other ground incidents were outside of the scope for this analysis. 91/189 cases were such that lead to a minor contact or a collision with the aircraft.

From these cases, we identified the most common incident and other occurrence types, so that the incident types could be reviewed from automated driving safety perspectives.

Half of these collisions (14/28) occurred when something was standing on the ACs path. 5/28 (18%) of collisions in our scope were caused by either the aircraft or ground vehicle's parking brakes failing (fault or user error). Driving in the way of the aircraft leads to a lot of occurrence reports, but rarely end up in collisions (2/28). We can say that both human error and human creativity (e.g. route selection) caused or at least contributed to many situations in the data.

In a scenario where vehicles transporting goods to and from the vicinity of the aircraft are automated, and a fleet management system is in place, we estimated potential increases and decreases in incidents for each deviation type. In such a scenario, most vehicles would move on predetermined routes and schedules at slow speed and would not deviate from the normal routes of other vehicles or the airplane. In addition to fleet management-controlled routes, the automated vehicle would be able to avoid collisions due to its moderate speed and collision avoidance systems.

Deviation types under our scope, their collision figures and assessed total reductions (% of cases) are presented in the following table:

Table 14: Estimated safety potential of automated ground vehicles

		Estimated incident reduction potential AGV adoption and fleet management			
Deviation type	**AC contacts in data**	**Safety benefit:** Relative reduction of AC collisions (%)	**Safety Cost:** Relative increase of AC collisions (%)	**Net safety impact** (% of collisions)	**Reasoning behind estimates**
GV Standing in the way of AC	13	-95%	+20%	-94 %	Automated vehicles stay out of the AC's planned path, which would eliminate most of these incidents. Possible malfunction of vehicles or sudden challenging weather conditions when operating (visibility, slipperiness etc.) might cause AGVs to get stuck on the route and operations to deviate from the norm.
GV misplaced	1	-95%	+20%	-94 %	
Object misplaced	1	-95%	+20%	-94 %	
GV driving in the way of AC	2*	-95%		-95 %	Automated vehicles stay out of the aircraft's planned path, which would eliminate most of these types of incidents. AGV adoption would not cause other manually driven vehicles to drive in the way of AC more than currently.

Other contact, GV hits AC	3	-90%	+20%	-88 %	AGVs drive slowly and according to fleet management restrictions. We expect this to reduce most random contacts caused by human error. New types of deviations are possible. E.g. unexpected heavy rain could halt AGV operations, requiring a switch to manual operations. This, along with tight schedules and poor visibility, could lead to risky actions.
GV sliding towards AC	2	-95%	+20%	-94 %	Wide automation and fleet management system reduce GVs operating and standing too near or in the way of the ACs path. We also don't see that parking brake malfunctions would be relevant to AGVs. Slipperiness (affecting 4% of scope cases in occurrence reports), could still cause some harm in operations due to AGVs lacking studded tires.
AC brakes not secured	2	-50%	+50%	-25 %	Currently, AGVs won't evade out of the way of AC if unexpected AC movements take place. This could lead to some increase in this event type. However, in occurrence data, evasions out of the way of AC only took place when GVs were driving in the way of AC. Wide automation and fleet management system reduce GVs operating and standing in the way of the ACs path. The operating and waiting locations are mapped so that sudden unexpected movements of AC would cause less of a risk compared to current manual operations.
AC parking brake failure	1	-50%	+50%	-25 %	
GV rolling towards AC	1			-95 %	We see that parking brake malfunctions and similar mishaps would not be relevant to AGVs.
Cart/trailer rolling towards AC	1	-25%		-25%	We assume moderate decrease due to fleet management rearrangements.
GV Reversing towards AC	1	-100%		-100 %	AGVs drive slowly and according to fleet management restrictions.

*24 near misses were caused by GV driving in the way of AC

The proportion of all cases that could potentially be influenced by early stages of ground vehicle automation, carrying cargo, was estimated to be around half of all the cases. From these possibly avoidable cases, 28 cases lead to contact. 24 were near misses and all of them took place when a ground vehicle was driving in the way of the AC.

Including initial estimates (above) on how large percentages of each accident type could be avoided, this analysis indicates that **a reduction of 26–31% of all ground handling incidents leading to AC damage** or AC contact could be reachable in a GV automation scenario discussed above.

As discussed earlier regarding unreported damage, a large portion of occurrences between ground handling vehicles and other vehicles or infra, were not included in our statistical analysis. Also, the analysis examined the safety aspects of automating baggage and cargo transport tasks between aircrafts and airport facilities. There has been preliminary discussion suggesting the potential for automating further transfers, and aircraft pushback and tow equipment. Moreover, there are ongoing trials at various airports where automated vehicles mimic the actions of a human-driven lead vehicle for tasks such as snow plowing.

We assume that expanding automation to also cover operations such as aircraft towing and pushback equipment, passenger stairs, and boarding bridges would extend the safety effects. More in-depth analysis would be required to estimate actual safety potential of automation for such tasks.

We might be discussing significant reductions for ground vehicle incidents taking place outside the AC vicinity. According to Balk's report (2008) there are approximately 28 times more incidents without AC damage than the ones with AC damage. However, more detailed information of such situations is not available and accident reports do not well cover minor ground handling incidents. Safety potential of automation on such events must be estimated on a more general level. Seeking an improvement in reporting practices or making efforts to collect ground handling minor accidents over a few years from a site could offer a more comprehensive view into damage and injuries.

As discussed before, at the project airport, one contact incident per month takes place (vehicle-to-vehicle or vehicle-to-infra). One noticed risk factor for these events is visibility barriers between ground vehicle drivers. This risk would be likely to be reduced after adoption of fleet management and collision avoidance systems, along with automated vehicles that are aware of each other's' locations.

When operating a mixed fleet, where automated and human-driven vehicles drive together, automated vehicles in their current phase would cause more overtaking accidents, as other drivers wish to drive faster. Also, when other drivers drift off their lane, automated vehicles might not be able to move to the side and compensate for the mistakes of other drivers. Such factors could decrease the safety potential of automated vehicles. Further, if vehicles get stuck, that causes also slow down and disruption of operations.

In a such scenario where majority of transport vehicles are automated and drive on separate lanes under fleet management restrictions, such overtaking incidents and several other incidents caused by human error could be avoided when operating. Automation, when working without human interaction, is usually considered very safe. Although not all ground handling tasks of servicing an airplane are easy to automate.

3.8.3. Efficiency

The efficiency impact assessment aimed to evaluate how the AWARD ADS influences financial, operational, and quality indicators in forklift operations. The research was guided by three primary questions:

- How does the ADS influence financial indicators?
- How does it affect operational indicators?
- And how does it impact the quality indicators in logistics operations?

To address these questions, we formulated several hypotheses and analyzed various performance metrics. The analysis involved segmenting the logs by session to represent each movement, allowing comparisons of manual versus autonomous operations. This approach helped isolate key performance indicators and apply mathematical analysis to draw meaningful insights. Some of the main findings are presented in Table 15.

Table 15: Efficiency hypothesis and main findings of the port use case

Hypothesis	Findings

The ADS supports reducing personnel costs.	The personnel time analysis reveals that for the driving task itself, the airport test data indicate savings between 91.4% and 76% of personnel time through automating the driving task. These savings could also be reflected in personnel costs savings in deployments where no safety driver is required. Since Oslo airport did not permit to drive without a safety driver, a reduction of personnel costs could not be realized within the tests. However, future applications of automated freight transport vehicles in combination with teleoperation could contribute to reducing personnel costs as well as mitigating driver shortages on the long run
The ADS reduces net transfer time.	The operator reports of the OSL1 dataset reveal 7 min manual driving time, about 10 min automated (for Mission 2). However, both are acceptable when considering requirements of the compact Oslo airport.
The ADS decreases personnel time to support the vehicle while driving.	Regarding the driving task itself, the Oslo airport test data reveals the following. In summertime tests (OSL1 dataset) the amount of manual driving to support automated driving trips was 11.6%, which was the lowest across all testing. 24% of all driving was manual in Oslo wintertime tests (OSL2 dataset). The MTBO within the winter tests ranges from a minimum of 4.26 to a maximum of 7.62 minutes. The median MTBO is 6.91 minutes. In case such overtakes may be resolved via teleoperation solutions the personnel time to support a transport vehicle might be reduced significantly.
The ADS reduces fuel consumption.	The collected data are not suitable for such an analysis, as the driving periods are too short. Possibly automation requires more energy, the difference here is 54.89%.
The ADS decreases vehicle speed.	The average automated driving speed in the OSL1 dataset (summer tests) was 7.6 km/h. This calculation disregards the stopping periods and calculated averages during moving, only. If stops are counted in and the whole task duration is selected, the average is 6.1 km/h for automated driving. The data gives 291 trips where automation percentage is above 60%. There was practically no human comparison available from the first summer tests, as the test was planned to be driven in automated mode only, but the data shows an average of 12.6 km/h for a human (when speed > 0), and 4 km/h during the whole task, if we select the leg with the lowest percentage of automation (5%) used. In wintertime tests (OSL2 dataset), where human comparison data was available, automated driving speed was in average 8.3 km/h (counting > 0) or 5.9 km/h. Average manual speeds were 15.3 km/h (> 0) and 9.2 km/h.
The operational availability of the ADS is lower than that of a manually operated vehicle.	The general availability of automated vehicles will be similar in case driver is available and vehicle still can be operated manually. L4-function availability: Potential operational hours could be improved from 7,815h (93.2% of 8445h; 89.2% of 8760h) to 8,369h (99.8% of 8445h; 95.5% of 8760h) through the AWARD ODD extension with respect to the 2023 Oslo airport weather data.

Subsequently, a more detailed analysis of the airport use case with respect to the efficiency assessment within the different phases is given.

Personnel Time and Operational Efficiency

In the summertime tests (OSL1 dataset), manual driving to support automated trips was 11.6%, or 7 minutes per hour, including handwritten stop documentation. This led to an estimated 5 minutes of human support per hour in simulations.

In the winter tests (OSL2 dataset), 24% of driving was manual, or 14 minutes per hour. Most manual interventions lasted about 40 seconds, including documentation via a mobile app. Some stops involved software debugging, unlikely in production use.

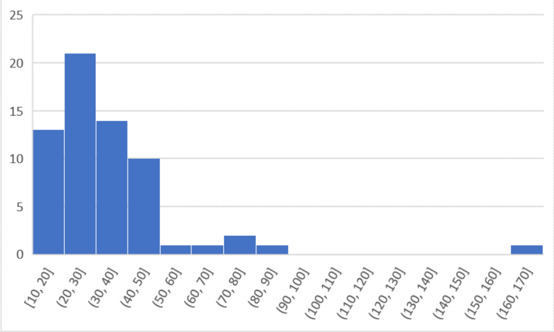

Figure 33: A histogram of manual intervention times and their durations

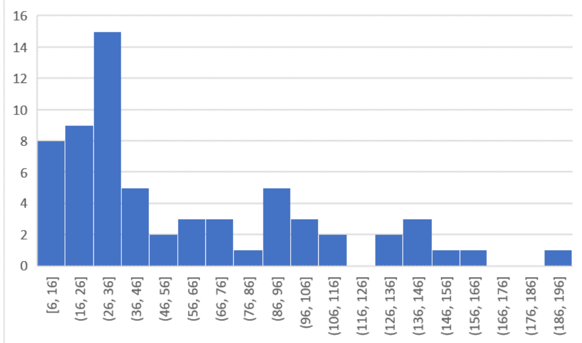

Figure 34: Manual interventions during winter tests

In addition to the share of manual and automated driving, the mean time between stops and human interventions was analyzed (see detailed description of MTBS and MTBO in section 0). Subsequently, the results for the OSL1 and OSL2 dataset are presented. Since the OSL1 data were collected in an early phase, the formats and available information differ from the OSL2 dataset. Therefore, the charts may slightly differ in terms of information categories.

OSL1 dataset (13.4.2022 – 17.6.2022)

The mean time between stops and human interventions was analyzed for both datasets. The OSL1 dataset (13.4.2022 – 17.6.2022) showed mean times between all types of stops for mission 1 ranging from 3.94 to 11 minutes, with emergency stops over 50 minutes.

Figure 35: Mission 1 @ Oslo Airport [OSL1 dataset] – Mean-time between stops

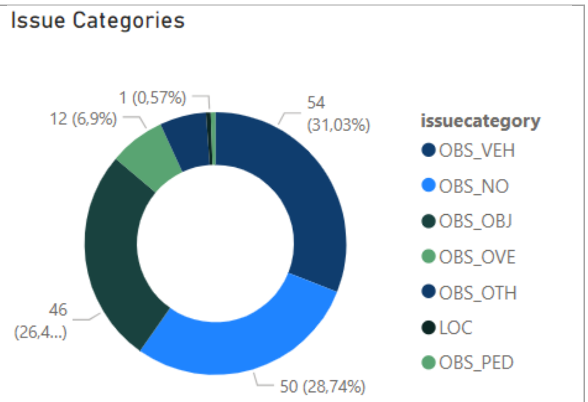

Figure 36: Mission 1 @ Oslo Airport [OSL1 dataset] - Issue categories

Figure 36 depicts the issue categories that led to stops. The three main issue categories are OBS_VEH (31,03%), OBS_NO (28,74%), and OBS_OBJ (26,4%). In other words, the automated vehicle mainly stopped due to other vehicles, faulty detection of "ghost" objects, and objects in the path of the vehicle.

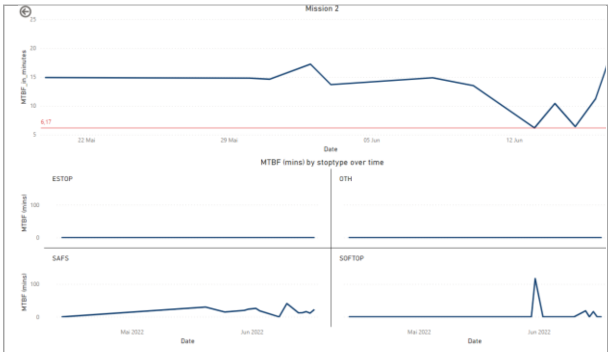

Figure 37: Mission 2 @ Oslo Airport [OSL1 dataset] – Mean-time between stops

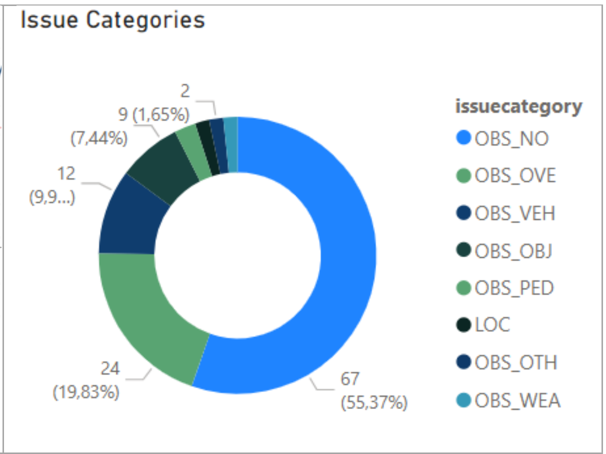

Figure 38: Mission 2 @ Oslo Airport [OSL1 dataset] - Issue Categories

For mission 2, stops ranged from 6.17 to over 20 minutes, with main issues being ghost objects (55.37%), overtaking vehicles (19.83%), and other vehicles (9%).

OSL2 dataset (21.9.2023; 24.1.2024 -1.2.2024)

For the OSL2 dataset the calculation of the mean-time between failure was adapted to calculating the Mean-Time-Between-Stops (MTBS) and the Mean-Time-Between-Overtakes (MTBO) by humans. The MTBS in the wintertime tests ranges from a minimum of 12.41 minutes to a maximum of 28.75 minutes. The median MTBS is 14.49 minutes. The MTBO ranges from a minimum of 4.26 to a maximum of 7.62 minutes. The median MTBO is 6.91 minutes.

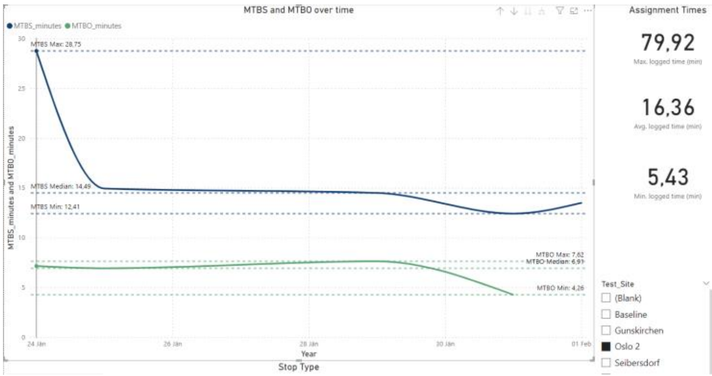

Figure 39: MTBS and MTBO @ Oslo Airport [OSL2 dataset] – Jan/Feb 2024

Vehicle Speed Analysis

In the OSL1 summer tests, the average automated driving speed was 7.6 km/h, excluding stops, and 6.1 km/h including stops over 291 trips with over 60% automation.

No human comparison was available for the first summer tests, but the data showed an average human driving speed of 12.6 km/h (excluding stops) and 4 km/h (including stops) for the least automated segment.

In the OSL2 winter tests, the average automated driving speed was 8.3 km/h (excluding stops) and 5.9 km/h (including stops). The average manual driving speeds were 15.3 km/h (excluding stops) and 9.2 km/h (including stops).

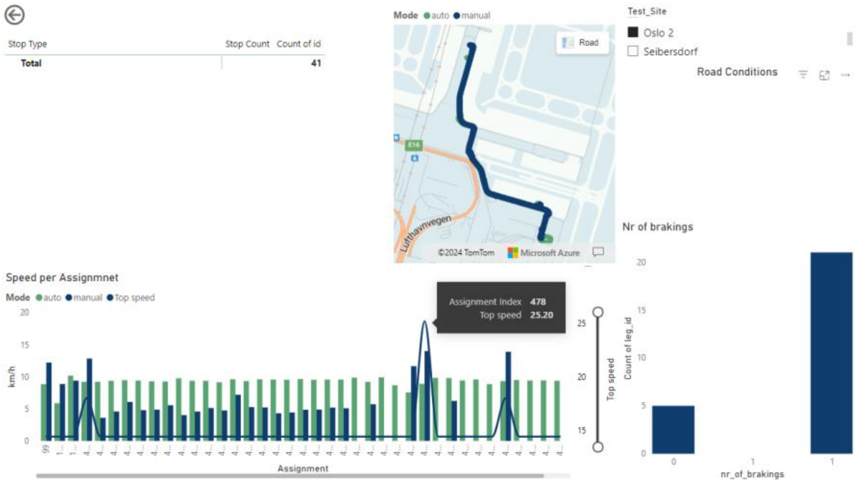

Figure 40: Speed per assignment – OSL2 dataset

Operational Availability

The L4-transport vehicle can operate manually or automatically, so its general availability is similar in both modes. However, the potential availability of the L4 automated function is crucial for logistics. Weather conditions were analyzed using OGIMET 2023 data, measured hourly, to evaluate different scenarios. The following table shows days and hours when harsh weather at Oslo Airport could impact the L4 vehicle, with restrictions like Temp < -10°C or Rain > 10mm.

Table 16: Recorded harsh weather periods at Oslo airport

Location	Difficult Hours	Difficult Days	Temp < -10°C Hours (Days)	Rain > 10 mm Hours	Visibility below 200 m (rainy)	Visibility below 200 m (non-rainy)	Heavy Rain Hours	Heavy Snowfall Hours	Thick Fog Hours	Hours of Dust and Sand	Hours of Thunder storms	Of year (%)
Oslo 2022	363	66	211 (20)	1	0	105	1	6	67	0	3	**4.1**
Oslo 2023	494	85	372 (40)	12	5	75	0	14	31	0	4	**5.6**

A dashboard has been developed to assess the L4-vehicle's potential availability based on weather data and the vehicle's ODD. It allows users to select harsh weather conditions, working hours per day, and the timeframe to calculate possible working hours. Figure 41 shows the dashboard and highlights the difference between EasyMile's L4 vehicle ODD before and after the AWARD project improvements. Considering constraints like temp > -10°C, precipitation < 10mm, and visibility > 200m, the yearly possible operating hours are reduced from 8,760 to 8,381. With the AWARD sensors, the potential operational hours improve from 7,815h (93.2% of 8445h) to 8,369h (99.8% of 8445h), a 6.3% increase.

Figure 41: Weather ODD Analysis for Oslo Airport 2023

Timeliness and Reliability of Transport Orders

The log data of the FMS provide insights into planned and actual times for start and end times of dispatch assignments. The standard deviation of the difference between actual and planned execution times is rather high within the test data with a value of 11minutes. However, the median difference between actual and planned execution times is only 1 minute.

Standard deviation for dispatch assignments	Median for dispatch assignments
• Diff. actual/planned start time = 79.96 sec -> ~1.3 min • Diff. actual/planned finish time = 670.07 sec -> ~ 11 min • Diff. actual/planned execution time = 662.34 sec -> 11 min	• Diff. actual/planned start time = 17 sec -> 0.3 min • Diff. actual/planned finish time = 97 sec -> ~1.6 min • Diff. actual/planned execution time = 64 sec -> ~1 min

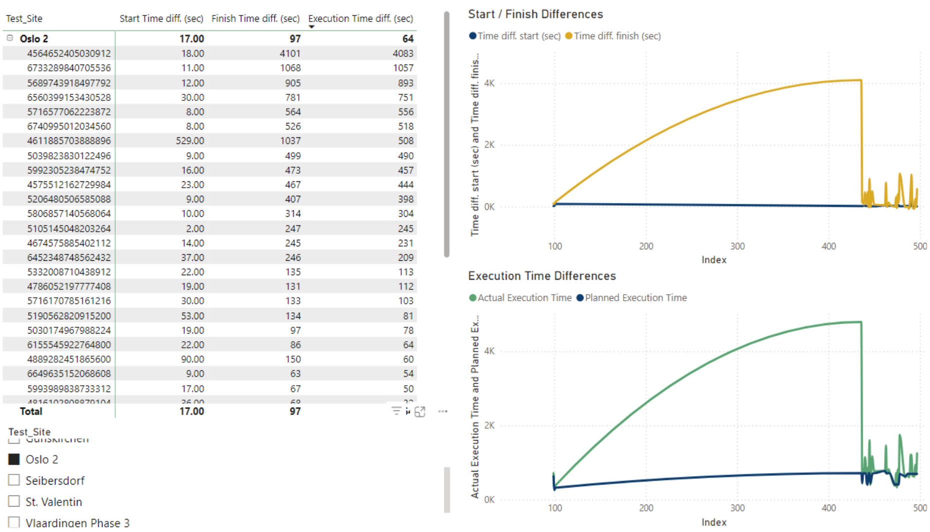

Figure 42: Dispatch assignment - timeliness analysis – OSL2 dataset

Main findings related to timeliness and reliability:

- Analyzing the timeliness of dispatch assignments performed in Oslo reveals that the majority of the assignments took longer than planned by the FMS.

- The median difference of actual versus planned times is around 1 minute for the analyzed assignments and not considered critical for the airport operations.
- Transport reliability is defined as the certainty that a transport order may be conducted within the expected time frame (schedule).
- At Oslo Airport 41 assignments were performed within a timeframe of 6 days. 12 assignments (29%) lasted shorter than planned and could be finished earlier. The remaining 29 assignments (71%) could not be performed in time and took longer than expected at Oslo Airport.

3.8.4. Environmental evaluation

This analysis is from Oslo wintertime tests, as there we got manual driving data for comparison.

When we split data by changes in battery level and count the total, how far a vehicle could travel with one percentage, either in fully manual mode or minimally 30% or 50% of the distance in automated mode, we get the following comparison:

- Manual mode 239.5 kilometers, 396% change in battery
- Automated mode: 95.8 kilometers, 160% change in battery (if > 30%)
- Automated mode: 68.7 km, 114% change in battery (if > 50%)

We get 0.605 km with a battery percentage change in manual and 0.598–0.603 km in automated mode. EZTow (airport) has battery size of 43 kWh. This indicates that automation would use 0.4–1.0% more energy. This difference is so small that given our limited data sample, we consider <u>no meaningful change in energy use</u>.

Simulations (Chapter 3.10) show considerable potential to reduce driven kilometers by up to 27% by optimizing where vehicles take breaks. Humans may not want to wait idly where automated vehicles could.

3.8.4.1. Braking event analysis

The total number of braking events, minimally with 1 m/s2 per driving hour, was about 10 in Oslo wintertime test data. This amount was the same for both manual and automated driving. The braking distribution where manual driver uses small braking considerably often indicates that the vehicle behaves slightly differently in manual and automated modes, practically some engine braking events being marked here as active braking. When comparing braking events above 1.5 m/s2, automated vehicles have 2.1 times the amount of manual driving.

It may be that this control difference between driving modes is one reason for very similar fuel consumption, as well.

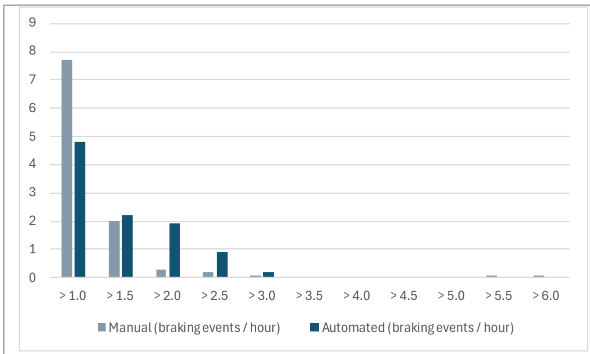

Figure 43: Braking events per hour

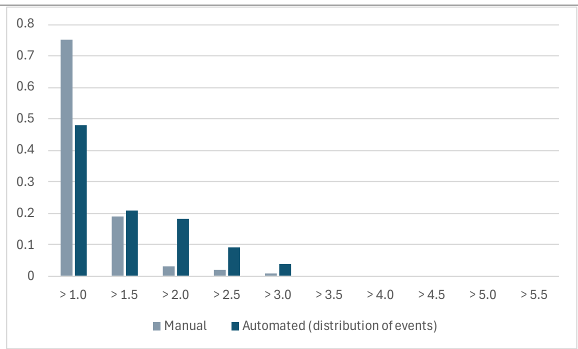

Figure 44: Normalized distribution of all braking events

3.8.5. Stakeholders and users' evaluation

The main results from the qualitative thematic analysis of the interviews (n=6) conducted with airport stakeholders are reported below, where the 12 most frequent or relevant codes (and respective occurrence) for this use case are described. Additionally, Figure 45 represents a word cloud of the most frequently recurring terms for the airport interviews. The analysis of the answers to the questionnaire items did not yield any significant result and no clear trend emerged.

Figure 45: Word Cloud Representing Frequency of Terms (airport interviews)

AVs (n=32): Several participants stated that AVs are not yet suitable to operate in the harsh winter conditions, for instance due to the snow cover on the guiding tracks, which confuses the navigation systems, or in close proximity with manned vehicles and, especially, airplanes, due to the very different types of aircraft and proximity procedures. At the same time, some participants were rather positive towards safety thanks to vehicles' automation and others remarked that successfully automating luggage transport processes would be extremely useful in high-pace operational contexts like airports. Conversely, this also implies that should something go wrong, the consequences might be disastrous.

Efficiency (n=31): Harsh weather, followed by mixing autonomous and manual technologies, and their consequences on not yet so adaptable technologies were seen as the main hindrance to process efficiency. Constantly available backup solutions such as manned vehicles and auxiliary electrical grids were envisioned as necessary, to not clutter or disrupt airports' (high pace) operations. If these requirements were met, efficiency was seen as one of the main benefits from automating logistics operations such as luggage handling, due to a reduction in human presence and, consequently, errors and accidents.

Technological readiness/time frame/flexibility (n=28-26-21): At the beginning, the technology will not be flexible (for instance to be used next to the airplanes, in mixed traffic, or in harsh conditions), or fine-tuned enough, so that the vehicles will stop for any minor inconvenience. At the same time, if it would not be ready to cover at least a certain number of predictable situations, or if it would not be safe for humans, it would not be used at all. Also, the feeling was expressed that technology might be considered not ready simply because not all situations can be foreseen. For such situations, human back-up (i.e., easy ways to take over, on-site support) is crucial to avoid expensive or dangerous mistakes, as humans are seen as more capable dealing with unforeseen situations. Eventually, as the technology is employed, time will help to increase usefulness and acceptance.

FMS Design improvements (n=24): When asked about FMS design improvement, the participants were unanimous in the view that overall better communication of relevant information is necessary. Specifically, more weather-related details (e.g., mm of rain/snow, forecasts, road friction, vehicle capability), differentiated graphic notifications for different events/situations, inside/outside camera view (possibly of multiple vehicles), communication between different operators (e.g., remote and on site) were suggested.

Location, personal experience, weather (n=21-20-19): Several participants indicated that the technology/infrastructure should be ready enough so that catastrophic events (e.g., power out) cannot occur, or that harsh weather can be dealt with. To this regard, it was suggested that task distribution (between operators, vehicles etc.) to handle planes landing, luggage claiming should be clear. The combination of high pace of airport operations and bad weather (and its effect on the roads, sensors etc.) is seen as potentially very dangerous. Forecasts and back-up solutions (human intervention, manual vehicles for difficult routes and conditions) are crucial, albeit not sufficient for the airport case and a certain degree of skepticism deriving from first-hand experiences regarding operations in harsh weather was expressed. Otherwise, participants seemed positive towards the acceptance of systems for automated operations in the airport context.

Human intervention, human-machine compatibility (n=21-20): As referred to above, human overseeing (remote) and the availability of intervention (on site) were seen as a requisite to ensure operational continuity amid uncertainties, prevent and deal with events. This was tied to the idea that the more serious the consequences at stake, the more important the human role would be. At the same time, automation was seen as desirable because it will partially remove humans from the loop (i.e., reduced physical presence on site and less human errors), hence increasing safety (of the operators, and other road users).

Acceptance (n=21): Preliminary results showed positive disposition from airport operators. However, it was noted that demonstrating the efficiency and current capabilities of automation (i.e., delivering an improved service like luggage handling) is essential to mitigate too high expectations and get more people on board. Additionally, maximizing safety measures was suggested as an approach for improving public perception. Again, the time dimension was identified as a key factor.

3.9. Integration and next steps

Automation at the Oslo airport must likely happen one step at a time. Currently the site is finalizing a new baggage handling system and its conveyor belts. There are plans, for example, to examine indoor AGVs to transfer luggage trolleys inside the building. In the future, as outdoor automated driving becomes a realistic option, automated trucks might exchange the trolleys with AGVs near the facility doors.

Currently, automated connecting and disconnecting of existing luggage carts is not possible. However, some remodeling of the carts seems a relatively easy possibility, as the vehicle fleet is fixed. Although a current problem, this would not likely be a problem in a larger take-up of automated driving.

The benefits of automation seem clear: a fraction of remote operators, compared to current fleet of human drivers, could theoretically operate many of the automated transports. However, the main hurdle is also clear: In regions as north as Oslo, there are still many days per year when automated driving is not feasible. During such a day, how could the airport ensure a larger host of human teleoperators or drivers? There might be options for that, but clearly a full transition needs more preparations.

Airports, even though they are restricted areas and one might therefore think easy to automate, are nevertheless constructed for human drivers and workers. They are not as straightforward to automate. For example, there are vehicles that don't fit on a single lane and avoiding them has to be thought of. Furthermore, there are areas where larger airplanes might block a lane – or not. Currently, when an airplane lands, the ground handling fleet working around it can take alternative positions. These positions would have to be minimally coordinated via a fleet management system, so that an automated vehicle could know where to park.

Fleet management and interaction with human workers clearly become topics in next phases of integration work. The demonstration in AWARD proved that driving is no longer the most difficult part of these operations. Gradual infrastructure and fleet management improvements will enable larger automation experiments.

3.10. Simulations and modelling of automated operations

Within the airport terminal simulation, both automated and human-operated vehicles are used to transport luggage. The simulation utilizes a route map derived from a Google Maps satellite image, as shown in Figure 46. The simulation uses real schedules for arrivals over the course of one day.

The simulation does not consider the possibility of vehicle route congestion or the impact of weather conditions that might affect real-world field tests. In terms of vehicle speeds, they are determined based on the average speeds measured during field tests, meaning that all journeys are conducted at a consistent average speed, without any acceleration or braking.

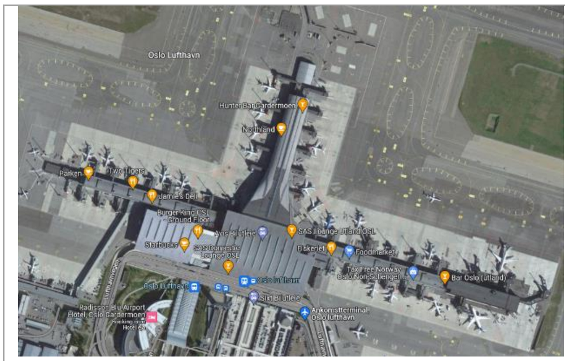

Figure 46: Satellite picture of the Oslo airport from Google Maps

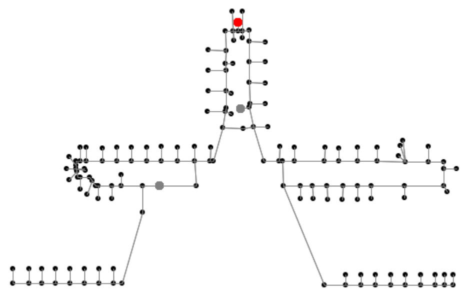

Figure 47: Simulator route map

In this scenario, airport luggage transfers are simulated for one day. There were several assumptions which are programmed to the simulator. The assumptions are listed in Table 17.

Table 17: Assumptions of the airport simulation

One day simulation (24 hours)
264 flights per day, three luggage tractors per flight were required
The total number of luggage items was 1056.
Average driving speed is based on actual data from first tests: 15.3 km/h for human vehicles and 8.3 km/h for automated vehicles.
Automated vehicles wait for the next plane at the stand to speed up the transport of bags.
Human-operated vehicles wait at the break room or at gates for the next flight.
Human drivers take three breaks: two breaks of 25 minutes and one break of 1 hour.
The time required to connect luggage carts or to load luggage was 2 minutes per vehicle.
The driving range of luggage tractors was 100 km.
Human employees take break when there is free time.
The simulator does not account for traffic that could impact vehicle speeds
5 min human remote operator work needed per operated automated vehicle hour.
The cost of human labor was 50 €/hour.
The cost per kilometer was €0.5 for the human vehicle, €0.5 for the AV.
Costs for human-operated vehicles include kilometer expenses and labor.
Costs for automated vehicles include kilometer expenses, remote operation costs, and labor for field/maintenance employees.
Three maintenance employees (field support) were responsible for the automated vehicle fleet, each working a theoretic 24-hour shift.
Maximum luggage transfer time must be 15 min to meet airport quality requirements.

Table 18: Results of the first airport simulation

	Human vehicle	Automated vehicle
Number of vehicles	25	25
Kilometers travelled	1913.87	1859.49
Transported luggage	1056/1056	1056/1056
Waiting time (h)	482.68	397.96
Minimum transfer time (min)	2.97	3.8
Average transfer time (min)	4.57	6.96
Maximum transfer time (min)	8.52	15.83
Human teleoperation costs (€)	0	841.01
Vehicle operation costs (€)	956.94	929.74
Vehicle ownership costs (€)	342.47	684.93

Total costs (€)	31299.4	6055.69
Total costs without waiting time costs (€)	7165.62	6055.69
Average utilization (%)	19.51	33.64
Active work time (h)	117.08	88.82
Driving time to pause locations (h)	23.63	39.46
Driving distance to pause locations (km)	361.5	327.54

Table 19: Results of the second airport simulation.

	Human vehicle	Automated vehicle
Number of vehicles	28	28
Kilometers travelled	1917.55	1889.71
Transported luggage	1056/1056	1056/1056
Waiting time (h)	554.43	466.14
Minimum transfer time (min)	2.97	3.8
Average transfer time (min)	4.56	6.83
Maximum transfer time (min)	7.33	13.25
Human teleoperation costs (€)	0	856.88
Vehicle operation costs (€)	958.78	944.86
Vehicle ownership costs (€)	383.56	767.12
Total costs (€)	34942.34	6168.86
Total costs without waiting time costs (€)	7220.76	6168.86
Average utilization (%)	17.46	30.6
Active work time (h)	117.32	89.14
Driving time to pause locations (h)	23.85	41.52
Driving distance to pause locations (km)	364.86	344.65

Table 20: Results of the third airport simulation.

	Human vehicle	Automated vehicle
Number of vehicles	31	31
Kilometers travelled	1919.13	1898.67
Transported luggage	1056/1056	1056/1056
Waiting time (h)	626.33	536.64
Minimum transfer time (min)	2.97	3.8
Average transfer time (min)	4.55	6.78
Maximum transfer time (min)	7.33	12.23
Human teleoperation costs (€)	0	863.1
Vehicle operation costs (€)	959.57	949.33
Vehicle ownership costs (€)	424.66	849.32
Total costs (€)	38584.22	6261.75
Total costs without waiting time costs (€)	7267.89	6261.75
Average utilization (%)	15.78	27.84
Active work time (h)	117.43	89.26
Driving time to pause locations (h)	23.97	42.27
Driving distance to pause locations (km)	366.72	350.85

There are several indicators that change when the number of vehicles is altered. Waiting times, costs and utilization decrease with a reduction in the number of vehicles. The most notable disparities were observed in costs and luggage transfer times. Human vehicles were faster as their average speed was higher. Automated vehicles wait near the aircraft stand for their turn, while human vehicles rest at designated rest areas. The maximum transfer time for automated vehicles is three times greater than the minimum transfer time due to variations in transfer distances.

The utilization of automated vehicles resulted in reduced costs, as there were less human time expenses involved. Airport automation has the potential to yield considerable cost reduction; however, it may concurrently lead to an increase in transport times. When an aircraft arrives at the gate, baggage is transported to either international arrivals or domestic arrivals, and this, along with the gate location of the airplane, affects the transport times.

Transfer times are influenced by the number of vehicles involved.

Table 20 indicates that the shortest maximum transfer time is approximately 12 minutes when using automated vehicles. In contrast, the average transfer time is 6.8 minutes. Automated vehicles tend to move slower than human-operated vehicles, which explains the longer maximum transfer time observed.

During actual tests conducted over a two-week period, the transfer times for automated vehicles ranged between 4 to 14 minutes, closely aligning with the simulation results. It is worth noting that the field tests did not strictly adhere to the same routes as those in the simulation, leading to minor discrepancies. The longest route in the field tests was 27% longer than in the simulation that matches the simulation results.

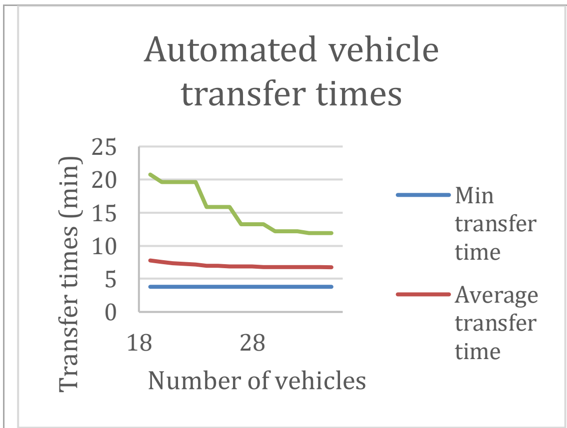

Figure 48: Transfer times as a function of the number of automated vehicles

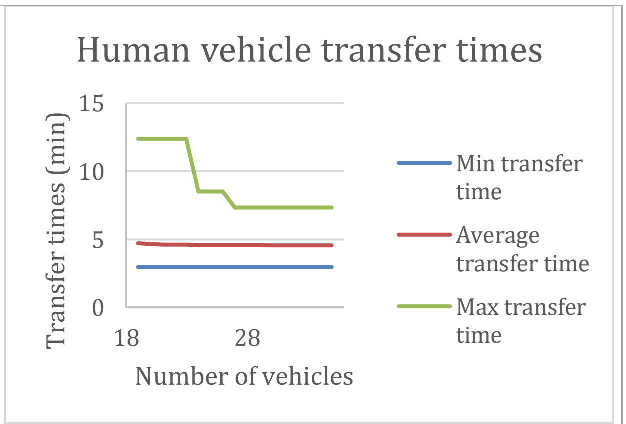

Figure 49: Transfer times as a function of the number of human vehicles

In planning the transportation system, several factors must be considered that influence the necessary number of vehicles and their optimal use. First, to meet the requirement of a maximum transportation time of 15 minutes, at least 15 human-operated vehicles and 27 automated vehicles are necessary. Simulation results suggest that the ideal number of vehicles is 27 with human-operated vehicles and 30 automated vehicles. These numbers minimize transportation times while also factoring in costs. However, fewer vehicles might be sufficient if longer transportation times are accepted.

Simply increasing the number of vehicles is not always the best approach, especially for human-operated vehicles. Labor costs can spike due to waiting times and wages for human drivers.

Additionally, the efficiency and utilization of automated vehicles can vary based on weather conditions. For example, automated driving might not be practical in rainy or adverse weather, necessitating a shift to human drivers. Therefore, our simulations are based on ideal weather conditions for automated driving.

Using automated vehicles, assuming continuous operation with partly automated loading and trailer coupling (the simulation results include 3 field support or maintenance persons), can lead to significant savings. The exact percentage of savings is dependent on specific parameters, but it can be substantial under these conditions. The costs and benefits of using automated vehicles will depend on the number of maintenance staff and other human workers needed.

Main findings

- Costs for automated vehicles were around 17% compared to human vehicles. When waiting time is not taken into consideration, the cost of an automated vehicle is approximately 85% of that of a human-operated vehicle.
- At least 15 human-operated vehicles and 27 automated vehicles are needed to fulfil the quality requirement of 15 minutes for delivering luggage.
- With 27 human-operated vehicles and 30 automated vehicles, the transport time consists solely of the time spent on loading and transportation, and adding more vehicles no longer improves transport times.
- Active work time decreases by 24% when automated vehicles are used, assuming teleoperation requirements of 5 minutes per operational hour, and three maintenance workers are needed.
- AVs drove 1–27% less than human vehicles because humans take breaks between luggage transports, and the trip to the rest areas causes extra kilometers. The difference decreased when automated vehicles parked near break points in between transports. When routes were optimized and AVs didn't stop at break points but proceeded to the next stand to wait, the driven distance was 27% less.

3.11. Implications on a larger scale

For the airport case, we start by identifying the total number of airports in the EU. According to Eurostat air transport statistics, in 2022 there were approximately 863 commercial airports in Europe.

Another relevant data to be able to scale results is the number of daily flights in the region. According to Supporting European Aviation, the EU average recorded 30,168 daily flights in 2022, a figure that increases during the summer and vacation period.[2] Of particular interest are large-scale airports with an average of 43 flights per hour. In total, it is estimated that there are 130 such airports in Europe[3].

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[2] https://www.eurocontrol.int/news/new-traffic-record-set-37228-flights-one-day
[3] https://www.eurocontrol.int/sites/default/files/2024-01/eurocontrol-european-aviation-overview-20240118-2023-review.pdf

In terms of simulation results, it was found that automated vehicles incur only 18% of the costs associated with human-driven vehicles. Even excluding waiting time, their costs are approximately 85% of those of manual vehicles. Another key finding is that, to meet the 15-minute baggage delivery standard, 15 human-driven or 27 automated vehicles are needed. Adding more than 27 manned or 30 automated vehicles does not significantly reduce transport time; in fact, no difference was found in the tests. The use of autonomous vehicles reduces human labor time by 24%, with teleoperation needs of 5 minutes per operating hour and requiring three maintenance workers.

To extrapolate the data, all 850 airports in the region are considered (proxy value). It has been identified that 130 of these airports are considered large-scale airports due to their passenger traffic, size and connectivity. At these airports, an average of 43 flights per hour are received. With the data obtained in the simulation, it was concluded that an airport requires 15 manual vehicles to disembark all the baggage in 15 minutes. This implies that large-scale airports demand about 83,850 manual vehicles (130 airports * 43 flights per hour * 15 vehicles), while the rest of the airports in the region have a total demand of 10,800 manual vehicles. In total, it is estimated that 94,650 unloading vehicles are used considering all airports in Europe are required.

Table 21: Number of manual vehicles needed in European airports

Manual vehicles			
	Top airports	**Medium-Small airports**	**Total**
Num. airports	130	720	850
Average number of flights per hour	43	1	
Number of vehicles required per flight	15	15	
Total	83,850	10,800	94,650

Table 22: Number of autonomous vehicles needed in European airports

Autonomous vehicles			
	Top airports	**Medium-Small airports**	**Total**
Num. airports	130	720	850
Average number of flights per hour	43	1	
Number of vehicles required per flight	27	27	
Total	150,930	19,440	170,370

When analyzed for the case of autonomous vehicles, the number of vehicles demanded at top airports is 150,930 in the region (130 airports * 43 flights per hour * 27 vehicles) and 19,440 at smaller airports. In total, there would be 170,370 autonomous driving vehicles in the region.

In addition, the findings indicate that, by employing autonomous driving vehicles, human labor time is reduced by 24%. The average salary of an airport luggage handling vehicle operator in the European region is estimated to be €33,500 per year. A saving of 24% implies a reduction of €8040 per year per operator by using autonomous vehicles at airports.

4. Hub2Hub impact assessment

4.1. Test site introduction and routes

Rotax and Schenker, in collaboration with Digitrans, are undertaking the "Industrial hub-to-hub" use case to automate the current empty goods milkrun between BRP Rotax's engine production factory and DB Schenker's logistics center in Gunskirchen, Upper Austria. This initiative aims to enhance operational efficiency and optimize infrastructure use. The sites are connected by public roads, including crossings and a main road, as illustrated in Figure 50. The testing phase focuses on an automated swap-body truck developed by KAMAG and equipped with EasyMile's driverless technology.

The implementation in Gunskirchen comprises two phases. Phase I targets low-traffic periods and uses connected traffic lights to manage traffic segregation. Phase II aims to improve safety margins and optimize traffic light schedules to reduce congestion. Additionally, teleoperation testing is conducted at the Digitrans proving ground to gather data under various weather conditions, ensuring a comprehensive assessment of the autonomous system's capabilities.

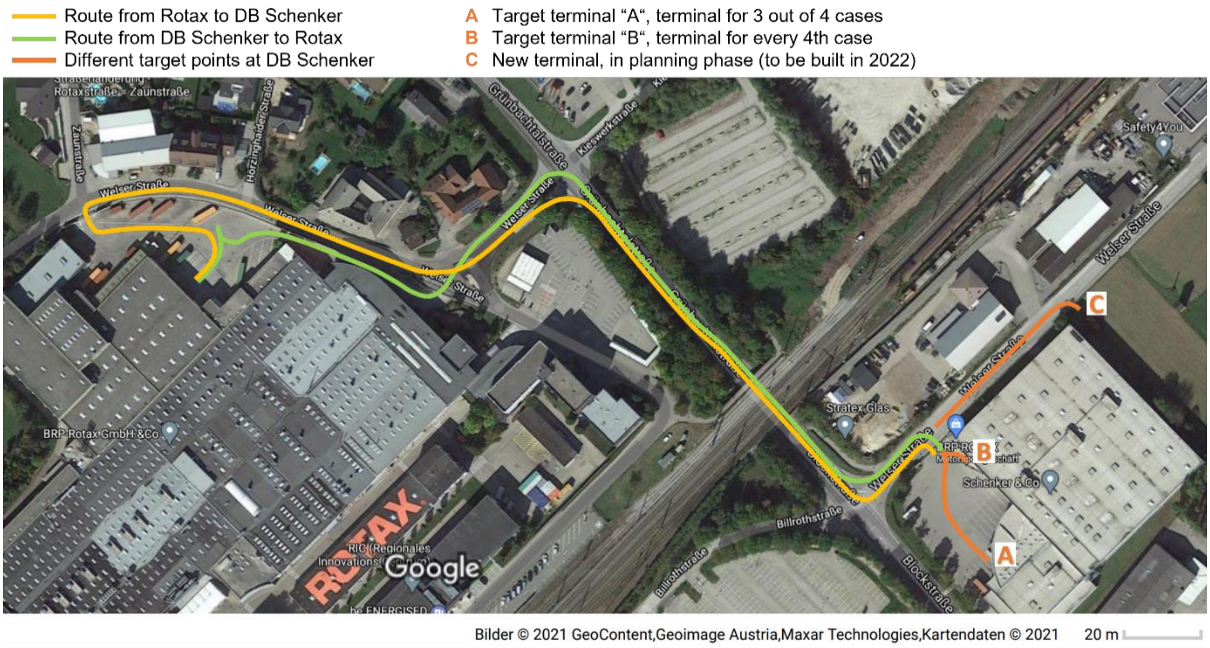


Figure 50: H2H route map

Without automation, a single operator needs to manage the entire truck operation, resulting in significant downtime, with one-third of their working hours being unproductive. The shift to 24/7 automated operations is expected to optimize work hours, improve safety, and reduce CO2 emissions during low-traffic night deliveries. This use case involves the automated transport of lattice boxes in a swap body between two hubs, connected by public roads and restricted areas. The process includes loading, transporting, unloading, and reloading boxes, aiming to increase efficiency, enhance safety, and minimize environmental impact. During the project, the autonomous vehicle operated with a safety driver on board to ensure smooth and secure operations.

4.2. Timeline

The preliminary testing phase commenced towards the end of 2022, with Phase 1 operations initiated with a safety driver on board. Phase 1, which coincided with the winter months, focused on assessing the capabilities of the automated swap-body truck developed by KAMAG, integrated with advanced EasyMile's driverless technology. Phase 2 aimed to demonstrate operations without a safety driver in the final months of the project. Testing at Gunskirchen lasted until September 2023 and was continued in October and November 2023 at the proving ground of Digitrans in St. Valentin.

Table 23: Timeline of UC2, phase 1

Phase	Start month	End month
Pre-testing		
First data sample for evaluation		26
Baseline data collection	20	27
Operations and interviews Phase I	30	33
Operations and interview Phase II	34	35
Dataset finalization		-36
Evaluation and reporting	30	42

4.3. Performance goals and pre-existing indicators/statistics

The Hub-to-Hub (H2H) use case aimed to enhance operational efficiency, safety, and environmental impact through the automation of goods transportation between BRP Rotax's engine production factory and DB Schenker's logistics center. Key performance goals included reducing manual labor, optimizing working hours, and ensuring safe autonomous navigation, particularly on public roads and intersections. The project also sought to reduce CO2 emissions and noise pollution by transitioning to electric vehicles and using shorter, optimized routes.

Pre-existing indicators provided a baseline for assessment, including labor efficiency metrics from manual operations, safety incident data, and environmental measurements of noise and CO2 emissions from diesel trucks. The objective was to demonstrate the benefits of autonomous logistics, setting the stage for future implementations and regulatory advancements.

4.4. Description of automated vehicle functionalities

The automated vehicles for the Hub-to-Hub use case feature advanced functionalities that enhance autonomous logistics. Equipped with state-of-the-art technology, these vehicles navigate traffic lights, unregulated intersections, side streets, and partially unmarked roads autonomously. A key feature is the intelligent traffic light system, allowing precise traffic stop requests and demonstrating the vehicle's capability to interact with existing infrastructure. The KAMAG swap-body truck (see Figure 51), integrated with EasyMile's driverless technology, excels in traffic simulation, communication, and obstacle detection. Safety remains a top priority, with rigorous testing under various weather conditions and complex environments. The vehicle operates at a reduced speed of 15 to 20 km/h for safety, with a safety driver ready to intervene if necessary. This meticulous testing ensures reliable operation for the shuttle service between BRP ROTAX and DB Schenker plants in Austria, setting the stage for future advancements in autonomous goods transport.

Figure 51: Automated swap-body truck

4.5. Affected other operations

Timely delivery is critical for the Hub-to-Hub use case, particularly for the production processes at BRP ROTAX. Even a slight delay, such as half an hour, can significantly disrupt manufacturing, where precision and strict adherence to timeliness are paramount. Currently, buffering options, which are essential for mitigating potential delays, remain under review.

The success of this testing phase depends not only on the seamless integration of autonomous transportation but also on its ability to enhance overall operational efficiency. Ensuring that autonomous vehicle deployment aligns with the stringent time constraints of modern manufacturing processes is crucial. Refining buffering mechanisms will be a primary focus as we work to assess and optimize the practical viability of integrating autonomous logistics into complex production systems. This integration aims to ensure that autonomous vehicles can meet the high standards required in a modern, efficient manufacturing environment.

4.6. Infrastructure modifications

Implementing the Hub-to-Hub autonomous logistics use case required several infrastructure modifications. Key changes included installing an intelligent traffic light system that allows the automated vehicle to request precise traffic stops, enhancing overall journey safety and integration with existing infrastructure. Localization poles were suggested to address positioning challenges caused by changes in vegetation, which interfered with recording-based positioning. Additionally, a dedicated weather station was set up to collect on-site data at 10-minute intervals, crucial for adjusting the vehicle's operations to varying weather conditions. These modifications aimed to ensure the reliable and efficient operation of the automated swap-body truck within both industrial and public road environments.

4.7. Data logging

4.7.1. Baseline data collection

During the baseline data collection phase, data from manually operated vehicles were gathered to establish a performance benchmark. This phase included monitoring various metrics such as travel time, fuel consumption, and cargo handling efficiency. Baseline data were recorded between June 2021 and September 2022 via a Vaisala MD30 sensor mounted on the manually driven truck in Gunskirchen as well as via vehicle data logs.

4.7.2. AV data collection

Autonomous vehicle data collection focused on capturing detailed information on performance in various scenarios, such as navigating traffic lights, handling intersections, and responding to different weather conditions. From August 7, 2023, to September 20, 2023, in Gunskirchen, AV driving data was collected over 42.4 km and 23.7 hours of logs, with 7.9 hours of actual driving. During this period, the vehicle operated in manual mode 40% of the time and in automated mode 60% of the time. For assignments where more than 40% of the driving was automated, the results improved to 17% manual vs. 83% automated driving. Data sources included FMS data from Applied Autonomy and LogPro data from VTT, along with weather data from the Gunskirchen weather station logs (January 1, 2023 - December 31, 2023, at 10-minute intervals).

Between October 11, 2023, and November 15, 2023, similar routes and tests were conducted at the Digitrans proving ground in St. Valentin. This phase also included teleoperation tests to evaluate remote control capabilities. The share of automated driving in these tests was higher at 73.46%. Data was sourced from the Fleet Management System (FMS) by Applied Autonomy and LogPro data from VTT.

4.7.3. Access to log data

Log data from both baseline and AV data collection phases were meticulously recorded and stored securely. Access to this data was restricted to authorized partners involved in impact assessment to ensure data integrity and confidentiality.

4.8. Results:

4.8.1. Technical evaluation

The automated vehicles developed for the Hub-to-Hub use case exhibited advanced functionalities that significantly impact autonomous logistics. These vehicles were designed to navigate complex routes involving traffic lights, unregulated intersections, side streets, and partially unmarked roads. A notable feature is the intelligent traffic light system that allows vehicles to request traffic stops, enhancing safety and demonstrating the integration of autonomous systems with existing infrastructure. Figure 52 illustrates automated vehicle speeds at different parts of the route. The main road lanes were considered to be too narrow for using higher speeds than about 25 km/h.

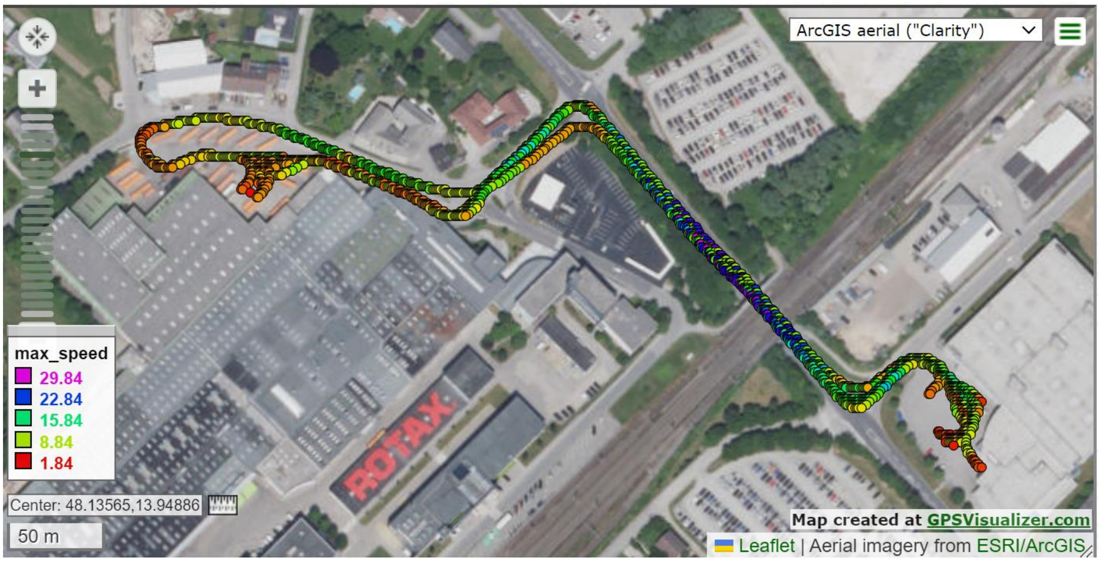


Figure 52: Maximum automated driving speed across different parts of the route

One challenge was maintaining accurate positioning on the main road due to changing vegetation, which affected the vehicle's recording-based positioning system. This could be mitigated by installing localization poles as landmarks. Additionally, the vehicle's emergency braking system, set for safety, caused cargo displacement due to an overly sensitive lidar filter. This led to frequent and unnecessary braking events, particularly in response to minor obstacles like tree leaves.

The Fleet Management System (FMS) played a crucial role in the testing phases, dispatching vehicles, collecting data, and visualizing information for supervisors. It also tracked delays during each trip. The system's capability was further demonstrated at the St. Valentin proving ground, where it managed teleoperation handovers and manual takeovers by the onboard safety driver, ensuring seamless control transitions.

Figure 53: Overtaking a parked vehicle using teleoperation (Pictures: AustriaTech)

Results from the tests revealed several key points. The automated goods transfer between BRP Rotax and DB Schenker underwent 86 hours of testing, with 26 hours automated. The public road segment, with a speed limit of 60 km/h, posed the most significant challenge due to the automated vehicle's maximum speed of 25–29 km/h, leading to quick queue formation. On average, human drivers operated the route at 16.1 km/h, compared to 6.2 km/h for the automated system.

The evaluation identified several lessons. For instance, a red light was set up to stop other road users to allow the AV to enter the road, but compliance was an issue, particularly in the evenings. Automation used up to 13% more energy than manual driving due to frequent stops, highlighting the need for improved braking controls and route setups. However, electrification allowed the use of a new, shorter route, reducing overall distance by 26%.

The most common reasons for stops included unnecessary emergency stops due to outdated maps and ghost obstacles, loss of localization, and weather-related issues. Despite these challenges, the tests showed that 17% of the driving required manual support, equating to about 10 minutes of operator intervention per hour.

In conclusion, the technical evaluation demonstrated that while the automated vehicles showed great promise in enhancing autonomous logistics, several areas require further refinement. Improved localization techniques, better integration of sensor systems, and optimization of braking controls are necessary to enhance performance and efficiency. The insights gained from these tests will be crucial in advancing the development and deployment of autonomous logistics solutions.

4.8.2. Safety evaluation

The Kamag truck's emergency braking software lacked a rain filter, leading to excessive braking incidents triggered by small debris, such as leaves, resulting in up to 11 times more stops than those of human drivers on the same route. This caused discomfort for the safety driver and frequent cargo displacement. Rainy conditions worsened the issue, with the truck braking unnecessarily, potentially causing near-miss rear-end collisions due to unexpected stops.

Data collected from August 7, 2023, to September 20, 2023, revealed 42.4 km and 23.7 hours of logs, with 7.9 hours of actual driving. Operators documented 47 stops, categorized as follows: 13 stops due to other vehicles, 12 from loss of localization, 9 weather-related, 4 safety stops, 3 miscellaneous emergency stops, 3 due to obstacles close to the path, 2 from vehicle overtaking, and 1 soft stop due to a container on the path. This resulted in an average of one stop every ten minutes of actual driving time.

A recurring problem was maintaining accurate positioning on public roads due to changes in vegetation, which disrupted the truck’s lidar-based positioning system. Enhancing the positioning system with secondary technologies like Ultra-Wideband (UWB) or installing pole-shaped landmarks was suggested to address this issue.

The testing also highlighted the need for precise synchronization between the traffic light and the autonomous vehicle’s movements to ensure compliance from other road users. Initially, drivers ignored the traffic light after waiting for 30 seconds if no activity was detected. Improved synchronization led to better compliance.

An additional development point identified was the truck’s inability to detect low-lying obstacles like a euro-pallet standing only 14.4 cm tall. Advanced techniques such as camera-based data fusion were suggested to address this challenge.

On most hub-to-hub sites, typically, only one or two vehicles are in use, making it difficult to gather comprehensive accident statistics. However, potential safety benefits include collision avoidance systems and reduced human error, while drawbacks include careless overtaking by other road users.

In the EU, many hub-to-hub sites focus on remote areas away from busy roads. While the likelihood of human injuries is low during low-speed demonstrations, operational problems like vehicles straying from their routes or minor collisions due to software glitches remain risks. Additionally, maintenance issues are possible due to the prototype nature of the vehicles.

Initial H2H demonstrations in Europe revealed challenges in automating large vehicles. The size of these vehicles limits safety margins during driving and parking. Using two smaller vehicles instead of one large one could enhance safety by allowing for slower and more manageable driving, despite potential changes in cost or efficiency.

This project did not address the safety of automated trucks on public roads, as tests were primarily conducted on industrial sites with slow-speed operations. Several other EU projects are currently examining public road safety for automated trucks.

Figure 54: Public road with vegetation that is difficult to map

4.8.3. Efficiency evaluation

The same as in the previous use cases, the research questions guiding this study are as follows:

- How does the AWARD ADS influence financial indicators?
- How does the AWARD ADS influence operational indicators?
- How does the AWARD ADS influence quality indicators in operations?

Table 24 provides detailed analysis of the hypotheses tested and the main findings.

Table 24: Efficiency hypothesis and main findings of the H2H use case

Hypothesis	Findings
The ADS supports reducing personnel costs.	Savings between 60% and 73% of personnel time for driving tasks, and up to 83% in assignments with more than 40% automated driving time. Due to the requirement of a safety driver, personnel cost savings were not realized in the tests. Future applications combining automated freight transport with teleoperation could reduce personnel costs and mitigate driver shortages.
The ADS reduces net transfer time.	Automated vehicles required more time to complete a route than human drivers, with an average trip time of 340 seconds compared to 222 seconds

	for humans. The difference is less significant if the slower driving does not require active human support.
The ADS decreases personnel time to support the vehicle while driving.	Personnel time savings ranged from 60% to 73%, increasing to 83% in assignments with more than 40% automated driving time. The median mean-time-between-overrides (MTBO) in Gunskirchen was 11.05 minutes, suggesting significant potential for reducing personnel time with teleoperation solutions.
The ADS reduces fuel consumption.	The energy consumption difference between automated and manual modes was minimal, around ±2%. Automated driving sessions showed slightly higher fuel consumption, likely due to frequent stops.
The ADS decreases vehicle speed.	The average speed in automated mode was 6.2 km/h, compared to 16.1 km/h for manual mode. In proving ground tests, the automated speed was 6.7 km/h, whereas manual driving was 20.3 km/h.
The operational availability of the ADS is lower than that of a manually operated vehicle.	General availability of the automated vehicle was similar to manual operation when a driver was available. Potential operational hours could be improved from 2021 hours annually (63.7% of possible hours) to 3039 hours (95.8%) with the AWARD ODD extension.

Detailed Analysis for each H2H test site

Gunskirchen (7.8.2023 - 20.9.2023)

The following chart depicts the mean-time between stops (MTBS) and the mean-time between human takeovers (MTBO) calculated for dispatch assignments performed between 7.8.2023 and 20.9.2023 in Gunskirchen, Austria (see detailed description of MTBS and MTBO in section 0). The MTBO provides insights into the need for human intervention. The median MTBO indicates that human intervention was required in median every 11.05 minutes in Gunskirchen. Assuming that a human intervention takes 1 minute, the automated vehicle would require around 5-6 minutes support per hour by humans. The MTBS summarizes stops where the vehicle is either able to continue by itself or human intervention is needed. During the test period in Gunskirchen the median MTBS was 22.11 minutes.

Figure 55: MTBS, MTBO - Gunskirchen AT

St. Valentin (11.10.2023 – 15.11.2023)

At the Digitrans proving ground a similar route as performed in Gunskirchen was tested. In this case also teleoperation tests of the vehicle were performed. The median MTBO and MTBS are similar to the values observed in Gunskirchen. However, the share of automated driving was higher at St. Valentin (73,46% automated driving).

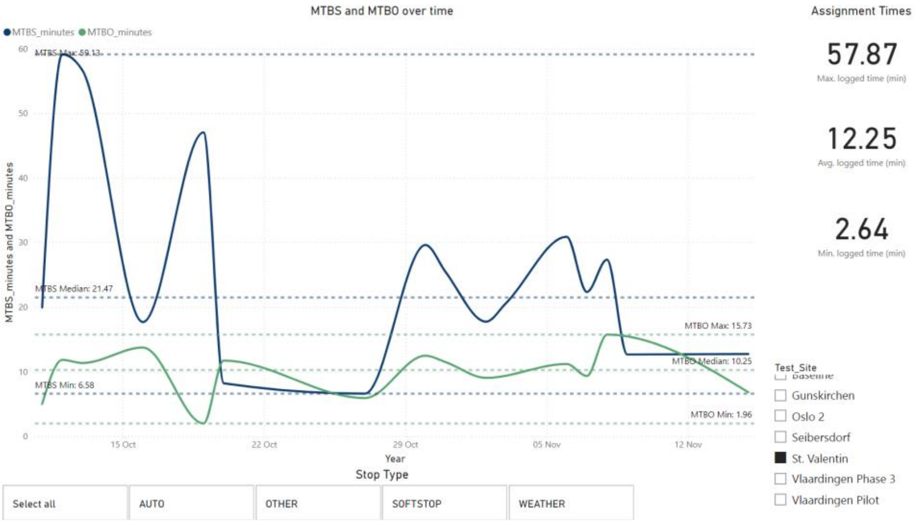


Figure 56: MTBS, MTBO - St. Valentin proving ground

Main Findings:

Personnel Time and Operational Efficiency: The H2H test data revealed significant savings in personnel time for driving tasks, ranging from 60% to 73%, with up to 83% savings in assignments with more than 40% automated driving time. The median MTBO in Gunskirchen was 11.05 minutes, indicating a need for human intervention approximately every 11 minutes, translating to around 5-6 minutes of support per hour. In St. Valentin, the share of automated driving was higher, indicating better performance in terms of automated operations.

Vehicle Speed Analysis: In the main H2H tests, the average automated driving speed was 6.2 km/h, compared to 16.1 km/h for manual mode. In proving ground tests, the automated speed was 6.7 km/h, whereas manual driving was 20.3 km/h.

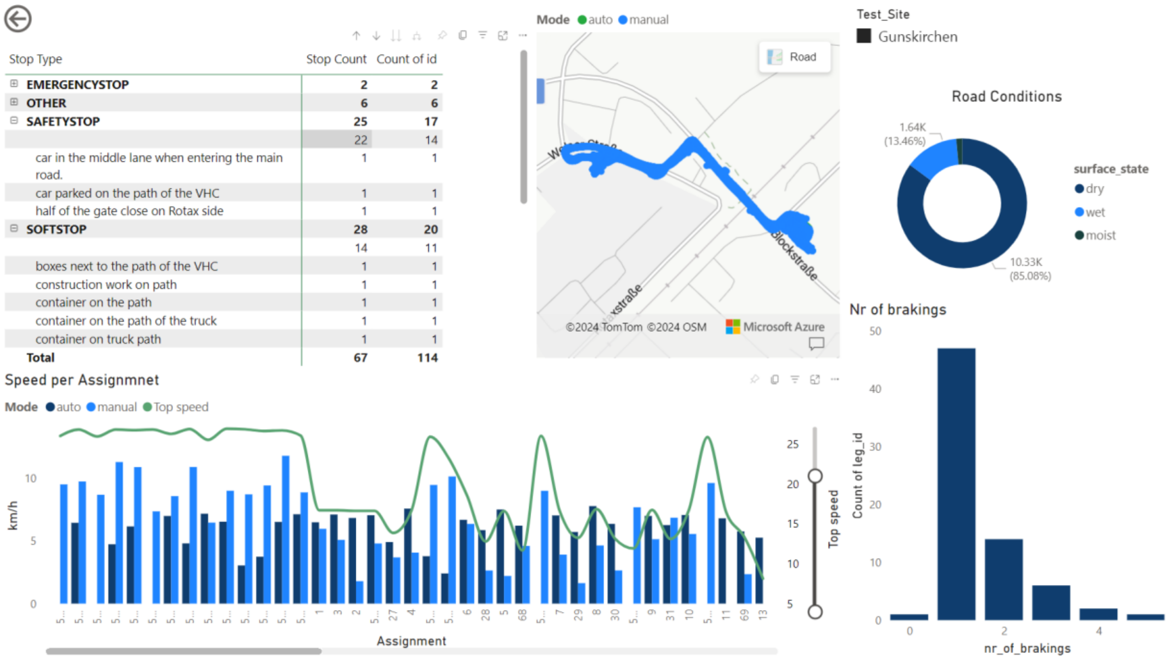


Figure 57: Speed per assignment - Gunskirchen AT

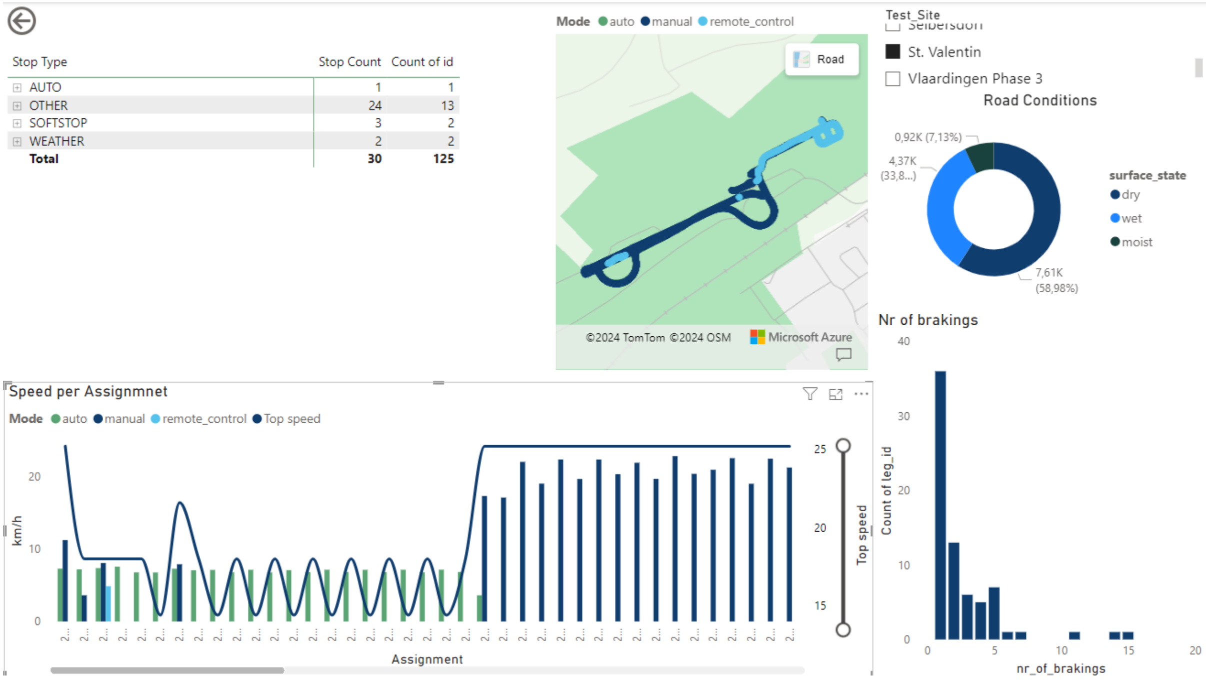


Figure 58: Speed per assignment - St. Valentin

Operational Availability General availability of the automated vehicle was similar to manual operation when a driver was available. Figure 59 illustrates that the potential operational hours could be improved from 2021(63.7% of possible hours) to 3039 (95.8% of possible hours) through the AWARD ODD extension with respect to the 2023 Gunskirchen weather data and the constraints given above (precipitation < 10mm, temp > -10, visibility > 200m). This corresponds to a potential improvement of 32.1%. The working hours are configured for a two-shift workday from 6:00 to 22:00, Mo-Fr, for the year 2023. The working hours also consider public holidays in Austria.

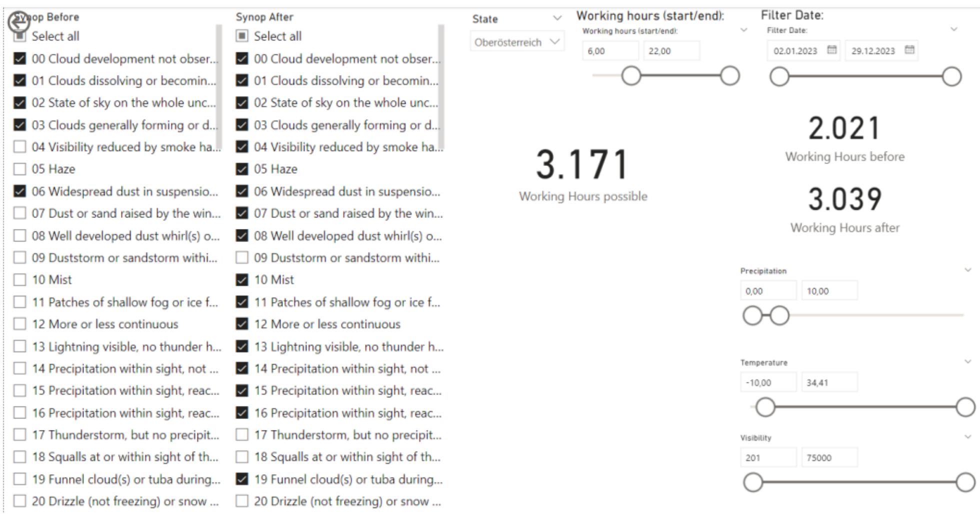
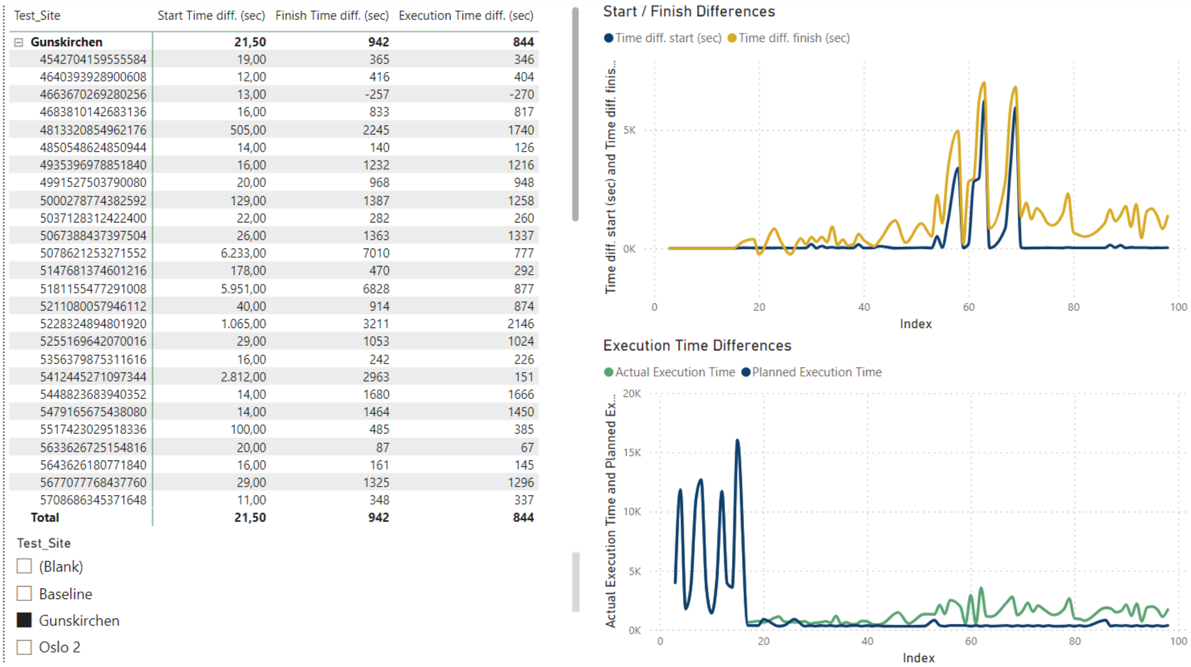


Figure 59: Weather ODD Analysis for Gunskirchen AT 2023

Timeliness and Reliability of Transport Orders Most dispatch assignments took longer than planned due to technical issues. Assignments with less than 12 minutes of deviation from the planned execution time had a median deviation of only 2.6 minutes. In Gunskirchen, 64 assignments were performed; 3% finished earlier than planned, while 97% took longer. Reliability was affected by technical issues such as localization loss.

Overall, the findings suggest that while the ADS has the potential to reduce personnel time and improve operational efficiency, further optimization and technological improvements are needed to fully realize these benefits.

Standard deviation for dispatch assignments (all assignments)	**Median for dispatch assignments (all assignments):**	**Median for dispatch assignments (Diff. actual/planned execution time <12min**
• Diff. actual/planned start time = 1271 sec -> ~21 min • Diff. actual/planned finish time = 1611 sec -> ~27 min • Diff. actual/planned execution time = 746 sec -> 12 min	• Diff. actual/planned start time = 21.5 sec -> 0.35 min • Diff. actual/planned finish time = 942 sec -> ~15 min • Diff. actual/planned execution time = 844 sec -> ~14 min	• Diff. actual/planned start time = 17 sec -> 0.28 min • Diff. actual/planned finish time = 334 sec -> ~5.5 min • Diff. actual/planned execution time = 267 sec -> ~ 4.45 min



Test_Site	Start Time diff. (sec)	Finish Time diff. (sec)	Execution Time diff. (sec)
Gunskirchen	**21,50**	**942**	**844**
4542704159555584	19,00	365	346
4640393928900608	12,00	416	404
4663670269280256	13,00	-257	-270
4683810142683136	16,00	833	817
4813320854962176	505,00	2245	1740
4850548624850944	14,00	140	126
4935396978851840	16,00	1232	1216
4991527503790080	20,00	968	948
5000278774382592	129,00	1387	1258
5037128312422400	22,00	282	260
5067388437397504	26,00	1363	1337
5078621253271552	6.233,00	7010	777
5147681374601216	178,00	470	292
5181155477291008	5.951,00	6828	877
5211080057946112	40,00	914	874
5228324894801920	1.065,00	3211	2146
5255169642070016	29,00	1053	1024
5356379875311616	16,00	242	226
5412445271097344	2.812,00	2963	151
5448823683940352	14,00	1680	1666
5479165675438080	14,00	1464	1450
5517423029518336	100,00	485	385
5633626725154816	20,00	87	67
5643626180771840	16,00	161	145
5677077768437760	29,00	1325	1296
5708686345371648	11,00	348	337
Total	**21,50**	**942**	**844**

Figure 60: Dispatch assignment - timeliness analysis – Gunskirchen AT

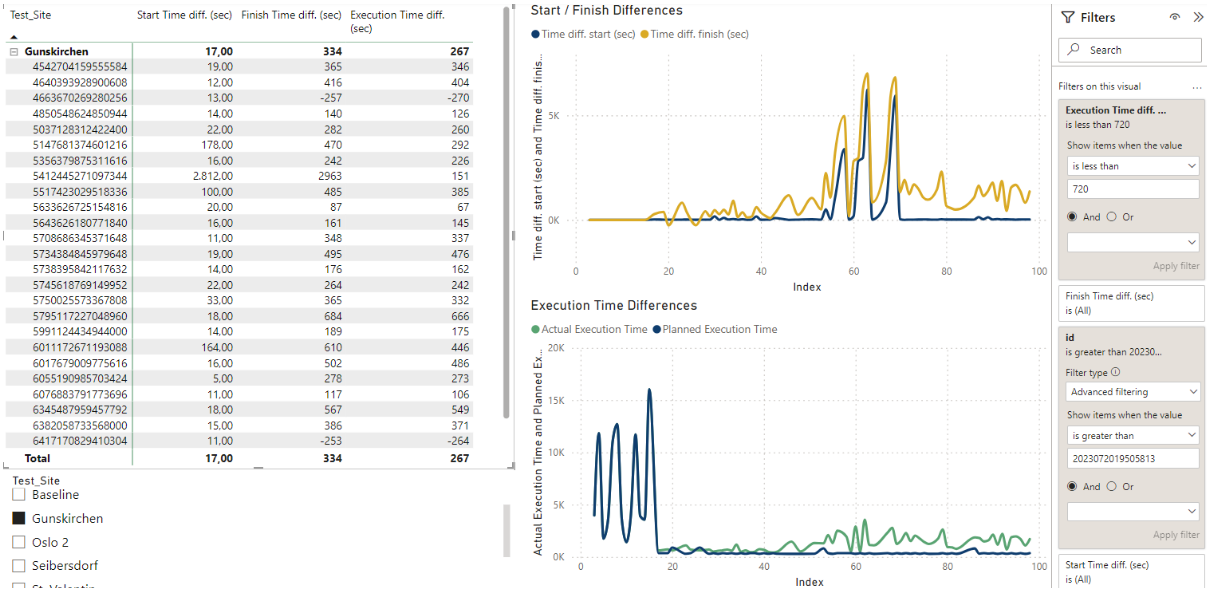


Figure 61: Dispatch assignment - timeliness analysis – Gunskirchen AT where execution time diff (sec) < 720 sec

4.8.4. Environmental evaluation

The environmental evaluation of the Hub-to-Hub (H2H) automated driving system (ADS) focuses on energy consumption, braking frequency, and operational availability under varying weather conditions.

Energy Consumption

Our study compared energy consumption between manual and automated modes by evaluating the distance travelled per percentage change in battery level. The results from actual test site operations showed that in manual mode, the vehicle travelled 430 meters per battery percentage change, whereas in automated mode, it covered 380-383 meters. This indicates that automation uses 12.3-13.2% more energy. Additional proving ground tests showed similar trends, with manual mode achieving 448 meters per battery percentage change and automated mode achieving 369-374 meters, indicating an increase in energy use by 19.9-21.4% (see Table 25).

Table 25: Distance travelled per percentage change in battery level

Mode	Total Distance (km)	Battery Change (%)	Distance per Battery Change (m)
Manual	30.527	71	430
Automated (>30% driving)	64.162	169	380
Automated (>50% driving)	55.917	146	383

The higher energy consumption in automated mode can be attributed to frequent braking events triggered by the vehicle's sensitivity to small obstacles, such as leaves, due to a missing lidar filter. This results in an 11-fold increase in braking frequency compared to human-driven vehicles, as shown in Figure 1. The normalized distribution of braking events highlights the prevalence of emergency braking (see Figure 63).

Braking Frequency

The H2H operational route revealed that the automated vehicle braked significantly more often than the human-driven vehicle, primarily due to the absence of a lidar filter to ignore trivial obstacles. This over-sensitivity led to increased energy consumption and frequent disruptions in smooth vehicle operation. This results in higher overall energy use, which could be mitigated by improving the vehicle's sensor systems to reduce unnecessary braking events.

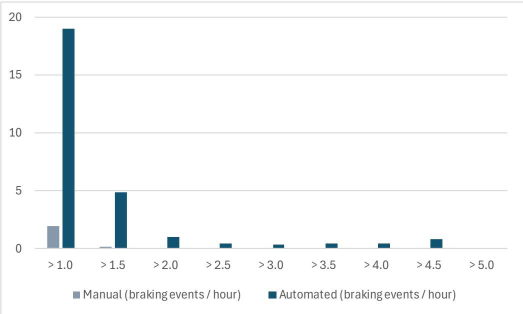


Figure 62: H2H comparison of braking frequency

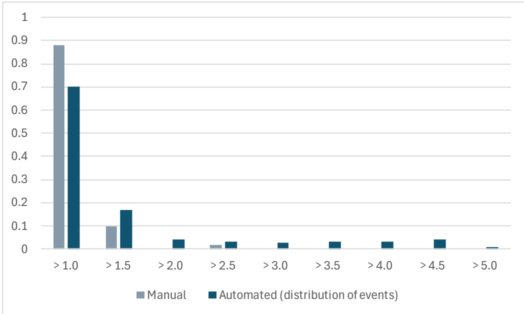


Figure 63: H2H normalized distribution of braking events.

Operational Availability and Weather Conditions

The operational availability of the automated vehicle was evaluated under different weather conditions. A dedicated weather station at the DB Schenker site in Gunskirchen collected data on temperature, precipitation, and road conditions. The analysis revealed that harsh weather conditions, such as temperatures below -10°C or precipitation above 10mm, could impact the availability of the automated driving function.

Figure 64: Weather data Gunskirchen 2023

An additional dashboard for investigating the potential availability of a L4-vehicle based on weather data and the vehicle ODD has been developed. The dashboard allows to select harsh weather conditions under which the vehicle is able to operate, working hours per day and the timeframe (start/end date) for which possible working hours are calculated. Based on the configured ODD the potential availability of the L4-function is the given in working hours. Figure 59 Figure 65 depicts the dashboard and illustrates the difference between EasyMile's L4 vehicle ODD before the AWARD project and the potential improvement after the project with the AWARD sensors set.

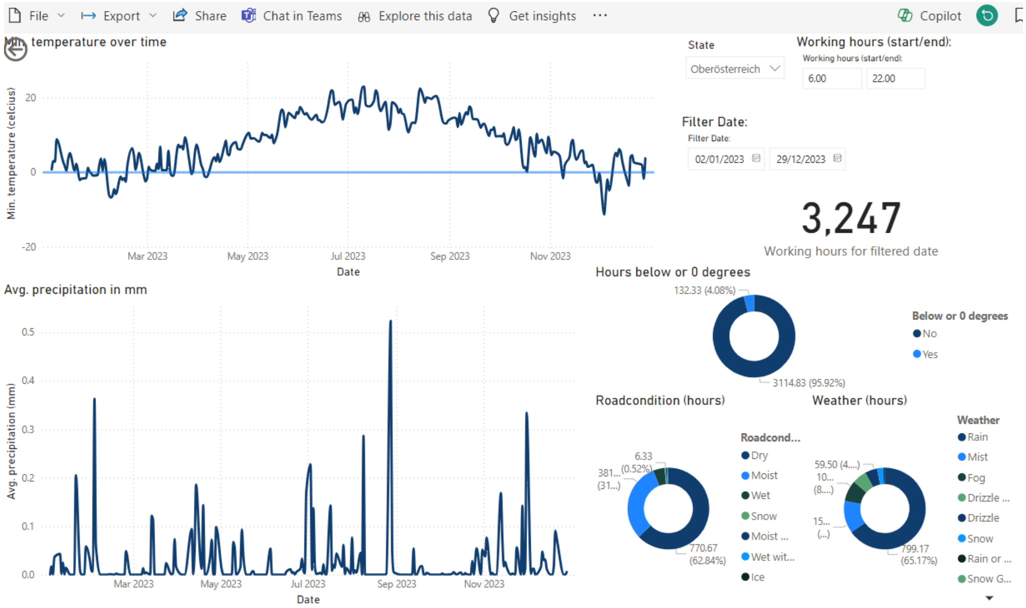


Figure 65: Weather & Road condition analysis - Gunskirchen AT

Enhanced operational availability means the vehicle can perform more tasks within the same timeframe, potentially reducing the number of vehicles needed and thus lowering the overall environmental impact. By optimizing the vehicle's performance under diverse weather conditions, the efficiency and sustainability of the automated transport system are improved.

4.8.5. Stakeholders and users' evaluation

The main results from the qualitative thematic analysis of interviews (n=9) with Hub2Hub stakeholders are summarized below. The analysis identified 11 frequent or relevant codes for this use case, represented in a word cloud (Figure 66). The questionnaire responses did not reveal significant trends. Four additional questions were included to explore perceptions of the FMS between trained/untrained drivers and remote/on-site presence.

Table 26: Research questions and main findings of the stakeholders and users' evaluation

Research questions	Main findings
Do you feel you would be capable of working with the FMS and completing similar tasks in similar conditions? Why/why not?	All participants felt capable of using the FMS, citing its intuitive design. Training or familiarization was suggested for success.
Can you think of any further operator's requirements to increase the chances of completing the task successfully and safely?	IT experience and vehicle knowledge were mentioned as necessary to handle potential issues.
Do you consider the operator's physical presence on the vehicle necessary to complete the task? Why/why not?	Participants had mixed feelings about the necessity of an operator's physical presence. On private grounds, remote controls were deemed sufficient, but a safety driver might be needed initially for manual tasks.
Imagine to be two years in the future, would you use/rely on FMS to carry out similar tasks in real life? Why/why not?	Participants expressed optimism about using the FMS for real-life tasks in the future, though some skepticism about mixed traffic control remained.

Figure 66: Word cloud of the most frequently recurring terms for the forklift interviews

Key Insights

Efficiency (n=81): Participants noted that having operators in the office doesn't ensure 24/7 operations but allows better workflow optimization and comfortable conditions. Key enablers for efficiency include proper infrastructure and training. The system's integration with manual vehicles can increase efficiency, though scaling up and managing multiple vehicles remain challenges. On private grounds, the system is expected to improve safety and efficiency, but public road operations are seen as more difficult, necessitating a backup plan for manual or remote operations.

AVs (n=79): Participants emphasized the importance of AVs communicating with operators, other vehicles, and infrastructure, especially in case of issues or accidents. AVs' advantage of not needing rest or sleep and having fewer mistakes due to sensors was highlighted. However, AVs' performance in bad weather and mixed traffic remains a concern, and boundary conditions must be defined. Remote operations are viewed as a bridge until fully autonomous vehicles are ready.

Remote Operations (n=55): Remote operations are deemed essential because vehicles are not yet fully autonomous. Fine-tuning the UI and addressing risks like signal leakage and latency are critical. Proper communication tools are necessary for broad event control and higher efficiency. Remote work might appeal more to workers than driving, potentially easing driver shortages. Training employees on system operation is crucial.

FMS Design Improvement (n=47): Too much information from multiple vehicles can overwhelm operators. Suggested improvements include pop-up overviews, clear camera views for better decision-making, and better notification clarity. The system should assist operators in understanding which vehicles can operate under specific weather conditions. Enhanced connectivity and communication between FMS, on-site operators, infrastructure, and emergency services are also recommended.

Time Frame (n=47): Participants viewed the technological improvement of vehicles, control systems, and infrastructure as expensive and bound by strict regulations. Initially, technologies are expected to be employed on private grounds. Extensive testing and safety improvements are crucial, and transitioning to remote positions will require retraining employees, which might face resistance. However, acceptance is expected to increase as more people see the benefits and more investments are made.

Acceptance (n=47): Participants noted potential issues with open road use and interaction with other people. Some believed people interested in technology would welcome the change, while others thought acceptance would vary by location. Demonstrating the safety and usefulness of AVs can increase acceptance. The media's focus on negative events like accidents impacts public perception. Participants saw remote work as a desirable alternative to driving, which might mitigate job loss fears.

Human Intervention (n=37): Good connectivity and useful information (e.g., weather forecasts, road conditions) are crucial for decision-making on remote or physical intervention. Participants highlighted the importance of this in the initial adoption phases, requiring frequent switches between operation modes for safety.

Location, Weather, Traffic, Personal Experience (n=31-29-27-17): Participants often mentioned that AVs will mainly operate on private grounds due to safety and infrastructure concerns. Poor connectivity and quickly changing weather in remote locations were common concerns. Latency negatively impacts operations in mixed traffic. Improving mobile networks, sensors, and extensive testing were suggested as enablers, with the ability to switch to remote or manual controls as a requirement for mixed traffic operations. Participants noted promising initial technological improvements and the potential for AVs to help road users become familiar with the technology.

4.9. Integration and next steps

The operational area includes various road users and potential obstacles, unlike controlled airport and port environments. Factory areas are less restricted, so limiting the vehicle's speed near visual obstructions can mitigate risks.

Public roads present a significant challenge, as slow-moving industrial trucks can disrupt traffic. Short route segments, especially with additional traffic lights, seem feasible. However, long, busy segments are problematic without a safety driver.

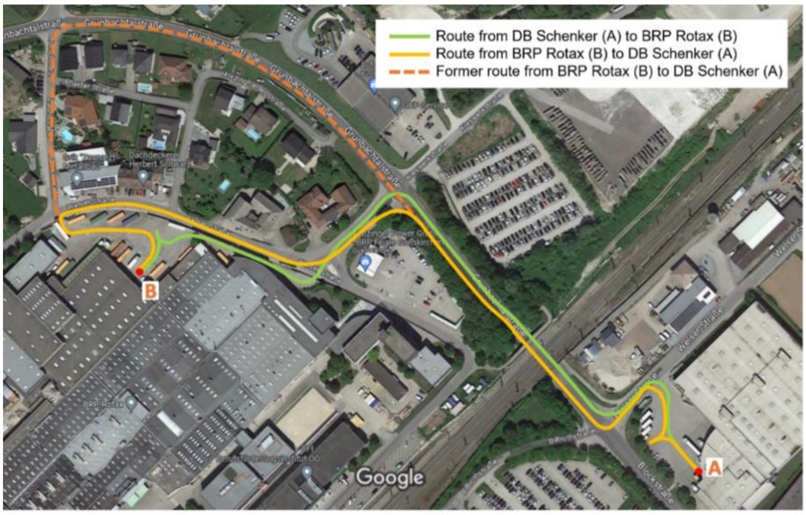
Automated driving is becoming viable, but automating loading and unloading processes is also crucial for business efficiency. Currently, drivers spend most of their time on these tasks. Although this project did not focus on loading/unloading automation, such changes could facilitate more frequent, possibly nighttime transfers.

Many European factories have similar transport needs, typically handled by a few drivers. Simply shifting drivers to teleoperators without other changes offers limited financial savings. Significant changes are necessary. A future model might involve third-party teleoperation companies managing multiple sites, with one teleoperator overseeing several vehicles and transfers, dedicating a few minutes per hour to each. This model would still require local maintenance support for tasks like manual cleaning.

4.10. Simulations and modelling

4.10.1. Simulation scenario and elements

In the Hub-to-Hub scenario, an old diesel truck is replaced by one or two automated electric vehicles or a human-operated electric vehicle. The electric vehicles use a 200-meter shorter route not allowed for diesel vehicles due to emissions and noise. The simulation uses satellite imagery from Google Maps, which are represented in Figure 67, Figure 68 and Figure 69.



Bilder © 2023 GeoContent,Geoimage Austria,Maxar Technologies,Kartendaten © 2023

Figure 67: Hub-to-Hub simulation route on Google Maps (source: Digitrans)

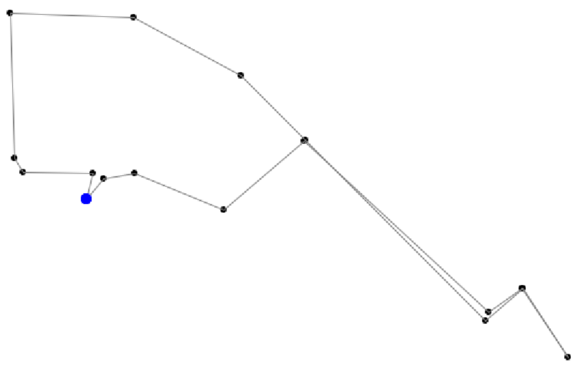


Figure 68: Simulation route for a diesel truck, 0.792 km

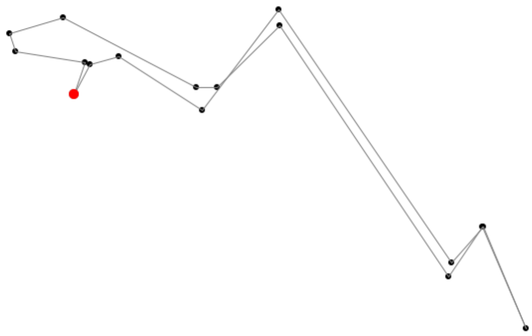


Figure 69: Simulation route for electric vehicles, 0.633 km

Opting for a diesel truck incurs an additional €10 per hour in diesel costs, and package loading time increases to 50 minutes. Larger vehicles have higher costs per kilometer and maintenance costs due to the limited vehicle count.

Maintaining an average teleoperation time of 5 minutes per hour for a single vehicle requires third-party services. Without this, a staff member must constantly monitor the vehicle, nullifying substantial savings from automation. Automated vehicles need immediate intervention when alarms are triggered, making it impractical to perform other tasks simultaneously. This analysis optionally factors in two smaller automated vehicles to replace one large diesel vehicle. Assumptions relevant to this scenario are documented in Table 27.

Table 27: Assumptions of the H2H simulator

One day simulation (24 hours).
Average speed based on actual driving data: 16.1 km/h for human vehicle and 6.2 km/h for automated vehicle.
Human drivers take three breaks: two breaks of 25 minutes and one break of 1 hour.
The time required to load cargo per vehicle was 15 minutes.
The cost of human labor was 50 €/hour.
The cost per kilometer was €6 for the old diesel truck, €7.2 for the AV, and €5 for the electric truck.
Diesel truck costs an extra 10 €/h due to the price of diesel.
Human employees take breaks or engage in secondary activities when there is free time. However, no benefits are calculated from secondary activity.
There is an absence of traffics.
Human teleoperator work was required for 5 minutes per operated hour.
One maintenance employee was responsible for automated vehicles, and the cost for one hour of maintenance work was incurred.
AVs active working time consists of the work time of the packing/unpacking worker, remote monitoring, and maintenance person.
Electric vehicles use the same parameters as diesel trucks except for the cost of diesel, which is €0 per kilometer.
Electric trucks follow the same route as AVs.

4.10.2. Results and discussions

The simulation results are detailed in the Table 28 and Table 29. The parameters include speed, breaks, loading time, labor costs, and vehicle costs.

Table 28: The first Hub-to-Hub simulation results

	Human vehicle (Diesel)	Human vehicle (Electric)	Automated vehicle
Number of vehicles	1	1	1
Kilometers travelled	22.12	19.47	18.38
Transported boxes	16/16	16/16	15/16
Waiting time (h)	13.33	13.33	13.04
Minimum transfer time (min)	52.93	52.35	56.15
Average transfer time (min)	52.94	52.36	69.44
Maximum transfer time (min)	52.95	52.37	77.62
Human teleoperation costs (€)	0	0	12.34
Vehicle operation costs (€)	132.7	77.9	110.27
Vehicle ownership costs (€)	9.13	9.13	18.26
Total costs (€)	1101.84	887.03	990.87
Average utilization (%)	8.58	7.54	18.51
Active work time (h)	16	16	17.25
Driving time to pause locations (h)	0.5	0.5	0
Driving distance to pause locations (km)	8.09	8.09	0

Table 29: The second Hub-to-Hub simulation results, with two electric vehicles

	Human vehicle (Diesel)	Human vehicle (Electric)	Automated vehicle
Number of vehicles	1	2	2
Kilometers travelled	22.12	38.95	36.76
Transported boxes	16/16	32/32	30/32
Waiting time (h)	13.33	26.66	26.08

Minimum transfer time (min)	52.93	52.35	56.15
Average transfer time (min)	52.94	52.36	69.44
Maximum transfer time (min)	52.95	52.37	77.62
Human teleoperation costs (€)	0	0	24.67
Vehicle operation costs (€)	132.7	155.8	147.02
Vehicle ownership costs (€)	9.13	18.26	36.53
Total costs (€)	1101.84	1774.06	1131.73
Average utilization (%)	8.58	7.54	18.51
Active work time (h)	16	32	17.49
Driving time to pause locations (h)	0.5	1	0
Driving distance to pause locations (km)	8.09	16.17	0

The parameters for cargo are adjusted based on the number of vehicles in use. In the second simulation, we utilize two electric vehicles, each with reduced transport capacity. Combined, these vehicles match the load capacity of a single diesel truck, facilitating process variations.

From a safety standpoint, deploying two smaller vehicles could offer advantages. Their smaller size might allow effective navigation with larger safety margins. However, productivity might remain consistent. In situations with short driving times, one vehicle might need to wait for its counterpart unless there are process adjustments or an increase in transported units.

In this scenario, most of the hour is dedicated to loading and unloading. Thus, the longer transport time of automated vehicles is not an issue since all packages are delivered promptly. Since loading/unloading takes about 50 minutes per trip, automated vehicles do not have time to make a trip every hour, increasing transport times. Therefore, for automated vehicles, unloading/loading should be sped up or automated vehicles should drive faster to achieve the same efficiency as human-operated vehicles.

The considerable costs associated with automated vehicles can be attributed to human labor, including maintenance and remote operations. The most notable differences in metrics concern costs, distances travelled, and wait times.

This simulation involves producing and transporting a variable number of boxes. Since multiple boxes might be delivered simultaneously, variations in peak transport durations across simulations are anticipated. Time randomization of available cargo has been carried out and fixed for all simulations, ensuring consistent replication.

It's worth noting that when the driver has time to work on secondary tasks, there isn't a significant difference in costs between automated and manually driven vehicles. The secondary task becomes relevant during inactivity periods, such as when no boxes are pending transportation. Such idle times might be used for tasks like cleaning. The table below displays the percentage of expenses/benefits that vary based on the amount of costs allocated to the simulation.

Table 30: Benefit from the secondary task

Share of Costs Caused by Secondary Task (Diesel Truck)	Costs (€)
10%	73
30%	219
50%	366
80%	585
100%	731

For traditional, human-operated vehicles, any increase in costs is primarily influenced by route-related expenses. In comparison, for automated vehicles, costs rise due to deploying two units. If an automated vehicle's transport capacity could replace a diesel truck, it would be more economical to deploy a single vehicle rather than two.

Main Findings

- Actual driving time is short compared to loading/unloading. Without automating these tasks, AVs are not profitable.
- Automated vehicles incur costs for loading, teleoperation, and maintenance personnel. Active work time is increased by 8% in automated mode compared to fully manual operations.
- Costs decrease by 10% if one diesel truck is electrified and automated. The main savings come from electrification. However, with the cost of one diesel truck, one could consider two smaller automated vehicles and their potential benefits to safety and processes.
- Costs increase by 11% if one electric truck is automated.
- Automated vehicles follow a route 20% shorter than those taken by human drivers, reducing emissions and noise. This shortened route is possible due to the inherently quieter and cleaner nature of automated vehicles. Since the route is shorter, transportation times for automated vehicles remain more manageable.

4.11. Implications on a larger scale

In the case of Hub-to-hub, the objective is to automate the transport of goods (either empty pallets or pallets with goods) between a manufacturing plant and a logistics distribution center. The Spanish case will be taken as a starting point and extrapolated to the rest of Europe.

According to Eurostat[4] by the year 2021 in Spain 271,689 tons have been mobilized "intermunicipal" and 869,430 tons "intermunicipal", for a total of 1,142 MM tons of goods. For the purposes of this analysis, these will be the routes of interest, since they are considered shorter distance routes, comparable to the h2h use case.

The same report indicates that for that year the total amount of goods transported in Spain was 1,626 MM tons. Thus, transportation of less than 150km in Spain represents 70% of the total (70%= 1,142 MM /1,626 MM). In addition, another data within the report is that a vehicle traveling internally in Spain mobilizes around 13.6 tons per trip.

Extrapolating these calculations to the rest of the European region, the report states that for 2021, the amount of goods transported in the region was around 13,589 MM tons. It is assumed that 70% are journeys of less than 150 KM, i.e. 957,785 tons. At the same time, it is possible to calculate the total trips made in the region by considering the above data that in each trip an average of 13.6 tons are transported, which means 702,625,000 trips in Europe.

Granularizing the analysis, this total number of daily trips is considered, which means that approximately 1,925,000 trips are made per day, i.e. almost 2 million large trucks are needed to meet the demand for goods by road over distances of less than 150 km in Europe.

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[4] Road freight transport by journey characteristics - Statistics Explained (europa.eu)

From the above, it is considered that at most there is the potential to replace 2MM vehicles. However, it does not seem reasonable to consider that all these trucks will be replaced by autonomous vehicles, considering that a total of 354,614 heavy trucks are sold per year. Therefore, let's assume that 10% of the current European fleet will be replaced by an autonomous one in the next 10 years. This means that at least 20,000 autonomous vehicles will be purchased per year. This figure is reasonable considering that the total sales represent less than 10% of the total number of freight vehicles purchased in Europe.

Regarding the simulation results, it was obtained that costs decrease to 74% if an autonomous diesel vehicle is used. With two vehicles, costs decrease to 68%. With an automated electric truck, costs decrease to 67%, and with two vehicles (electric and automated) costs decrease to 80%. However, if the human driver has free time during the loading and unloading phases to perform additional tasks, this virtually negates the benefits of automating the transfer and requires full end-to-end automation of the loading and transfer. Human labor time is reduced by 78% in automated mode compared to fully manual operations. In addition, automated vehicles follow a 26% shorter route than human drivers, resulting in a reduction of both emissions and noise. Because the route is shorter, transport times for automated vehicles remain more manageable. The above was obtained assuming that the cost per kilometer was 6 euros for the diesel truck, 7.2 euros for the AV and 5 euros for the electric truck. As well as the cost of human labor was 50 euros/hour.

Thus, by replacing 20,000 vehicles annually in Europe with automated vehicles, and considering labor and per kilometer costs, significant savings can be achieved. According to the information obtained from the simulation and the assumptions described above, with automated diesel trucks, the annual savings would be approximately 86,140,000 euros (savings per trip = (cost per km diesel) - (cost per km diesel AV) + (cost per hour labor x (1-0.74 cost reduction)). For the automated electric trucks, the same formula is applied but considering a 67% reduction in costs, the annual savings would be approximately 127,750,000 euros.

5. Forklift impact assessment

5.1. Test site introduction and routes

The AWARD Automated Forklift Use Case marks a significant milestone in logistics automation, taking place 30 kilometers south of Vienna in Seibersdorf, Austria, at the AIT facilities. Led by the AIT Austrian Institute of Technology in collaboration with various partners, this initiative features an autonomous outdoor forklift system powered by the Crayler vehicle, specifically designed for warehousing environments. The collaborative effort involves the AIT Center for Technology Experience and the Center for Vision, Automation & Control. Safety testing is led by Digitrans, with sensor recording management by EasyMile, Adasky, Continental, and Foresight. Applied Autonomy oversees the remote interface, ensuring seamless integration and operational efficiency.

The test area is an open space of approximately 40m x 30m, featuring natural obstacles like trees and bush lines, alongside man-made structures such as small houses and containers. Unlike conventional test tracks with predefined routes, this site requires the forklift to dynamically plan a suitable path for each loading cycle. This approach simulates real-world logistics operations, enhancing the forklift's adaptability and efficiency. Two potential (un)loading scenarios are depicted in Figure 70, showing the top view of the test facilities in Seibersdorf. In these scenarios, the truck is parked at the top-left of the test area, marked with a red rectangle. The (un)loading areas L1 and L2 are designated by the operator or the Fleet Management System (FMS). To reach L1, the forklift must navigate through a narrow passage between a bush line and a small hut for energy supply. For L2, the forklift requires a longer path through an open area, challenging the system's localization and precise navigation capabilities. This mix of challenging and everyday scenarios tests the forklift's operational limits and reliability.

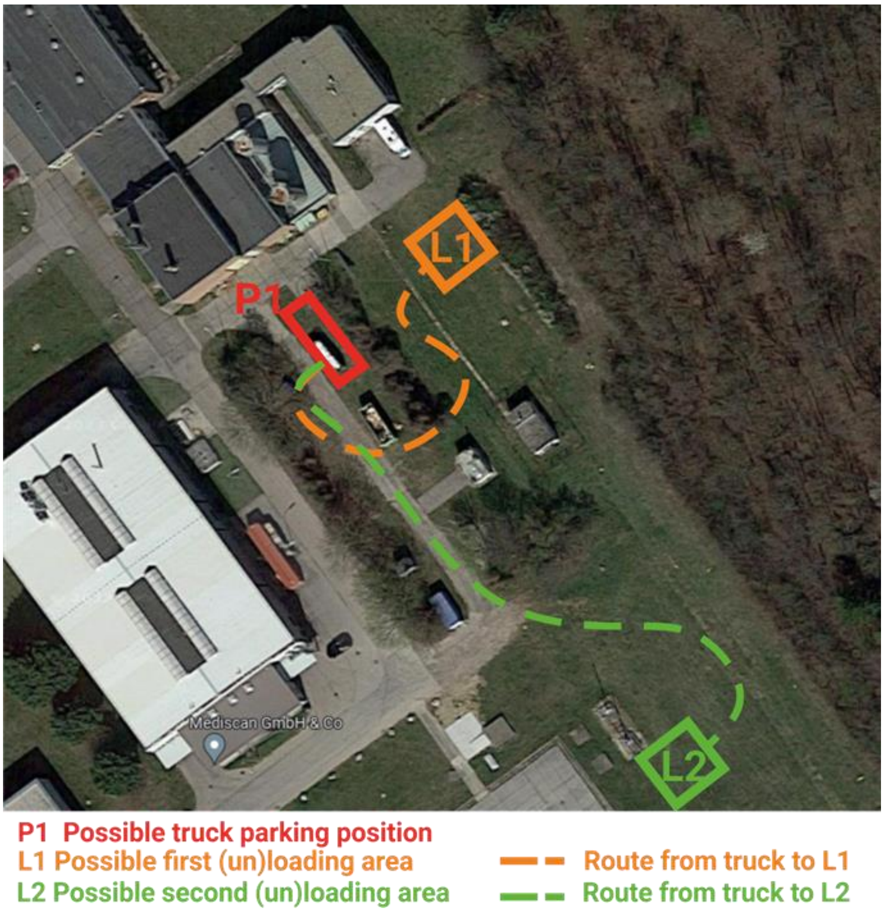

Figure 70: Top view of the test facilities in Seibersdorf with a possible parking position of the truck and two possible (un)loading areas

Testing at Seibersdorf progresses through three pivotal phases from mid-September 2023 to mid-May 2024. The phases include ensuring safe movement in open environments, demonstrating the ability to handle standard EU pallets and various load carriers, and achieving fully automated logistics operations. The integration of the Automated Driving System into the Crayler forklift, along with measures to handle adverse weather conditions, particularly snow, ensures efficient and safe operations. In November 2023, rigorous safety tests were conducted at the Digitrans test track in St. Valentin, Austria. Despite near-freezing temperatures, the forklift showcased exceptional safety performance, accurately stopping before obstacles taller than 50cm even in medium to harsh rain conditions. With a low rate of false positives, the forklift successfully navigated narrow corridors with only 40cm clearances on each side. This highlights a significant advancement in operational safety and efficiency for autonomous forklifts in real-world logistics scenarios.

5.2. Timeline

Table 31: Timeline of the forklift use case

Phase	Start month	End month
Pre-testing	32	32
First data sample for evaluation		During 2023
Baseline data collection	32	39
Operations and interviews	33	39

Dataset finalization		41
Evaluation and reporting	34	42

5.3. Performance goals and pre-existing indicators/statistics

The performance goals for the AWARD Automated Forklift Use Case focus on enhancing safety, efficiency, and reliability. Key objectives include achieving precise navigation, reducing loading and unloading times, and ensuring robust operation in various environmental conditions. The main indicators evaluated are average speed, resource usage, average working time, total distance travelled, and pallet handling accuracy. Pre-existing indicators such as historical accident rates, cycle times, and energy consumption from manual forklift operations provide a baseline for comparison.

5.4. Description of automated vehicle functionalities

The Crayler vehicle forklift, developed under the AWARD H2020 initiative, represents a major step forward in logistics automation. Manufactured by Palfinger, this autonomous forklift is designed for warehouse environments through a partnership led by the AIT Austrian Institute of Technology and various collaborators. The Crayler system equips the forklift with features that transform logistics operations.

The Crayler forklift excels in handling standard EU pallets and various load types, showing its flexibility in different scenarios, from routine loading to complex unloading tasks. Its standout feature is its ability to navigate different environments, such as construction zones, varied loading points, and supply stations, moving smoothly over surfaces like asphalt, gravel, and grass. This is made possible by its advanced sensing technology.

In addition to its loading and unloading skills, the Crayler forklift offers real-time precision, allowing operators to make quick adjustments and handle unexpected situations efficiently. This sets a new standard in logistics and supply chain management.

Figure 71: The Crayler vehicle forklift during project demo

5.5. Affected other operations

Since the testing was conducted in a controlled environment at the AIT test site, no other operations were affected. The dedicated test area allowed for uninterrupted testing and evaluation of the autonomous forklift without impacting ongoing activities in real-world logistics settings.

5.6. Infrastructure modifications

Additional sensors and cameras were installed to enhance pallet detection and navigation accuracy. The layout of the test area was adjusted to create clear and obstacle-free pathways, ensuring safe and efficient operation. Improvements to the collision avoidance system were made to handle varied obstacles, and regular recalibration of the perception system was performed to maintain accuracy. Additionally, provisions were made for operating in various weather conditions, such as installing protective measures for sensors and cameras.

5.7. Data logging

Data logging for the autonomous forklift tests was meticulously managed to ensure comprehensive evaluation. The overseer of the test site-maintained authority over the dataset, ensuring secure storage and restricted access. The dataset included detailed logs of vehicle movements, sensor readings, and performance metrics such as average speed, resource usage, total distance travelled, and pallet handling accuracy. The data analysis was performed using Python with libraries such as Numpy, Pandas, Math, and GeoPandas. Power BI was used to visualize the results.

5.7.1. Baseline data collection

Baseline data collection involved extensive testing of the remote driving vehicle. Approximately 20 tests were conducted from March 11 to March 12, yielding 80,101 observations. Two scenarios were run for both autonomous and manual modes, with no significant differences in the routes travelled or the objects transported. However, nearly half of the manual tests did not adhere to the established route and were thus excluded from the final analysis to ensure accurate results. Both series of tests were conducted in the same controlled environment, with video evidence available to support the tests. Figure 72 graphically represent the paths for the baseline data (manual cases), and Figure 73 shows the discard criteria for manual tests based on route deviations.

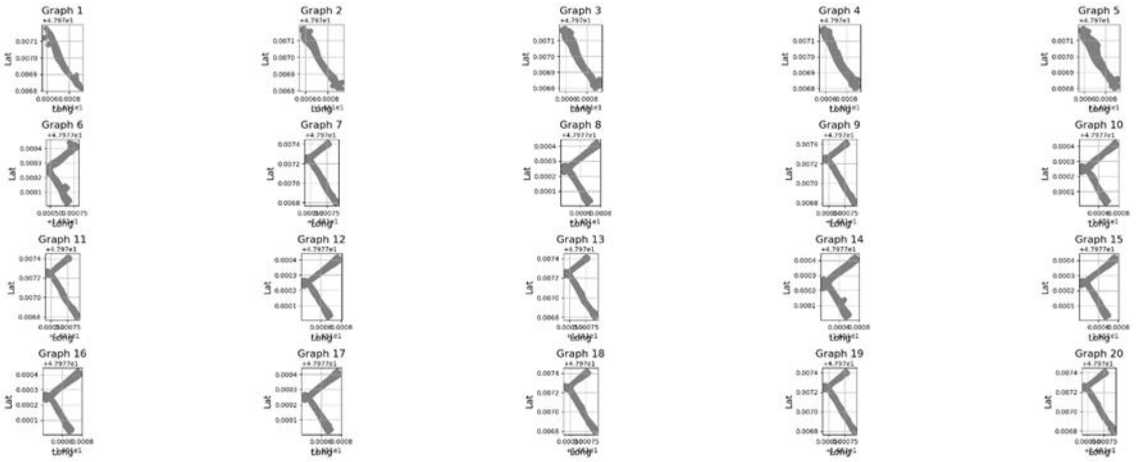

Figure 72: Graphs of the different tests run in manual mode

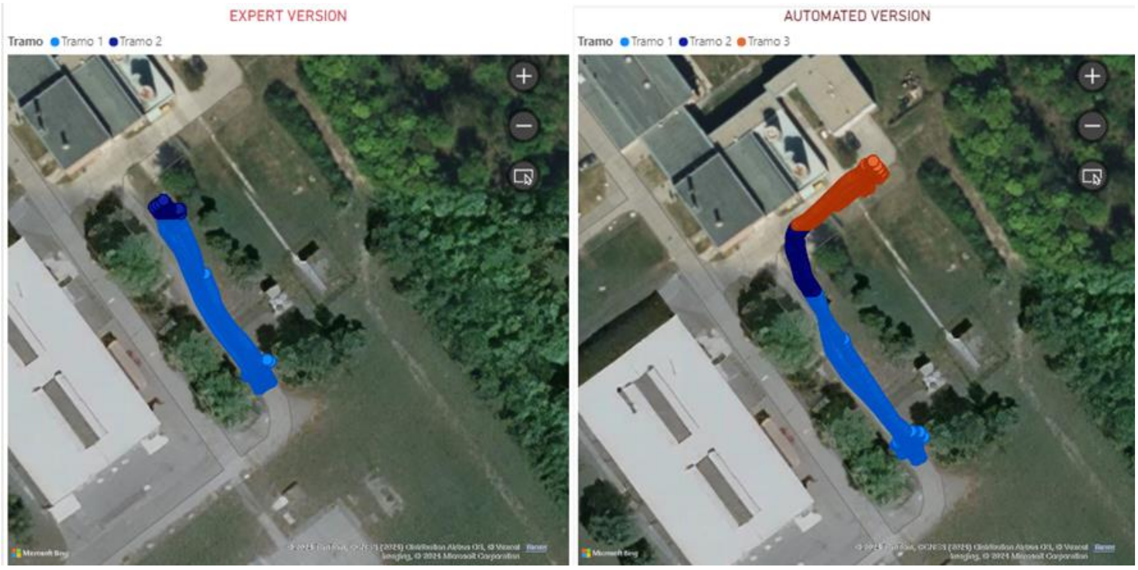

Figure 73: Differences in test routes with Google Maps image.

5.7.2. AV data collection

The first pilot for the autonomous vehicle was carried out from April 02 to April 04, 2024, during which five tests were performed, accumulating a total of 42,468 observations. The second pilot, conducted from April 03 to May 08, featured tests that combined both manual and autonomous modes within the same route. Twenty-one tests were conducted under these conditions, resulting in 447,645 observations. The routes in these pilots were executed with greater flexibility and did not strictly adhere to the original route.

For the final analysis, non-comparable scenarios were discarded. Scenarios 1, 2, 3, 8, 11, 12, and 13 were retained since they shared similar routes and characteristics in terms of the percentage use of autonomous and manual modes throughout the route.

5.7.3. Access to log data

Access to the log data is controlled by the overseer of the test site, ensuring data security and confidentiality. Data is shared only with specified individuals conducting evaluations under strict confidentiality agreements. Any potential release of sample data requires a separate agreement to maintain data integrity and privacy. This controlled access ensures that the data is used responsibly and ethically for evaluation purposes.

5.8. Results

5.8.1. Technical evaluation

The automated forklift differs from human-operated forklifts in several key ways. Human drivers typically drive towards the direction of the fork, select better areas for turning with more space, and use stand-still steering more frequently to maneuver the vehicle while stationary.

During development and testing, various challenging weather conditions were considered:

- Snow: Skidding and wheel spinning were observed, necessitating limited acceleration to maintain precision. Pallet detection became more difficult with snow-covered pallets.
- Dark: Operations were generally successful using forklift headlights, though the detection field of view was limited without forward-facing headlights. Lidar performed better in darkness than in daylight.
- Rain: While there were no control issues, pallet detection dropped to about 80% effectiveness, causing more manual interventions. Reflective puddles created map gaps, but obstacle detection was effective in light to moderate rain.

Pallet placement accuracy is a critical performance indicator, measured at plus or minus 5 cm in short tests. Accurate placement requires relatively flat ground, as 3D ground mapping is still in development. Otherwise, the forklift may struggle to disengage from the pallet, necessitating human intervention.

Forks must enter the pallet with about 10 cm accuracy. If the initial attempt fails, the forklift makes a second attempt by reversing and detecting again. The system correctly picks up pallets approximately 49 out of 50 times when the detection system is properly calibrated. However, calibration can be affected by minor collisions, vibrations, or environmental changes, necessitating regular recalibration to maintain accuracy.

5.8.2. Safety evaluation

There were no incidents during testing. Major issues encountered included incorrect pallet placement, getting stuck with pallets, and driving away with pallets that should have been set down. However, the forklift's sensor effectively detected whether a pallet was on, preventing load drops. Logical problems were also noted when approaching the truck for unloading, requiring collision avoidance adjustments to balance proximity and safety margins.

Since the SOTIF testing, the system has been enhanced with a lidar point cloud processing component, offering a larger horizontal field of view and reducing blind spots compared to stereo vision alone. This improvement has likely resolved issues such as the non-detection of metal pipe fences. The vehicle can now react within 0.2 seconds and initiate braking, ensuring safety at low operation speeds. However, future enhancements should include improved 360-degree monitoring to reduce speed when people enter the forklift's immediate area.

The sensor setup, combined with shielding the lidar window from rain droplets and the forklift's low driving velocities, results in very rare false alarms across varying environmental conditions.

5.8.2.1. Emergency stop statistics

The two main reasons for human intervention during tests were incorrect pallet entry (occurring approximately 1 in 50 times) and the collision avoidance system's caution around soft obstacles like bushes and tree branches. These sites often had obstacles close to the operational area, requiring a safety distance of about 2 meters. Additionally, uneven drop sites occasionally required human intervention to adjust the forks' angle.

Developers plan to reduce these interventions by:

- Deploying a lidar line scanner for fine positioning during pallet pickup.
- Increasing camera detection rates to reduce errors and noise through filtering and optimization.
- Classifying obstacles in the collision avoidance system to approach static obstacles more closely and classify soft obstacles like leaves and branches as non-obstacles.

5.8.2.2. Observations and SOTIF proving ground test lessons

The forklift, using AIT navigation software, showed improved behavior in critical scenarios with a new and larger safety zone for slowing down when objects are detected. Previously, the vehicle engaged in abrupt braking when detecting objects in a critical zone. The rain filter worked well, but the camera protection needs improvement to keep lens drops off.

5.8.2.3. Impacts on accident types and statistics

Understanding the safety impacts of automation in forklift operations is crucial, even though specific large-scale test data for outdoor automated systems is limited. Initial demonstrations and insights from Automated Guided Vehicles (AGVs) used indoors, which generally experience few serious accidents, provide useful indications.

In the US, common fatal accident types involving forklifts include being crushed by a tipping vehicle or between a vehicle and a surface. In 2009, approximately 80% of forklift accidents involved a pedestrian, with over 18% occurring when a forklift struck a pedestrian.

Table 32: The most common types of fatal forklift accidents in U.S.

Fatal Accident Type	%
Crushed by vehicle tipping over	42%
Crushed between vehicle and a surface	25%
Crushed between two vehicles	11%
Struck or run over by a forklift	10%
Struck by falling material	8%
Fall from platform on the forks	4%

These statistics highlight several common accident types:

- Forklift Rollovers: These occur on uneven surfaces, with imbalanced loads, or from sudden, forceful movements.
- Pedestrian Collisions: These happen when a forklift hits a pedestrian, often resulting in serious injuries or fatalities.
- Falling Loads: These occur when loads shift, tilt, or fall from the forklift, usually due to uneven lifting or unstable loads.

Accidents can also result from dangerous or new working methods, lack of cooperation, poor compliance with instructions, and technical faults.

European forklift safety statistics are less comprehensive but working environments in most EU-27 countries are similar to those in the US. Finnish national statistics from 2016–2020 show the most common deviations leading to injuries:

- Vehicle breakdown, falling, etc.: 26.7% of forklift-caused accidents.
- Stepping on a sharp object, bumping, etc.: 18.2%.
- Loss of control of the device or work equipment: 16.3%.
- Falling, jumping, slipping: 14.1%.
- Sudden physical strain: 10.4%.

In fatal and serious forklift accidents, victims are typically pinned between or under the forklift or its load. About 40% of fatalities were forklift drivers, 25% assisted in forklift work, and 35% were bystanders [5].

The following tables outline the type of accidents that automation could affect:

Table 33: Types of accidents automation could reduce

Accident Type	Impact of Automation
Reduction in Rollovers	Stable speed control reduces the risk of tipping. However, this also requires ground monitoring capabilities.
Collisions while driving	Sensors and software detect obstacles and workers, stopping as necessary.

Table 34: Positive safety impacts of automation

Impact	Description
Reduced Human Error	Fatigue or carelessness does not affect automated forklifts.
Continuous Monitoring	Software identifies potential technical problems before they lead to accidents.
Improved Workplace Safety	Less physical strain and danger for drivers not directly involved in loading or unloading.
Enhanced Safety Culture	Automation allows workplaces to focus more on improving safety and managing risks.

Table 35: Negative safety impacts of automation

Impact	Description
Technology Malfunctions	Software errors or sensor problems can lead to unexpected behavior. If the automated forklift does not work or operates slowly, there might be a

	temptation for a person to speed up a work process, potentially in a hazardous manner.
Limited Response to Unforeseen Events	Automated systems may not recognize or understand significant environmental changes such as sudden storms or chemical spills. This can lead to the machine failing to stop when needed, potentially exacerbating the local situation.
Dependence on Technology	Over-reliance on technology may lead to neglect of precautions.
Need for Training and Expertise	Workers need to understand and operate automated forklifts to ensure safety.

Automation in forklift operations can significantly enhance safety and efficiency. However, it also introduces new challenges that require careful management through proper training and implementation of technology.

5.8.3. Efficiency Evaluation

The efficiency impact assessment aimed to evaluate how the AWARD ADS influences financial, operational, and quality indicators in forklift operations. The same as in other use cases, the research was guided by three primary questions:

- How does the ADS influence financial indicators?
- How does it affect operational indicators?
- And how does it impact the quality indicators in logistics operations?

To address these questions, we formulated several hypotheses and analyzed various performance metrics. The analysis involved segmenting the logs by session to represent each movement, allowing comparisons of manual versus autonomous operations. This approach helped isolate key performance indicators and apply mathematical analysis to draw meaningful insights. Some of the main findings are presented in Table 36.

Table 36: Efficiency hypothesis and main findings of the forklift use case

Hypothesis	Findings
The ADS supports reducing personnel costs.	The ADS showed a reduction in personnel time, primarily related to loading and unloading operations. It's too early to draw definitive conclusions on overall personnel cost reduction.
The ADS reduces net transfer time.	The autonomous vehicle's net transfer time was longer compared to the manual vehicle. Autonomous: 23:35 minutes, Manual: 14:47 minutes. Autonomous vehicle travelled a shorter distance (70 meters vs. 80 meters for manual) but took more time due to slower speeds and additional processing.
The ADS decreases personnel time to support the vehicle while driving.	The automated mode was active 89% of the time, meaning manual support was needed for only 6.6 minutes per hour, indicating a decrease in personnel time required for driving support.
The ADS reduces fuel consumption.	It is too early to draw definitive conclusions on fuel efficiency. Initial observations suggest differences in operating speeds between autonomous and manual vehicles have implications for resource usage.

The ADS decreases vehicle speed.	The autonomous vehicle operated at slower speeds compared to the manual vehicle. Average speed: Autonomous - 2.01 km/h, Manual - 3 km/h. This decrease in speed aligns with the hypothesis.
The operational availability of the ADS (with respect to varying environmental conditions) is lower than the availability of a manually operated vehicle.	The operational availability of the automated vehicle was found to be lower due to the ADS's slower speeds and additional processing times. Improvements in sensor technology and recalibration could mitigate this. General availability of automated vehicles will be similar in case driver is available and vehicle still can be operated manually. L4-function availability: Potential operational hours could be improved from 3,635 (87% of possible hours) to 4,147 (99.4% of possible hours) through the AWARD ODD extension with respect to the 2023 Vienna weather data.
The ADS increases the timeliness of transport orders.	Data for analyzing the timeliness of transport orders was not available within the deployment context, so no conclusion can be drawn for this hypothesis.
The ADS increases transport reliability.	Similar to timeliness, data for transport reliability was unavailable, and no conclusion can be drawn for this hypothesis.

Financial Indicators

The ADS demonstrated potential in reducing personnel costs through decreased personnel time for loading and unloading. While automated operations significantly reduced the time required for these tasks, comprehensive statistical analysis is still needed to draw definitive conclusions.

Operational Indicators

First Pilot Findings:

- Average Distance Travelled: Autonomous - 70 meters, Manual - 80 meters (-13%).
- Average Speed: Autonomous - 2.01 km/h, Manual - 3 km/h (-33%).
- Number of Turns: Autonomous - 11.17, Manual - 11 (+2%).
- Total Travel Time: Autonomous - 23:35 minutes, Manual - 14:47 minutes (+60%).
- Average Time from Start to End Point: Autonomous - 1:46 minutes, Manual - 1:13 minutes (+45%).

The autonomous vehicle showed a tendency to travel the shortest distance due to GPS optimization settings, but it took more time due to slower speeds and additional processing.

Second Pilot Findings:

- Total Distance Covered: 270 meters.
- Average Speed: The autonomous mode had a significantly lower average speed, with a maximum recorded speed of 1.7 km/h.

Table 37: Samples from second pilots

Sample	Distance	% Auto	% Remote	Manual/Auto Ratio
Base 1	0.19 km	15.33%	22.64%	68%
Base 2	0.18 km	21.32%	40.67%	52%
Base 3	0.19 km	1.30%	4.54%	29%
Base 8	0.18 km	3.20%	11.96%	27%
Base 11	0.18 km	16.13%	10.26%	157%

Base 12	0.20 km	21.01%	14.77%	142%
Base 13	0.18 km	16.49%	14.24%	116%

The analysis revealed that manual mode consistently achieved higher speeds than autonomous mode. The operational availability of the ADS was lower, primarily due to the slower speeds and additional time required for scanning and processing.

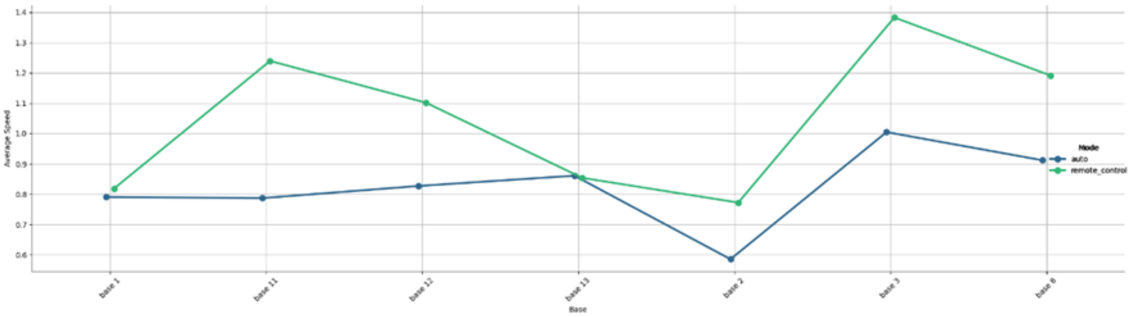

Figure 74: Autonomous vs manual mode average speed

Additionally, the current prototype uses a maximum speed of 6 km/h due to regulatory reasons, leading to fewer restrictions at slow speeds. Thus, its speed is not directly comparable to human-driven forklifts, which operate much faster. However, a human operating this specific forklift remotely cannot drive much faster than the automated vehicle. The data shows a human operator remote controlling the forklift at an average speed of 3.55 km/h while the automated navigation reached 3.14 km/h.

The time difference in completing transfer operations is mainly due to the automated vehicle stopping for three seconds before pallets to estimate and scan the area. When transferring to or from a truck, the lift mast extends for scanning, taking an additional five seconds. After scanning, the forklift takes the nearest pallets, which may not always be optimal for the overall loading process. In two comparable scenarios, an expert driver completed tasks in 67% of the time compared to automated operations.

Human operators can stack pallets and reduce the number of driving cycles more efficiently, a task difficult to automate due to the required accuracy and analysis. Automated forklifts typically cannot detect pallets not on the ground. Humans can also place pallets close together by pushing them, a logic not yet programmed into automated forklifts.

While automation has limited capabilities compared to humans, its primary purpose is to free up human time. Automation can also facilitate better inventory management and optimized storage solutions, making it ideal for factory-like environments with regular, slow-speed pallet movements between warehouses or indoor and outdoor locations.

Due to ongoing development, it's too early to determine the exact percentage of time human help would be needed. Currently, a human is required to set up transfers and define the operational area. Occasionally, human intervention is needed to help the forklift enter or free a pallet, but such instances are decreasing. Until safety monitoring improves, a human is needed for safety. In tested scenarios, automated mode was active 89% of the time, meaning manual support was needed for 6.6 minutes per hour.

The general operational availability of the automated versus manual vehicle is similar. However, the potential availability of the L4 automated driving function is of particular interest (further analysis in subsection 8.4).

5.8.4. Environmental Evaluation

The automated forklift is powered by a 40-kW engine, with the automated system consuming a maximum of 1 kW. From an environmental perspective, the difference introduced by automation is minimal. However, the shift to electric forklifts offers significant advantages over older, fossil fuel-powered models. Electric forklifts reduce both noise and emissions, contributing to a quieter and cleaner working environment.

A comprehensive life cycle assessment (LCA) of electric forklifts done by Pawel Fuc et al (2016) [6] highlights their environmental benefits compared to fossil fuel-powered models. The total carbon footprint of electric forklifts primarily arises from the generation of electricity used to charge their batteries, accounting for over 90% of their total emissions. This is significant when considering the operational phase, where electric forklifts demonstrate zero tailpipe emissions.

In practical terms, the energy consumption during the operational phase is crucial. For instance, electric forklifts operating in warehouses and distribution centers can significantly reduce their carbon footprint by using electricity generated from renewable sources. In the United States, the carbon footprint of an electric forklift varies depending on the state's energy mix. States like California and Texas, which have increased their share of renewable energy, present a lower carbon footprint for electric forklifts compared to states relying heavily on coal (Max Khabur, 2023) [7].

The operational efficiency of electric forklifts also impacts their environmental footprint. The current prototype in our study operates at a maximum speed of 6 km/h due to regulatory restrictions. Data showed that the human operator controlling the forklift remotely had an average speed of 3.55 km/h, while the automated navigation reached 3.14 km/h. The difference in speed and the additional time required for scanning pallets by the automated system indicate potential areas for improvement in efficiency.

Moreover, human operators can stack pallets more efficiently, reducing the number of driving cycles, a task that remains challenging for automation due to the required accuracy and complexity. Automation in this context aims to free up human time and facilitate better inventory management and optimized storage solutions. While the current automated systems have limitations, they represent a step towards more sustainable operations by potentially reducing the total kilometers driven by forklifts through process optimizations.

One of the main environmental benefits of electric forklifts lies in their potential to streamline operations. Automation can lead to process optimizations that may reduce the total kilometers driven by the forklifts.

Weather conditions significantly impact the operational availability of the ADS. OGIMET weather data collected in Vienna for 2023, measured at 60-minute intervals, was used to evaluate different scenarios. The table below illustrates days and hours when an automated L4-vehicle might face difficulties due to harsh weather conditions in Vienna.

Table 38: Days and hours in which an automated L4-vehicle might face difficulties due to harsh weather conditions in Vienna

Location	Difficult hours	Difficult days	Temp <= 10°C hours (days)	Rain >10mm hours	Visibility below 200m (rainy)	Visibility below 200m (non-rainy)	Heavy rain hours	Heavy snowfall hours
Vienna	97	45	1 (1)	1	3	14	4	23

A dashboard was developed to investigate the potential availability of an L4-vehicle based on weather data and the vehicle ODD. The dashboard allows the selection of harsh weather conditions under which the vehicle can operate, working hours per day, and the timeframe for calculating possible operational hours. The potential availability of the L4-function is presented in working hours. The dashboard illustrates the difference between AIT's L4 vehicle ODD before the AWARD project and the potential improvement after the project with the AWARD sensors set. The potential operational hours could improve from 3,635 (87% of possible hours) to 4,147 (99.4% of possible hours) through the AWARD ODD extension, corresponding to a potential improvement of 12.4%. The working hours are configured for a two-shift workday from 6:00 to 22:00, Monday to Friday, considering public holidays in Austria.

In conclusion, while the shift to electric forklifts offers clear environmental benefits, the full impact depends on several factors, including energy sources, operational efficiency, and adaptability to weather conditions. Continuous advancements in technology and process optimizations are essential to maximizing these benefits and achieving more sustainable logistics operations.

5.8.5. Stakeholders and users Evaluation

The qualitative thematic analysis of interviews conducted with six forklift stakeholders revealed several key insights regarding the use of automated vehicles. This analysis identified the ten most frequent or relevant themes, illustrating the perspectives and concerns of various stakeholders. Additionally, Figure 75 represents a word cloud of the most frequently recurring terms for the forklift interviews. The analysis of the answers to the questionnaire items did not yield any significant result and no clear trend emerged.

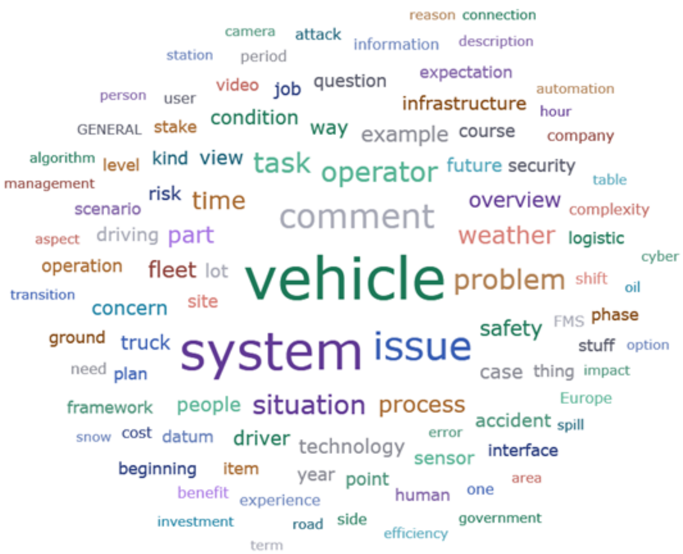

Figure 75: Word cloud of the most frequently recurring terms for the forklift interviews

AVs (n=38): With regards to benefits of AVs, it was mentioned that, unlike humans, they are not prone to drinking or getting distracted. However, it was also stressed how AVs are slow because of high internal safety and safety regulations. Consequently, their use was seen as limited, for the time being, to private ground, where things are more under control (hence affecting efficiency). Concerning comparisons with manual vehicles, the majority commented that tasks would stay the same as with manual vehicles, but overall operations should benefit from automation (e.g., the vehicles can schedule the charging cycles). It was noted that some processes (e.g., securing loads on the vehicles) are too complex for the vehicles to do autonomously. Several participants mentioned that for a transition to fully autonomous processes, more money must be invested, and more supportive regulations must be put in place. Participants also suggested that people need to see that AVs are efficient and the actual return on investments. This was tied to the perception that negative events have a greater impact than normal smooth operations, and that it will take some time for people to get used to AVs. Also, some participants noted that people might have too high expectations on the positive environmental impact of AVs.

FMS design improvements (n=33): Several potential improvements were suggested. For instance, time, location and destination and status for all vehicles in the fleet, overview of the planned tasks for the fleet, although this could be problematic with big fleets. Pop-up windows that can be recalled when needed have been suggested as a solution there. Camera views of the vehicles and weather forecasts were also mentioned as desirable to check for better task planning and execution. Different icons for different (pop-up) notifications and individual status updates for the various situations (and perhaps removing icons when resolved), including a timeline of interventions from different operators could improve the usability of FMS. Furthermore, some participants suggested how getting an overview of other shifts (i.e., what has been done to be up to speed) could bring operators “up to speed” more quickly. A few participants stated that sometimes, written information (e.g., updates on events) may be more helpful than graphic information.

Time frame, flexibility (n=30-15): While accidents will have more media coverage and people will be initially suspicious, participants believed that with time people will appreciate the benefits and get used to AVs. Furthermore, it was stated that Europe will handle the transition better than, for instance, the US. Several participants indicated that human intervention would be needed in the first phases, before full digitalization, improved safety and security (also compared to manual operations), and higher flexibility are achieved. To this regard, participants added that unflexible systems might be less reliable, and most likely slow in carrying out tasks, but that safety is the priority. Human-like flexibility was seen as a real challenge, since unpredictability must be always accounted for. Costs were also expected to be higher at the beginning, before full benefits and return on investments manifest. Finally, it was mentioned that the transition must be supported by better external conditions (e.g., concerning jobs, infrastructure etc.).

Efficiency (n=29): Concerning efficiency, participants mentioned high safety standards as a (necessary) hindrance, at least in the upcoming future. Otherwise, automating processes (e.g., autonomous charging cycles) and controlling operations remotely were seen as crucial for increasing efficiency, for instance by having vehicles operating longer shifts, or having one operator monitoring multiple vehicles through optimized and user-friendly interfaces. Further fine tuning of the algorithms, use and testing time were considered a requisite to increase efficiency. Then, results should start emerging in economics terms. Also, some positive cascading effects might be expected in terms of digitalization/automation, meaning that more people will be interested in adoption new technological solutions. Hardware issues (e.g., blocked sensors) might as well reduce efficiency, and require human intervention (e.g., one person in charge of intervening on the vehicles when needed).

Public response (n=20): It was noted that accepting automated technologies in logistics will be easier, as opposed to mass distribution. Initially, mistakes will have a bigger negative impact, also due to media emphasis (i.e., proper functioning does not make the news) but with time, people are expected to get used to the new technologies. Participants also identified potential negative attitudes or concerns in public in relation to job losses, or due to other reasons (e.g., some people might be against big companies, or lack experience with these technologies). Discussing the topics openly with the public was suggested as an approach to increasing acceptance.

Location, weather (n=17-14): Participants stated that some companies (and countries like, e.g. northern European ones) will be quicker in adopting new technologies and providing support (e.g., infrastructure investments). Additionally, it was believed that the private sector will move faster than the public one. The idea that, eventually, regulations will have to pick up with the pace of technological progress, because of external pressure, and to remain competitive was seen as a key enabler. To this regard, it was also mentioned that the process of scaling up for big companies might be a more difficult and longer process. Interestingly, the weather was not brought up too often as a problematic aspect. Concerns primarily referred to possible hardware damage, vehicle orientation and safety from the elements, all of which were seen as limiting efficiency.

Remote operations (n=16): Several participants were concerned that operators might feel detached from the real events and what happens around the vehicles. Likewise, they mentioned that, if remote operations become too easy, people might get lazy. However, it was identified as crucial that working conditions improve in terms of schedule optimization, efficiency, operations overview, comfort.

Hardware: Participants expressed the concern that the "amount of technology" involved could pose risks in terms of cyber security and reliability (e.g., blocked or broken sensors). On the other hand, they are necessary to ensure vehicles and operators have all the data they need.

5.9. Integration and next steps

Currently, there is no collision avoidance for loads exceeding the forklift footprint, which will need further development if special cargo is to be transferred. Handling special cargo may also pose challenges in ensuring that it does not fall off during transport. Initial automation cases will likely focus on fixed cargo to mitigate these issues.

Regarding possible infrastructure support, installing a camera in the loading zone could help optimize the loading routine, and detect hidden pallets. This would allow for a smoother calculation of the pallet approach, enhancing overall efficiency and reliability of the automated forklift in industrial environments.

An indoor positioning system might be required to support the operations, or lidar and map-based positioning, which would necessitate a previously recorded map.

5.10. Simulations and modelling

5.10.1. Simulation scenario and elements

The forklift simulation aims to compare the performance of automated and human-operated vehicles in transporting pallets of beverages from Beverage Market Wagner, located in Laakirchen, Austria. In this scenario, the driver transports a loaded vehicle from the warehouse to the market via public roads. Upon arrival, the truck is parked about 30 meters from the entrance. The driver then unloads the truck-mounted forklift and prepares for unloading. The forklift picks up the 34 pallets, placing them on the entrance ramp or in the outdoor storage area, completing the unloading. A manual forklift then moves the pallets inside, with an employee assisting by carrying the crates into the store.

Figure 76: Satellite picture of Beverage Market Wagner from Google Maps

Using the autonomous forklift, both outdoor unloading and indoor movement of pallets could be managed simultaneously by the truck driver, enhancing efficiency. Once unloading is complete, the forklift picks up the empty pallets and loads them back onto the truck.

The simulation replicates this realistic scenario by considering only one type of pallet containing beverages and the speed of both vehicle types based on average field test results. Factors such as route congestion or weather conditions were not incorporated, focusing solely on comparing the efficiency and effectiveness of the two vehicle types.

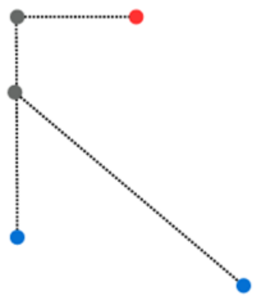

Figure 77: Simulator route map

A discrete event simulation (DES) methodology was implemented, modelling the system as a sequence of discrete events. The key components and parameters are outlined in Table 39, including forklifts (autonomous and human-operated), pallets, trucks, and drivers, as well as the loading and unloading processes.

Table 39: Assumptions of the forklift simulation

Total number of vehicles for the operation: 1
Truck delivers between 6 to 21 hrs.
There are 7.5 operations (daily stops/deliveries) per day
Truck carries 34 pallets containing beverages.
Capacity: 800 kg per pallet
Average driving speed is based on actual data from the first tests: 3 km/h for manual forklift and 2.01 km/h for autonomous. Then, second simulation considers: 3 km/h for manual forklift and 2.01 km/h for autonomous, values from the best run testing of second round of testing.
The average length, in minutes, of operation from the first tests: 14:47 min for manual forklift and 23:35 min for autonomous.
Two routes are determined:
o Route 1 is from the truck to the entrance ramp, 30 mts distance.
o Route 2 is from the truck to the outdoor storage, ~ 60 mts distance.
Total distance: 90 mts
The vehicle is 90% of the time in motion. It is not in motion when loading and unloading cargo or waiting for pedestrians or other vehicles to cross the path.
Vehicle usage per day 104.35min
There is one driver and one helper in the unloading process. Assistance is still human; truck preparation, cart pulling, etc.; monitoring of the operation is still required. Average salary of a driver operator & helper is €4000 per month.
Vehicle is diesel combustion type
Cost of manual forklift: €35.000
Insurance (estimation): €500p.a. (attributed from the company's insurance)
Vehicle maintenance cost: 2-3times a year; total cost (full-service contract) ca. €2,500 p.a.

5.10.2. Results and discussions

The simulation evaluated the performance and cost-effectiveness of autonomous and remote-control forklifts under different operational speeds. For the autonomous forklift, increasing the speed from 2.01 km/h to 2.5 km/h resulted in a slight increase in total operation time, ranging from approximately 109.87-110.73 minutes to 114.78-117.32 minutes. Correspondingly, total costs saw a minor rise from around €3143.88-3145.00 to €3150.30-3153.64. However, waiting time experienced a marginal reduction from 5.65-5.67 hours to 5.54-5.59 hours. Transfer times, including minimum, average, and maximum times, showed a small increase with the higher speed.

Table 40: Results of the first forklift simulation

	Autonomous			**Remote control**		
Total Operation Time (min)	117.1905	117.3232	114.7761	178.4992	176.9283	184.8776
Total Costs (â‚¬)	3153.464	3153.638	3150.302	3233.749	3231.692	3242.102

Kilometers Travelled	0.675	0.675	0.675	0.675	0.675	0.675
Transported Pallets	255	255	255	255	255	255
Waiting Time (h)	5.546825	5.544613	5.587066	4.525013	4.551195	4.418706
Min Transfer Time (min)	15.19925	14.5032	15.23408	21.3677	19.51283	24.29606
Avg Transfer Time (min)	16.7415	16.76046	16.39658	25.49989	25.27547	26.41109
Max Transfer Time (min)	18.25772	18.00107	17.82533	28.37547	28.61193	29.70187

In contrast, the remote-control forklift demonstrated improved efficiency with the increased speed. The total operation time decreased from approximately 182.86-188.36 minutes to 176.93-184.88 minutes. Total costs also saw a slight reduction, from around €3239.46-3246.67 to €3231.69-3242.10. Waiting time slightly decreased as well, from 4.36-4.45 hours to 4.42-4.55 hours. Transfer times, including minimum, average, and maximum times, generally decreased with the higher speed, indicating more efficient operation.

These findings highlight the benefits of optimizing operational speeds for different forklift types to enhance performance and cost-effectiveness. While the autonomous forklift's increased speed led to marginally higher operation times and costs, it slightly reduced waiting times. The remote-control forklift, however, became more efficient with increased speed, showing reductions in operation times, costs, and transfer times.

In summary, the simulation results suggest that while automation can enhance efficiency and operational capacity, optimizing the speed of autonomous forklifts is crucial to achieving maximum performance benefits. This optimization could lead to better inventory management, streamlined processes, and ultimately, reduced operational costs.

5.11. Implications on a larger scale

To scale the forklift use case scenario, the first thing that will be needed is to conduct an analysis of the EU retail market.

The first step is to determine the number of supermarkets in the European Union, considering only large and medium-sized supermarkets. According to Euromonitor International, to determine whether a supermarket is medium-sized, it is considered that the sales volume is between 10 and 50 million annually, and to be considered large it must exceed 50 million annually. Another important piece of information from this source is that a significant proportion of supermarkets in the European region are small stores or convenience stores. By 2020 there were approximately 75,000 large/medium supermarkets in the European Union.

From the simulation, one of the main conclusions was the fact that the use of remote-controlled vehicles required the participation of two operators: the driver and a supermarket employee, which implied the participation of supermarket personnel in tasks that were not strictly related to the supermarket's service. Additionally, it was obtained from the tests that the average operation time for an autonomous forklift is approximately 30 minutes.

We will start from a maximum scenario, assuming that 30% of the supermarkets adopt this technology. In such a case, and based on the above information, 22,156 supermarkets would use the autonomous forklift. Considering at least one delivery per day, this would result in significant savings in staff time. If each daily delivery with an autonomous forklift frees up approximately 0.5 hours of supermarket staff time, this translates into 11,078 hours per day that can be redirected to other critical activities within the supermarket (22,156 * 0.5 hours).

This additional time could be spent on improving customer service, optimizing product organization, performing cleaning tasks, and managing inventories with greater accuracy. In addition, the adoption of autonomous technology not only improves operational efficiency, but also reduces the likelihood of human error and workplace accidents, increasing the safety of the work environment. In the long term, these benefits could result in increased customer satisfaction and better resource management, making supermarkets more competitive and sustainable. In addition, the implementation of autonomous forklifts could serve as an incentive for the modernization of other logistics processes, promoting a culture of innovation and technological adaptation in the retail sector.

6. Conclusion

This project successfully adapted the FESTA methodology for carrying out and evaluating field operational tests of industrial automated trucking in real-world scenarios. The core principles of FESTA proved effective, with extensions made to gather data on related industrial processes. It includes integration options, driver tasks beyond just driving, indirect savings achievable from automation, teleoperation, industry-specific accidents, and efficiency statistics.

In terms of efficiency, automation operated at little over half the speed (50.8% over 3 EM test sites, 67% for completing forklift tasks) of human drivers. However, the project experimented cases which allowed for slightly slower driving as long as delivery time requirements were met. The main goal was indeed to free drivers and achieve financial savings.

These financial savings could reach as high as 85% if around 30 human-driven vehicles are replaced by an automated fleet supported by a few teleoperators. However, we have to keep in mind the considerable investments and teleoperation development needed to implement this solution.

Regarding environmental implication, automation might reduce energy consumption theoretically with fluent driving style and by further avoiding unnecessary stops. In this project, however, our best results only equal human drivers' consumption. As AVs were extra careful and stopped often for safety, the energy required to accelerate again was significant. In this regard, we conclude that there is no meaningful environmental impact that resulted from driving style. A bigger impact could come from replanning operations. For instance, AVs do not need to drive for lunch or other pause locations. Thus, savings between 1 to 27% were simulated in driven kilometers for the airport use case, depending on waiting locations.

Clear economic benefits can be expected when replacing a fleet of human drivers. The project results indicate that a couple of teleoperators could probably oversee a dozen automated vehicles. Teleoperation thus becomes a topic for future research, proving confident teleoperation, so that legislation would better allow remote operations of automated vehicles, especially at restricted areas such as airports and ports.

However, the financial benefits with one vehicle are neglectable. This was investigated at the hub-to-hub and forklift test sites in the project. Discussion becomes rather about changes in current processes (could the driver then be free to do something new, could loading be automated as well and not only driving). Findings suggest that a third-party teleoperation company handling several such 1-vehicle sites, freeing the drivers there, might provide some new business models and ways to benefit from automation. Otherwise, automation becomes rather an assistance function only.

Moreover, diminishing marginal returns were evident in some cases as increasing the volume of the autonomous fleet did not always result in higher productivity or lower costs. For instance, simulations at airports demonstrated that adding more than 30 automated vehicles no longer improves transport times.

On the safety dimension, careful automated vehicles are unlikely to be involved in accidents caused by the vehicle itself. However, there is a higher likelihood of rear-end collisions and overtaking accidents caused by other drivers, as the automated vehicle drives more slowly and makes frequent stops. During all the tests, there were no accidents with automated mode on. However, a small reversing incident occurred when a human driver reversed to a loading bay in difficult weather conditions.

In a mixed fleet setting, other drivers might cause accidents when eagerly overtaking the slower AV. Although, it was reported from the airport use case that other drivers rapidly learned the driving behaviors of automated vehicles and could therefore adapt to it. Hence, improved collaboration will be a research topic. Currently, automation should avoid the busiest human routes or moments and rather carry out transfers during off-peak.

In ports, collision avoidance systems present a clear safety potential to avoid small dents and scratches. The operation of loading trailers to ships involves many tight places where improved sensor systems could help. However, human drivers currently carry out tasks such as checking the condition of arriving trailers and connecting/disconnecting them. Such processes could be automated as well.

At the port test site, using DFDS's statistics, we estimated a potential to address 29% of damage reports, if we count out most of the reports regarding trailers that are already damaged when they arrive at the terminal. Mainly, the benefit would come from collision avoidance when maneuvering trailers in tight spaces. Still, numerous cases such as broken connectors, equipment failures, tire blowouts, and damage by a third party would not be immediately affected.

At airports, there are occasionally ground handling accidents caused by reckless driving. That is where the safety potential lies. However, current airports are designed for human drivers, and automating operations is not always straightforward despite the area being access controlled, and theoretically more suitable for automation than public roads in city centers. Automation will thus likely happen step by step.

Furthermore, we estimated that a reduction of 26–31% of all ground handling incidents in airports leading to AC damage or AC contact could be reached by automating a big part of ground transfers. There is little statistics available regarding collisions that do not include an aircraft, but we estimate similar potential there, using collision avoidance systems to reduce the number of minor collisions.

Automated driving has been demonstrated to be possible. Some 0.6% to 5.6% of the year, the weather conditions were not favorable at the test sites, especially becoming more difficult over Nordic winter months. Nevertheless, AVs might still continue to operate, slow, or with some support persons. Road maintenance becomes a priority in winter operations, as long as the automation cannot flexibly modify its route.

Overall, this project successfully demonstrated the feasibility of industrial automated trucking, highlighting its potential economic and safety benefits. Further research is crucial to achieve deeper integration of automated driving with other industrial processes as driving is just one part. This project has demonstrated reasonable capabilities to drive, but future projects should aim for deeper industrial integration. That, however, is easier to say than accomplish, as taking up fleet management systems is usually a precondition for such integration, and it becomes rather a real attempt to take system into use rather than a proof of concept any longer.

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Annex I - Impact assessment methodology

The detailed impact assessment plans were documented in deliverable D7.4. This chapter gives a summary and supplement of the impact dimensions and evaluation approaches considered within the impact assessment.

A1. Technical evaluation

Technical evaluation assesses the potential of the automated vehicle to perform defined tasks without or with minimal human assistance. The purpose of these assessments is to identify strengths as well as areas for further development. This analysis was carried out in parallel and in addition to other verification and validation tasks of this AWARD project such as WP3 and WP4. The verification and validation scenarios related to functional safety and SOTIF activities were planned in WP4 and focused on the ODD parameters. In the WP7 analysis, the focus was on the performance of the vehicle and its components within operational tests. The technical evaluation for the use different AWARD use cases is provided in sections 2.8.1, 3.8.1, 4.8.1, and 5.8.1.

A2. Safety impact assessment

A2.1. Overall concept

The evaluation of safety impacts focused on the potential of automated systems to prevent accidents and injuries commonly occurring in manual operations. The assessment reflected occupational safety statistics for moving work machines. The aim was to understand risk mitigation on industrial sites, excluding the broader scope of automated vehicles on public roads.

The evaluation combined statistical information with on-site observations of vehicle behavior and the behavior of other actors, for an expert assessment of which type of accident scenarios might be avoided in the future. Observations and collected test data provided also insight into accident types that could become more common, unless precautions were taken. As an example, human overtaking accidents might increase due to slow-moving automated vehicles.

It was unlikely to experience many close-call situations in short testing, also thanks to safety precautions. It is possible to compare secondary factors such as driving speed and safety margins. The safety assessment also collaborated with proving ground safety tests, carrying out braking tests in critical scenarios. This was to assess which types of accidents might still be possible. Proving ground tests for SOTIF (safety of the intended functionality) compensated for the lack of safety margin data collection (no free space measurement to the front) during operational tests.

A comparative analysis was made between automated operations and manual operations, noting the cautious driving behavior of automated vehicles, albeit with limitations in complex situations. The assessment recognized the inherent safety improvements offered by automation but also acknowledged potential new risks.

Research questions guided the data collection for evaluation, focusing on accident types in automated trucking, occupational accident prevention, material damages, and the frequency of safety-relevant events among other factors. Data collected from operational tests provided insights into the reliability of automated vehicles, worker perceptions of safety, and the dynamics of mixed fleet interactions.

A2.2. Research questions and PIs

Based on the planning outlined in D7.4, the initial questions we aimed to address from a research perspective were as follows. These questions, which are detailed in the Appendix Table 1, served as the foundation for our inquiry, guiding our investigation effectively.

Appendix Table 1: Safety impact assessment research questions

ID	Research Question	Clarification	Priority
SA-1	What are the foreseen accident types in different operational modes of automated trucking on industrial grounds?	Review different accident types in different phases of piloted transport operations: e.g. loading, interactions with ground workers. Expert assessment and observation, comparison against current accident statistics.	High
SA-2	How many and which types of occupational accidents, injuries and diseases could be prevented through automated trucking?	To examine statistical safety potential in similar industrial operations and scenarios than in the tests	High
SA-3	What are the changes in material damages, when comparing manual operations with automated operations?	Collect information on material damages and small accidents that include no human injuries	High
SA-4	What is the frequency of safety-relevant events during automated vs manual transport operations?	Detect and analyze close call situations (low time-to-collision, maximal braking) and compare safety margins generally used while driving	High
SA-5	How reliable automated prototype vehicles prove to be during operational tests?	Analyze human take-over actions, unexpected stops, undetected objects, nuisance alarms and similar.	High
SA-6	How ground workers and maintenance men view safety, reliability and trustworthiness of the new vs old operations and interactions?	Conduct interviews, study how much concentration working safely with automation requires.	High

SA-7	How does the interaction between vehicles change in a mixed fleet?	Study the interactions between automated and manually driven vehicles, e.g. surprising situations, overtaking, queues. Interview drivers and measure changes also in manual driving.	High
SA-8	How does the risk management process change at the test site, when taking self-driving vehicles into use?	Examine changes in risk assessment and mitigation methods, incident reporting processes.	Medium
SA-9	Assess the difference in safety related events and related prevention strategies on industrial premises vs public roads	Compare different road segments. Compare AV operations on different road segments. Finally, compare industrial processes and current traffic safety research.	Medium

A3. Efficiency impact assessment

A3.1. Literature Review

Measuring the efficiency impact of innovative technologies such as autonomous vehicles in logistics is crucial in order to achieve cost savings, increase productivity and safety, and improve asset utilization and environmental sustainability. Therefore, measuring how efficiency is impacted by the use of these technologies can help companies in the optimization of their logistics operations. To do that, there are different methods to measure the efficiency impact. This sub-section provides a non-exhaustive list of the most common methodologies available.

<u>Simulation-based modeling:</u> this method is also detailed in the environmental impact assessment method; however, related to efficiency, this model may take into account variables including traffic flow, paved surfaces, and vehicle characteristics. Additionally, it can be used by researchers to test alternative scenarios, such as different levels of AV adoption or various traffic circumstances and examine the influence on different efficiency indicators including energy consumption, emissions, and trip time. Computer models of the delivery system can be made by researchers that take into account variables like package volume, delivery routes, and vehicle characteristics. The model can be used to mimic how autonomous delivery vehicles behave and examine how delivery times, energy use, and emissions are affected. This method may give researchers insights into the potential impacts of AVs by enabling them to investigate a wide range of scenarios in a safe environment.

<u>Field testing:</u> Testing autonomous vehicles in the field includes performing such tests in controlled environments, such as test tracks, or in real-life scenarios, such as cities or highways. In the testing phase, AV performance, including speed, acceleration, and fuel consumption, as well as their effects on traffic flow, safety, and pollution, may be measured. In a controlled environment, this method can enable the use of drones or self-driving delivery vehicles at a warehouse or along a planned delivery route. Researchers can collect information on the automobiles' performance, including information about delivery times, energy consumption, and safety. With this information, the efficiency impact of autonomous vehicles in logistics can be studied, and potential areas for improvement can be identified.

This approach can offer insightful information about how AVs' performance in the real world might assist in spotting potential problems that might need to be fixed before wider use.

Cost-benefit analysis: This analysis weighs the advantages and disadvantages of autonomous vehicles versus conventional automobiles. In addition to the expenses related to developing and deploying AVs, this analysis may take into account aspects like fuel savings, reduced congestion, and safety advantages. With the help of this strategy, decision-makers may better understand the potential economic effects of AV adoption and integration into the transportation system.

Surveys and interviews: Surveys and interviews can also be used to gauge how autonomous vehicles' impact on logistics has affected efficiency. Data can be gathered on issues including the perceived advantages and disadvantages of autonomous vehicles, potential adoption barriers, and logistics providers' willingness to make investments in autonomous vehicles. With the help of this information, decision-makers can better understand the possible effects of autonomous vehicles on logistics.

There are undoubtedly further techniques and metrics to assess the efficiency impact; as technology develops further, more procedures will emerge, allowing for a more accurate assessment of the efficiency impact of new technologies.

A3.2. Overall concept

The overarching concept of the efficiency assessment within the AWARD project is centered on evaluating the impact of automated ground transport systems (AGTS) not only in terms of safety but also with a keen focus on enhancing process efficiency and quality. As delineated in the project documentation, specifically in D7.4, our evaluation primarily revolves around two core aspects: fleet efficiency and vehicle efficiency. Fleet efficiency entails a holistic examination of the optimization of overall fleet operations, encompassing route planning, resource allocation, and coordination, while vehicle efficiency scrutinizes the individual performance of AGTS vehicles across diverse scenarios. Additionally, the assessment extends to the handling efficiency of goods, recognizing that automation may induce changes in handling procedures, thereby influencing overall process efficiency and quality. The evaluation framework poses key research questions pertaining to these aspects and adopts a comprehensive data collection strategy, incorporating interviews, existing system analysis, and on-site observations. By comparing log data from human-driven vehicles with that from automated vehicles, the project aims to discern changes in process efficiency and quality across various use cases. Simulations of the fleet management system, as outlined in Work Package 5 (WP5), are integral to assessing fleet efficiency under different scenarios. Given the extensive scope of hypotheses and constrained project resources, a prioritized approach will be adopted, focusing initially on high-impact hypotheses with subsequent activities contingent upon resource availability. This overall concept underscores a structured and strategic effort to comprehend and optimize the influence of AGTS on fleet operations, vehicle performance, and the efficiency of goods handling within the AWARD project.

A3.3. Used method

In the pursuit of evaluating the efficiency impact of automated ground transport systems (AGTS) within the AWARD project, diverse methodologies were strategically employed to analyze key performance indicators, namely speed, fuel consumption, battery consumption, and mileage.

Speed Assessment: To assess the impact on speed, statistical methods were instrumental. The logged data was meticulously cut into 1-hour or 2-hour pieces, allowing for comparisons between manual and automated driving segments. Various metrics, including minimum and average speed, were computed to discern variations and patterns in driving speeds.

Fuel Consumption Analysis: A comprehensive approach was adopted to analyze fuel consumption. The logs were methodically segmented by session, representing distinct movements. This segmentation facilitated a nuanced comparison of parameters under similar circumstances, differentiating between manual and autonomous driving scenarios. Median and average fuel consumption values were calculated iteratively to draw meaningful conclusions.

Battery Consumption Evaluation: Similar to fuel consumption, electronic vehicle data was scrutinized to evaluate battery consumption. Segmentation occurred based on the percentage of automation, considering periods with automation levels less than 10% or exceeding 50% over a 2-hour duration. Future assessments are planned to incorporate a comparative analysis against diesel vehicle baselines, recognizing that changes may stem from various factors beyond automated driving.

Mileage Assessment: The assessment of mileage involved a systematic segmentation of logs by session. This approach allowed for a focused comparison of parameters in similar circumstances, distinguishing between manual and autonomous driving. Key performance indicators (KPIs) were isolated for targeted mathematical operations. Subsequently, calculations were reapplied to the extracted figures to derive insights into the impact on mileage.

Weather Data Assessment: This assessment estimates the number of days and hours of severe weather conditions in a year, that likely pose challenges to automated driving. Weather data was sourced from the nearest airports to test sites: Oslo airport (a test site, WMO number[5] 01384), Rotterdam airport (9 km from the test site, WMO number 06344), Linz (20 km from the test site, WMO number 11010), and Wien (20 km from the test site, WMO number 11036), mainly covering the year 2023, as well as from dedicated weather stations installed at the Austrian test-site.

The data included SYNOP messages, which are hourly surface synoptic observations from weather stations. SYNOP is an internationally standardized format used by meteorologists to

[5] World Meteorological organization's 5-digit numeric code to identify a land weather station

uniformly record and transmit weather data such as temperature, humidity, wind, and atmospheric pressure.

The data processing was conducted using Java software (a feature of the project tool LogPro) and involved parsing SYNOP message parameters such as temperature, precipitation, visibility, and specific weather codes (heavy snowfall, heavy rain, and thick fog). This process helped identify the hours and days that could present challenging conditions for autonomous driving systems. While automated driving might not stop, the vehicles would at least drive more slowly.

We identified several weather conditions that currently pose challenges to autonomous driving:

- Low Temperatures: Temperatures below –10°C are outside the current system specifications. Such low temperatures can hinder sensor operations or exceed tested limits, although the latest lidars can operate in temperatures as low as –20°C.
- Reduced Visibility: Visibility under 200 meters, often due to thick fog or heavy precipitation, significantly impacts the effectiveness of cameras and laser scanners. The visibility estimates from weather stations may not fully reflect the effective range of vehicle lidars in such conditions.
- Heavy Rain: Significant rainfall can interfere with vehicle sensors and obstacle detection. In SOTIF tests, vehicles were tested to manage under 20 mm/h rain. From the weather data, we marked hours with at least 10 mm/h (a longer average that may have included heavier rain) as potentially difficult. We also considered hours with SYNOP weather codes indicating heavy or thunderous rain conditions (64, 65, 82, 92, 95–99).
- Heavy Snowfall: For heavy snowfall, we used SYNOP codes indicating intermittent to continuous heavy snow, moderate to heavy snow showers, and thunderstorms with snow (72, 73, 74, 75, 79, 86, 87, 88, 90, 94).
- Thick Fog: Thick fog, which disrupts lidar and camera functionality, was identified using specific weather codes for dense fog conditions (SYNOP weather codes 43, 45, 47, 49).
- Dust and Sandstorms: Conditions of dust and sandstorms were identified using specific weather codes (9, 30, 31, 32, 33, 34, 35).

Overall, the methods given above collectively ensured a comprehensive and systematic exploration of AGTS efficiency, providing valuable insights into how speed, fuel consumption, battery consumption, and mileage are influenced by the transition from manual to automated driving. The segmentation of data and iterative calculations enhanced the depth and precision of the efficiency impact assessment, contributing to a robust understanding of AGTS performance across diverse driving scenarios.

A3.4. Research questions and PIs

In accordance with the strategic framework presented in D7.4, we sought to address specific research questions outlined in the initial planning. These questions, elaborated in the

Appendix Table 2 provided below, formed the cornerstone of our research, effectively guiding and shaping our investigative efforts.

Appendix Table 2: Efficiency impact assessment

ID	RQ	Hypothesis	Priority
Fleet Efficiency			
EF-1	How does the AWARD fleet management system influence financial indicators?	The FMS reduces fuel costs	High
EF-2		The FMS reduces total costs per kilometer	Medium
EF-3		The FMS reduces costs for spare parts	Low
EF-4		The FMS reduces labor costs	Medium
EF-5		The FMS reduces maintenance costs	Low
EF-6	How does the AWARD fleet management system influence operational indicators?	The FMS increases vehicle utilization	High
EF-7		The FMS increases the amount of shipped goods	Low
EF-8		The FMS minimizes the distance driven	Medium
EF-9	How does the AWARD fleet management system influence quality indicators?	The FMS minimizes the number of vehicle breakdowns	Low
EF-10		The FMS minimizes the average maintenance downtime	Low
Vehicle Efficiency			
EF-11	How does the AWARD ADS influence financial indicators?	The ADS supports reducing personnel costs	High
EF-12		The ADS increases purchase costs	Low
EF-13		The ADS decreases costs of vehicle operation	Medium
EF-14	How does the AWARD ADS influence operational indicators?	The ADS reduces net transfer time	High
EF-15		The ADS reduces net waiting time	Medium
EF-16		The ADS increases vehicle uptime	Medium
EF-17		The ADS decreases mean time between failures	Low
EF-18		The ADS decreases personnel time to support (AD) vehicle while driving	High
EF-19		The ADS decreases personnel time to support (AD) vehicle in unexpected situations (breakdown, accidents...)	Medium
EF-20		The ADS decreases personnel time to maintain (AD) vehicle	Low
EF-21		The ADS increases transport capacity	Low
EF-22		The ADS reduces fuel consumption	High
EF-23		The ADS increases vehicle range	Low
EF-24		The ADS decreases vehicle speed	High
EF-25		The ADS requires tighter maintenance intervals	Low

EF-26		The operational availability of the ADS (with respect to varying environmental conditions) is lower than the availability of a manually operated vehicle	High
EF-27	How does the AWARD ADS influence quality indicators in operations?	The ADS decreases the number of damages of transported goods	Low
EF-28		The ADS increases the timeliness of transport orders	High
EF-29		The ADS reduces transport time	Medium
EF-30		The ADS reduces transport costs	Medium
EF-31		The ADS increases the transport reliability	High
Goods handling Efficiency			
EF-32	How does the AWARD AGTS influence financial indicators related to the handling of goods?	The AWARD AGTS reduces personnel costs for handling of goods	Low
EF-33		The AWARD AGTS increases purchasing costs for supporting logistics systems	Low
EF-34		The AWARD AGTS increases costs for supporting logistics systems operation	Low
EF-35	How does the AWARD AGTS influence operational indicators related to the handling of goods?	The AWARD AGTS application reduces net waiting times for goods handling	Low
EF-36		The AWARD AGTS application decreases personnel time to support goods handling	Low
EF-37		The AWARD AGTS application decreases personnel time to support goods handling in unexpected situations	Low
EF-38		The AWARD AGTS application decreases personnel time to maintain goods handling (logistics support) systems	Low
EF-39		The AWARD AGTS application decreases inventory size	Low
EF-40	How does the AWARD AGTS influence quality indicators related to the handling of goods?	The AWARD AGTS application increases timeliness of handling of goods	Low
EF-41		The AWARD AGTS application reduces (un)loading time	Low
EF-42		The AWARD AGTS application reduces costs for (un)loading	Low

Within the efficiency assessment of the different use cases (compare section 4-7) mainly **results regarding vehicle efficiency** are presented. The pilot cases were less suitable for evaluating the optimization capabilities of the FMS, and its ability to support efficient, large-scale operations. In general, a FMS may reduce fuel costs through optimizing the loading factor, the transport routes of a vehicle fleet with respect to a given set of transport orders and optimization criteria. When the FMS is fully integrated into commercial operations, it can be expected to manage fleets of larger numbers of vehicles, tasked with dozens or hundreds of jobs per day. To demonstrate the scalability of the FMS and its integrated optimization algorithm, the AWARD-Team generated different test lab scenarios (on a road network in

Toulouse). To demonstrate the performance of the optimization algorithm different settings, e.g., for the time being late at orders (0, 5, and 10 minutes), were tested. The results are presented in D5.6.

Main findings of simulated test scenarios for fleet management:

- It is possible for all scenarios to serve almost all given orders (50,70,100 orders for 3 vehicles within 8 hours) with a good solution quality regarding being late with orders. [where order due date = 8 hours]
- Waiting times for the vehicles are rather high (66-80%), which implies the possibility to serve even more orders during the operations time of 8 hours. [where order due date = 8 hours]
- When the order due date is changed from within 8-hours to 1 hour the waiting times decrease to 3.8-42% and the percentage of driving time doubles.

Even if no direct contributions to the fleet efficiency within the Hub-to-Hub pilot could be measured the simulation findings indicate that an FMS could

- reduce fuel costs (EF-1: The FMS reduces fuel costs),
- increase vehicle utilization (EF-6: The FMS increases vehicle utilization).

The potential of different optimization algorithms is also actively discussed in literature, e.g., by:

- Berbeglia, G., Cordeau, J.-F., Laporte, G.: Dynamic pickup and delivery problems. *European Journal of Operational Research 202*(1), 8-15 (2010).
- Gmira, M., Gendreau, M., Lodi, A., Potvin, J.Y.: Tabu search for the time-dependent vehicle routing problem with time windows on a road network. *European Journal of Operational Research 288*(1), 129-140 (2021).
- Vidal, T., Crainic, T.G., Gendreau, M., Prins, C.: Time-window relaxations in vehicle routing heuristics. *Journal of Heuristics 21*, 329-358 (2015).
- Pisinger, D., Ropke, S.: An Adaptive Large Neighborhood Search Heuristic for the Pickup and Delivery Problem with Time Windows. *Transportation Science 40*(4), 455-472 (2006).

A4. Environmental impact assessment

A4.1. Literature Review

It is important to measure the environmental impact of innovative technologies such as autonomous vehicles in order to (i) understand the benefits and pitfalls of these technologies, and (ii) assess the extent to which these technologies bring improvements on the path to environmental protection. This is especially critical in Europe, where the EU has made sustainable growth and reducing greenhouse gas emissions a priority. We can determine whether autonomous vehicles are a practical approach to achieving these goals by assessing their actual environmental impact. To do this, we need to be aware of their potential to reduce carbon emissions through route optimization and a reduction in the number of vehicles on the road, but also consider indirect impacts such as changes in land use and transportation patterns. Understanding the environmental impact of the manufacturing process for autonomous vehicles is also critical, as much energy and resources are consumed in the process.

This section aims to provide a brief overview of the different methodologies used in Europe and other parts of the world, for measuring environmental impact of the use of autonomous vehicles, making emphasis in the logistics sector. Nevertheless, given that the use of AVs in logistics is still developing, there is no established approach for evaluating the environmental impact of these technologies, but we gathered the most common methodologies:

Life Cycle Assessment (LCA): The widely used LCA methodology assesses the environmental impact of a good or service throughout its life cycle, from extraction of raw materials to disposal. LCA can be used to assess the environmental impact of the development, use, and disposal of autonomous cars and the energy source that powers them. In addition to LCA, the following alternative approaches can be used: 1. Cradle-to-Cradle (C2C) certification that assesses the sustainability of a product' or service' based on its impact on the environment and society throughout its life cycle. The main objective is to produce goods that can be recycled repeatedly or used in new ways without losing quality or value. 2. Environmental Product Declarations (EPDs) are standardized, validated documents that detail how a product or service affects the environment over the course of its entire life cycle. It contains details on GHG emissions, energy use, and waste production.

Greenhouse Gas (GHG) emissions: GHG emissions are a key metric for measuring the environmental impact of transportation. In the case of autonomous vehicles, GHG emissions can be calculated by estimating the energy consumption and emissions from the production and operation of the vehicles. Methodologies like the Global Warming Potential (GWP) method or the Carbon Footprint method can be used to quantify GHG emissions. There are additional methodologies to measure GHG emissions such as the Intergovernmental Panel on Climate Change (IPPC) Guidelines and the Greenhouse Gas Protocol.

Energy consumption: Another important aspect in estimating the environmental impact of autonomous vehicles is energy consumption. The amount of energy consumed by autonomous vehicles will vary depending on the type of vehicle, the way it is driven, and the energy source that powers it. This analysis can take into account the energy needed to produce materials, manufacture cars, and transport them, as well as the energy needed to charge or refuel the vehicles while they are in use. The environmental impact of various vehicle types, such as those driven by gasoline, electricity, or hydrogen fuel cells, can be compared using energy consumption analysis. This type of study is crucial because it sheds light on the energy needs of autonomous vehicles and can guide the creation of more environmentally friendly technology and regulations. Methodologies like the Well-to-Wheel (WTW) method or the Tank-to-Wheel (TTW) method can be used to measure energy usage.

Air quality: Pollutant emissions from autonomous vehicles, such as particulate matter and nitrogen oxides (NOx), can have an influence on air quality (PM). Methodologies like the Air Quality Index (AQI) or the National Ambient Air Quality Standards (NAAQS) can be used to calculate the effect of autonomous vehicles on air quality.

Noise pollution: Via their operation, autonomous vehicles can also contribute to noise pollution. Methodologies like the Sound Exposure Level (SEL) or the Community Noise Equivalent Level (CNEL) might be used to quantify how autonomous vehicles affect noise pollution.

Simulation-based analysis: The process of simulation-based analysis includes building digital representations of autonomous vehicle behavior and environmental effects. These simulations can be used to test various hypotheses and evaluate how various autonomous car technology and regulations will affect the environment. Simulation models, for instance, can be used by academics to assess how changes in road infrastructure, traffic patterns, or vehicle speeds affect the environmental performance of autonomous vehicles. The performance of various vehicle types, including electric and hydrogen fuel cell vehicles, can also be evaluated using simulation models. The benefit of simulation-based analysis is that it eliminates the need for costly and time-consuming field studies by allowing researchers to examine various scenarios in a controlled setting.

Vehicle emissions testing: In vehicle emissions testing, emissions from autonomous vehicles are measured under various driving circumstances, including various speeds, driving styles, and weather conditions. Carbon dioxide (CO2), nitrogen oxides (NOx), particulate matter (PM), and other pollutants can all be included in the emissions monitored. On the basis of the findings, the environmental impact of driverless vehicles may then be calculated. For instance, researchers can compare the environmental effects of gasoline-powered autonomous vehicles with those of electric or hydrogen fuel cell vehicles using emissions testing. Emissions testing is significant because it offers precise information on the real-world effects of autonomous vehicles on the environment.

Clearly, there are other methods and measures to evaluate the impact on the environment; as technologies continue to evolve, more methodologies will arise, achieving a better estimation of the impact of new technologies in the environment.

A4.2. Overall concept

The overall concept of the environmental impact assessment within the framework of the AWARD project is centered on scrutinizing and evaluating diverse dimensions of environmental impact, primarily focusing on the logistics sector. Unlike previous analyses, which often concentrated on passenger vehicles, AWARD seeks to comprehensively address environmental impacts in the local (air pollution, noise), global (GHG emissions), and indirect (congestion, land use) domains. This assessment encompasses six distinct sections, including energy, health, greenhouse gas emissions, nuisances, and vehicle behaviors.

The dimensions of the assessment are explored through a comparative analysis, utilizing data from the baseline situation of conventional non-automated logistics and the scenario during project implementation. Notably, the assessment distinguishes between conventional manually operated vehicles and automated and electrified vehicles, concentrating solely on the usage phase.

While acknowledging the potential benefits of autonomous vehicles in optimizing driving operations and planning, the assessment recognizes the uncertainty regarding their effects on greenhouse gas emissions. Factors contributing to emissions reduction, such as eco-driving and platooning, are weighed against those increasing emissions, such as easier and faster travel. The environmental impact assessment aims to capture high-impact factors relevant to AWARD through test site experiments and data logging, focusing on key dimensions like energy, health, greenhouse gas emissions, nuisances, vehicle behavior, and other indirect effects like land use and traffic jams. The assessment methodology remains consistent with conventional manually operated vehicles, considering vehicles as "complex systems," and evaluates global impacts. Detailed emissions information will be obtained through relevant sensors or estimated via surrogate measures and literature models, emphasizing clarity and accuracy across different dimensions.

A4.3. Research questions and PIs

Aligned with the strategic framework outlined in D7.4, our focus was on addressing precise research inquiries delineated during the initial planning phase. These inquiries, detailed in the Appendix Table 3 presented below, served as the foundational basis for our research, efficiently directing and molding our investigative endeavors.

Appendix Table 3: Research hypothesis priorities

ID	RQs	Refined hypothesis	Priority
EN-1	What is the impact of Autonomous & electric logistics on energy share & consumption?	Autonomous & electric logistics reduces energy consumption	High
EN-2		Autonomous & electric logistics improves energy efficiency	Medium
EN-3		Autonomous & electric logistics improves the share of renewable energy	Medium
EN-4	What is the direct impact of Autonomous & electric logistics on health?	Autonomous & electric logistics reduces air pollution	High
EN-5	What is the direct impact of Autonomous & electric logistics on greenhouse gases emissions?	Autonomous & electric logistics reduces the impact on climate change	High
EN-6	What is the direct impact of Autonomous & electric logistics on other nuisances?	Autonomous & electric logistics reduces traffic noise	Medium
EN-7	What is the indirect impact of Autonomous & electric logistics on environment?	Autonomous & electric logistics reduces traffic jams	High
EN-8		Autonomous & electric logistics reduces land parking needs	Medium
EN-9		Autonomous & electric logistics reduces the stay of ships in ports and related fuel consumption	Medium
EN-10	What is the impact of Autonomous & electric	Autonomous & electric logistics reduces brake wear	High

EN-11	logistics on vehicle's behavior that could have an indirect effect on the environment & health?	Autonomous & electric logistics reduces exhaust emissions (through smoother driving behavior)	Medium
EN-12		Autonomous & electric logistics reduces tire wear	Medium
EN-13		Local emissions versus global emissions (including construction phase, and recycling phase-life cycle)	Low

To validate these research hypotheses, we must employ experimental setups along with an appropriate data collection procedure. The development of an experimental plan hinges on defining the specific data requirements. These needs should stem from the hypotheses, contingent upon our ability to connect them to a performance indicator (PI) capable of measuring the targeted factor or behavior.

Appendix Table 4: Performance indicators linked to the hypothesis

ID	Hypothesis	Linked performance indicators
EN-1	Autonomous & electric logistics reduces energy consumption	– Volume of fuel (or total energy) consumed per unit distance per unit mass of cargo transported; e.g., l/100 kg·km or MJ/t·km (To be computed from similar period).
EN-2	Autonomous & electric logistics improves energy efficiency	– Distance per vehicle per unit energy; e.g., miles per gallon equivalent (mpg-e).
EN-3	Autonomous & electric logistics improves the share of renewable energy	– Percentage of renewable energy sources (%)
EN-4	Autonomous & electric logistics reduces air pollution	– Emissions of air pollutants (Tailpipe, brakes, tires): – PM 10 levels (ug/m3); PM2.5 levels; NOx, Sox, CO, O_3, emissions – In case of unavailability of the adequate sensors, use models instead (from the literature if any exist) or surrogate measures (driving behavior, see EN-11)
EN-5	Autonomous & electric logistics reduces the impact on climate change	– GHG emissions: CO_2, N_2O, CH_4
EN-6	Autonomous & electric logistics reduces traffic noise	– Average traffic noise (dB), noise level, number of people exposed to noise levels
EN-7	Autonomous & electric logistics reduces traffic jams	– Average Traffic queue length per day
EN-8	Autonomous & electric logistics reduces land parking needs	– Total land parking surface
EN-9	Autonomous & electric logistics reduces the stay of ships in ports and related fuel consumption	– Average duration of the parking time (duration of stay in port)

EN-10	Autonomous & electric logistics reduces brake wear	– Deceleration rate of braking (ms^{-2}) – Average deceleration rate of braking – Braking distance – Braking time – Initial speed when braking – Average initial speed when braking
EN-11	Autonomous & electric logistics reduces exhaust emissions (through smoother driving behavior)	– Aggressiveness (% of time in acceleration >0.9 ms^{-2}) – Average acceleration – % of time in speed interval of 20–50 km/h – Average speed – Average driving speed without stops – % of time in deceleration interval of -0.9 to 0 ms^{-2} – Average deceleration
EN-12	Autonomous & electric logistics reduces tire wear	– Deceleration rate when right braking – Acceleration rate when right accelerating
EN-13	Local emissions versus global emissions (including construction phase, and recycling phase-life cycle)	– Automation may have collateral positive effects (side effects) that may improve efficiency of the overall system – Rebound effect, improvement of efficiency may increase the demand (like robots working day and night)

A5. Stakeholders and users impact assessment

A5.1. Literature review

With the growing presence of automated driving technologies, the issue of users' and stakeholders' acceptance of new technologies in the context of logistics operations emerges as crucial. This section provides a brief overview of key factors that should be considered in investigations of human factors, such as user interface requirements and acceptance, in the context of automated logistics operations.

User interface for teleoperation: Teleoperation holds promise for automated vehicles, allowing humans to intervene when needed. However, the physical separation between operator and vehicle creates challenges for user interface (UI) design. This physical separation impacts user perception and awareness, requiring UIs that effectively bridge the gap.

Research explores various teleoperation design concepts, like direct and shared control, each influencing UI design and information presentation for successful task management. Additionally, UI/HMI proposals aim to improve the experience by using well-designed elements to enhance situation awareness and task allocation during remote vehicle operation.

Despite these advancements, a comprehensive set of validated design recommendations remains elusive due to limited real-world studies. Research hasn't fully integrated UI design with the broader teleoperation system, hindering user-centered solutions. The work conducted in the context of this task, precisely the evaluation of HMI design for AGTS fleet management, aims to bridge this gap, paving the way for validated recommendations and a more seamless teleoperation experience.

Technology acceptance: Researchers have developed technology acceptance models (TAM, TAM2, TAM3, UTAUT) to understand user adoption of new technologies. These models identify core factors like perceived usefulness, ease of use, and behavioral intention to use, with TAM extensions including social norms and experience.

The UTAUT model integrates concepts from various models for a broader understanding. In the context of automated vehicles, the C-TAM model incorporates trust within the UTAUT framework, while the ARTLAM model, developed within the AWARD project with the goal of capturing a greater range of nuances of technology acceptance, builds on these models and identifies perceived usefulness, job relevancy, social dimension, and perceived safety as key factors for automated road transport logistics acceptance.

ARTLAM further extends trustworthiness, facilitating conditions, and situational constraints to provide a comprehensive framework for user acceptance in this specific context. These models emphasize the importance of considering a range of factors beyond just usability when assessing user acceptance of new technologies.

A5.2. Overall concept

This task is related to T2.2 (D2.2) from which the user and stakeholder requirements were derived. Furthermore, the work carried out in this task is aligned with the framework outlined in T7.4 (D7.4). Finally, this task integrates the lessons learned in T5.3 regarding HMI design for fleet management systems. The goal of this task is to assess users' and stakeholders' acceptance of and experiences with the core technologies employed to automate logistics operations. As the relevant technologies used in the AWARD project are diverse and with a broad range of purposes, it is important to capture stakeholders' experiences across different interaction domains.

To achieve this goal, four main investigations phases were carried out with different formats:

- A broad identification and evaluation of acceptance factors across use cases, stakeholder and user groups by means of surveys and interviews.
- Iterative evaluations of HMI (human–machine interface) designs.
- Investigations within the specific context of the pilots' sites.
- Investigation of potential users' perception and acceptance of automated vehicles and operations by means of a widely spread survey.

A5.3. Used method

Contextual evaluation of AGTS and work environment at the pilot site

Due to COVID-19 restrictions, a hybrid approach to pilot site visits was employed, allowing both on-site and remote participation for stakeholders across the project's four use cases. This facilitated understanding of sites' working environments, engagement, and identification of potential participants for the AGTS acceptance evaluation (interviews & surveys).

The hybrid format offered flexibility, enabling stakeholders from each use case (except the port) to participate either in-person for a more immersive experience or virtually through tours. This allowed for familiarization with the site context and specific user requirements for each use case (e.g., understanding traffic flow patterns for a logistics use case). While on-site visits provided firsthand insights into physical layout, movement of vehicles/personnel, and real-time interactions, the virtual option ensured information accessibility in noisy environments. This hybrid approach facilitated comprehensive workflow observation without disruption.

The evaluation confirmed the value of on-site participation for spontaneous interactions and in-depth understanding of use case specifics. However, the hybrid approach also proved beneficial in overcoming logistical challenges associated with COVID-19 restrictions.

Evaluation of HMI design for AGTS fleet management

To evaluate HMI design for fleet management, a user study was designed and conducted. A teleoperation environment was developed with two UI versions: minimal (essential elements) and maximal (all prioritized requirements). These interfaces were presented to logistics experts who validated their relevance and helped prioritize features. The final set of 36 requirements was implemented as UI elements and integrated into a virtual reality simulation framework for user testing. The UI design included various elements like camera feeds, status displays, navigation information, environment awareness indicators, and assisted driving visualizations. All interfaces were presented simultaneously within the simulation environment for user evaluation.

The user study utilized an extended reality (XR) setup with a physical steering wheel, pedals, and a miniature vehicle in a physical environment. The operator wearing an XR headset remotely controlled the miniature vehicle in another room, receiving information through four camera feeds and displaying UI elements as floating virtual panels. The XR environment allowed for flexible UI placement and the miniature vehicle enabled realistic driving experience with potential for errors. Sensors on the vehicle provided real-time data like proximity to objects.

The user study design employed a within-subjects experiment with 16 participants. They experienced both minimal and maximal UI versions in easy and challenging driving environments. A combination of qualitative (questionnaires, interviews) and objective measures (eye tracking, task completion time) were used to assess user experience, workload, and performance.

Investigation of overall user and stakeholder acceptance of AGTS

This task addresses the gap in understanding how various logistics stakeholders across different categories and locations perceive the key technologies employed in the AWARD project. Specifically, this task investigates:

Stakeholder Acceptance: For this study, we used the ARTLAM model to understand factors influencing how logistics stakeholders accept new technologies.

Human-Machine Interface (HMI) Requirements: The study explores user needs for interfaces controlling remote operations, such as fleet management systems (FMS).

Impact of Harsh Weather: The research addresses the often-overlooked challenge of harsh weather conditions on automating logistics operations.

To gather data, semi-structured virtual interviews were conducted with participants across two rounds between 2023 and 2024. The interviews included a 5-point Likert scale survey with 34 items and open-ended questions. Participants also viewed three videos showcasing various functionalities of the FMS related to task planning, weather information, and issue resolving. After each video, participants were asked one question about these functionalities.

28 stakeholders recruited from among the project partners participated in the study. They were recruited strategically to represent five stakeholder categories (as defined in T2.2) and experience with one of the four project use cases, the related vehicles and operation modes (manual, remote, autonomous).

During the interviews, participants were asked to imagine themselves as logistics managers overseeing a fleet of autonomous vehicles. They then viewed videos demonstrating FMS functionalities related to task planning, weather information, and issue resolving. Following the videos, participants completed a questionnaire with eight sections aligned with the ARTLAM model, each section focusing on a specific aspect of technology acceptance. They rated statements on a Likert scale and answered open-ended questions (two per section) referring to positive expectations and concerns in relation to the specific topic of each section.

Widespread survey on technology acceptance and perception among potential users

This task aims to gather insight into the public's perception on the core technologies required to automate logistics operations, particularly automated vehicles. Importantly, the aim to capture the public perception of these technologies extends, at least in part, beyond their application in the logistics domain. This goal was pursued by means of a short survey to be spread by project partners through their networks. A total of 254 responses were collected using LimeSurvey between the end of January and May 2024.

To collect these observations, after giving their explicit and informed consent, participants had to watch a short video of one of the vehicles employed in the AWARD project driving autonomously on an open road. The video also had a background narration briefly explaining the challenges and potential benefits of autonomous technologies. After watching the video, participants were asked to answer a series of 13 5-point Likert scale questions focused on the potential usefulness and benefits deriving from the adoption of these technologies, as well as their perceived reliability, safety (for operators and other road users), security, predictability, trustworthiness, impact on the job market, and overall acceptance. The structure of the survey was closely informed by the ARTLAM model. The last question was open, non-mandatory, and it asked participants for any further concerns, expectations, or considerations on future developments of automated vehicles.

Closing the procedure, participants were asked a set of standard demographic questions (gender, age, nationality), as well as 5-point Likert scale question to self-assess their expertise in the context of automated vehicles, and their involvement (or lack thereof) in the AWARD project.

A5.4. Research questions and PIs

The final objective of the user and stakeholder evaluation is to determine the impact of the developed technology on the stakeholders' experience and acceptance within the specific context of the project pilot sites.

For each of the different activities within the cycle of human AGTS fleet operation, a set of research questions for comparative user interface evaluations has been defined:

- Refocus attention:
  - Which HMI techniques should be used to gain attention of operators working in different contextual environments?
  - How should notifications be designed not to distract the operators from their respective main activities?
- Achieve global situation awareness:
  - Which information should be provided in a user interface, in order to make users quickly understand the overall situation of a remote vehicle?
  - How can decisions be supported on what to do next (e.g., whether to intervene immediately, postpone the intervention or hand over to another person)?
- Achieve local situation awareness:
  - Which user interface design elements support spatial situational awareness, i.e. indicate the position, heading and surroundings of the vehicle?
  - Which user interface design elements assist users best in assessing the state of the vehicle?
- Remote driving:
  - Which features must be displayed in the HMI for successful teleoperation, in scenarios with different levels of complexity?
  - Do information items only require temporary visualization? When are these needed by the user to successfully complete the task (before, during, after)?
  - Does immersive technology (e.g. virtual reality, VR, and moving bases) increase the quality of the teleoperation task?
  - Can a visual mission briefing at the beginning of the journey adequately prepare an unprepared operator for the via teleoperation?
- Preparation for new task:
  - Which features help to bring operators up to speed again to their previous task?
- What is the influence of the designed AGTS on work processes?
- How is efficiency of work processes perceived by workers and managers?
- How are safety, security and reliability perceived?
- How does the fleet management interface impact situational awareness?
- Acceptance:
  - What are the main factors contributing to acceptance of AGTS?
  - In what respect do stakeholder groups differ regarding acceptance?
  - In which regard do the different use cases differ regarding acceptance?

A5.5. Main findings

Hereby, we report the main findings from the studies conducted to capture stakeholders' and users' experience with and perception of the relevant technologies employed in the project.

Evaluation of HMI design for AGTS fleet management

Findings for this study must be described according to the two phases of the study, orientation and navigation.

Concerning the orientation phase, eye tracking and questionnaires were used to assess the usefulness of each UI element. Results show that participants focused most on the vehicle's status and the loaded cargo, as highlighted by both high dwell times and reported usefulness. Other elements like weather and light controls were not looked at for long and usefulness ratings were low. The speedometer and navigation system were also not essential in this phase. Furthermore, the task information caused perceived stress due to time pressure. Interestingly, participants tended to fixate on UI elements located on the left side of the screen first.

Concerning the navigation (driving) phase, task completion time, user experience (UEQ+), workload (NASA-TLX), and perceived usefulness of each UI element were investigated. Here, the analysis shows a trade-off between UI complexity and task completion time. While the full UI (MAX) provided more information, this also resulted in longer navigation times. Interestingly, people using the basic UI also speed more often despite having the speedometer. The NASA-TLX showed that difficulty level had a greater impact on both workload and task completion time. However, the complexity of the UI did not impact the workload.

User experience remained positive across all conditions (interface complexity and difficulty) as measured by the UEQ+ questionnaire. However, slightly higher ratings for "Usefulness" and "Trustworthiness" were assigned to the full UI (MAX). Specific UI elements like cameras, navigation system, lane guidance, objects' proximity, and the speed limit were most valuable during navigation, while information reviewed earlier (vehicle status, cargo) became less important.

Among possible improvements, more detailed vehicle status information (also to predict potential problems) emerged. While weather information did not emerge as crucial (i.e., the weather conditions were static), it is likely important in real-world situations. The task information was seen as confusing and not essential for the navigation tasks. Finally, another improvement could concern the way the information was laid out on the screen, for instance by grouping things together based on whether they're needed during orientation or navigation.

Investigation of overall user and stakeholder acceptance of AGTS

Findings of this study are grouped according to the main code categories that emerged from the qualitative analysis.

Technology Features and Human-Machine Interaction: Participants were optimistic about the potential of remote and autonomous logistics for improving efficiency and safety. They foresaw these technologies leading to better planning, fewer accidents, and increased productivity. However, concerns arose about reliability and safety, particularly in harsh weather or unforeseen circumstances. Users emphasized the need for better user interface design and clear communication between human operators and the machines. Ideally, human-machine interaction would provide operators with a good situational awareness to plan operations safely and intervene when necessary.

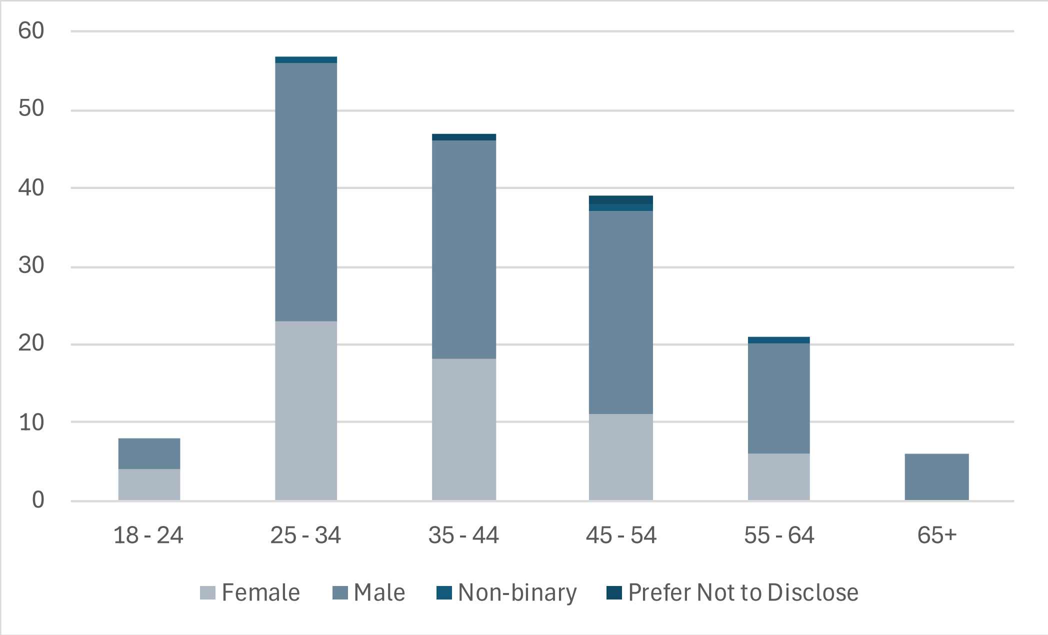
Fleet Management System Design: The design of the Fleet Management System (FMS) directly affects human-machine interaction. Participants offered mixed feedback on the current system. While some found it user-friendly and helpful for planning and monitoring, others considered it complex. Regardless of their initial impression, most participants agreed that the FMS should provide operators with clear information about the vehicles' status, tasks, and surrounding environment. Features like camera views and real-time weather data and forecasts were seen as crucial for effective remote operation.

External Enabling Factors: Beyond the technology itself, successful adoption hinges on various external factors. Supportive regulations, employee training, and adequate infrastructure are all essential. Participants highlighted the urgency for regulations to catch up with the pace of technological development, particularly in Europe where safety standards are high. Training programs are crucial to prepare the workforce for the changing landscape of logistics operations. Finally, proper infrastructure, such as distributed cameras and intelligent traffic lights, can optimize operations and integrate autonomous vehicles into existing transportation networks.

Public Response and Acceptance: Public acceptance of remote and autonomous logistics is a major concern. Participants expressed mixed feelings, with many anticipating a transition phase as the technology proves its worth. Job losses due to automation were a major point of discussion. While some feared widespread unemployment, others saw an opportunity for creating new and better jobs through employee retraining. Clear communication about the technology's benefits and its impact on jobs was seen as essential to overcome public resistance. Interestingly, environmental impact was not a major concern for participants, as automating processes were not seen as crucial in that regard as, for instance, vehicles' electrification.

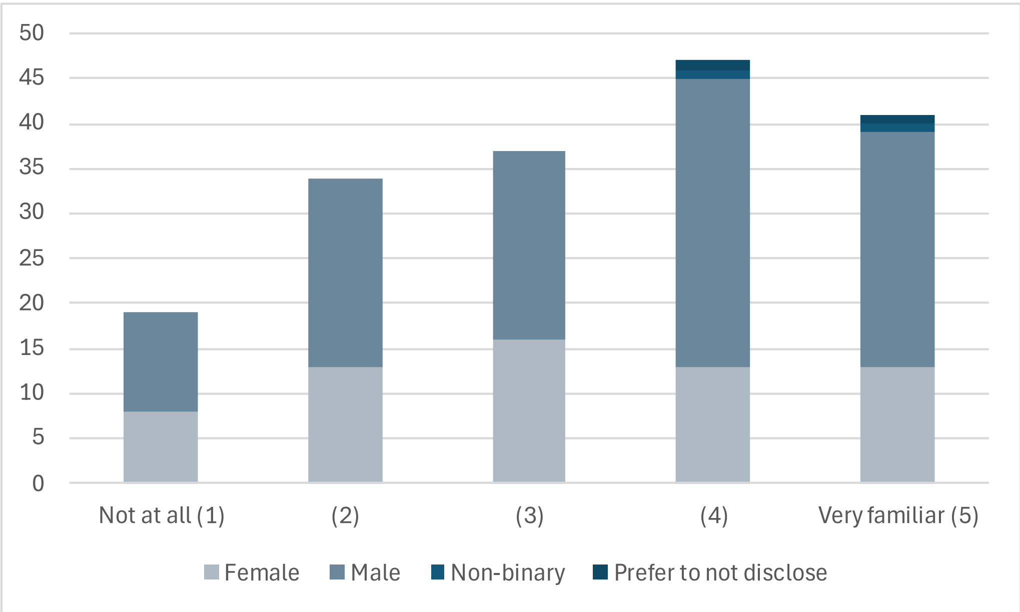
Widespread survey on technology acceptance and perception among potential users

Hereby, we briefly describe the main survey findings. Of the 254 observations, 178 were complete and used for the analysis. The nationalities of the respondents were mostly French (53%) and Austrian (20%), with the remaining responses distributed across a variety of countries. Regarding the gender of the participants, about two-thirds were male (n=111) and one-third were female (n=62), with a small number specifying non-binary or not providing their gender. As illustrated in Appendix Figure 1, the age of the participants was spread across all age groups. However, the younger age groups were noticeably larger.



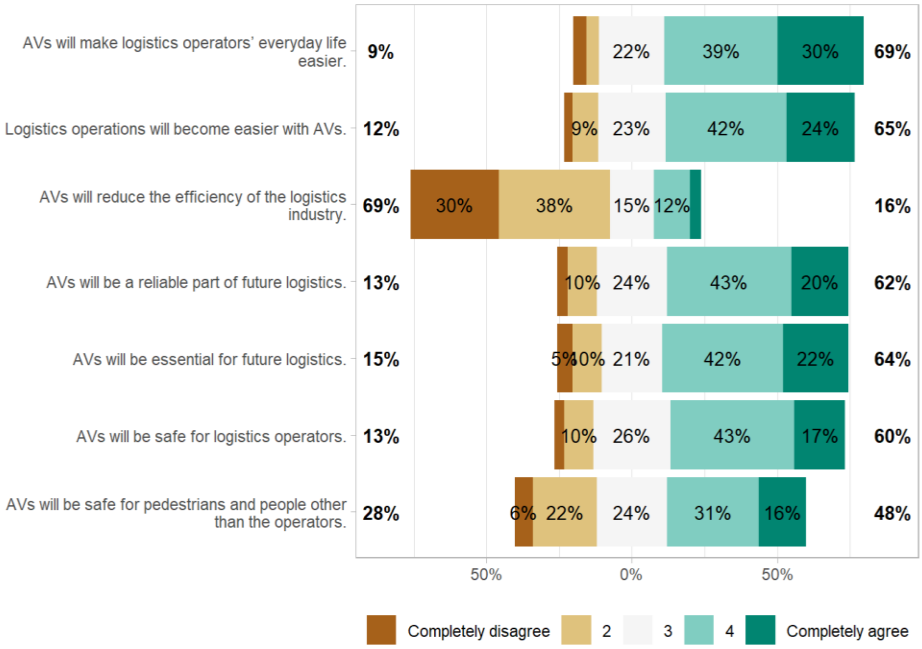
Appendix Figure 1: Age and gender of participants

As Appendix Figure 2 illustrates, responses regarding familiarity with automated vehicles showed a distribution across the entire spectrum. Most of the respondents were familiar with AVs.

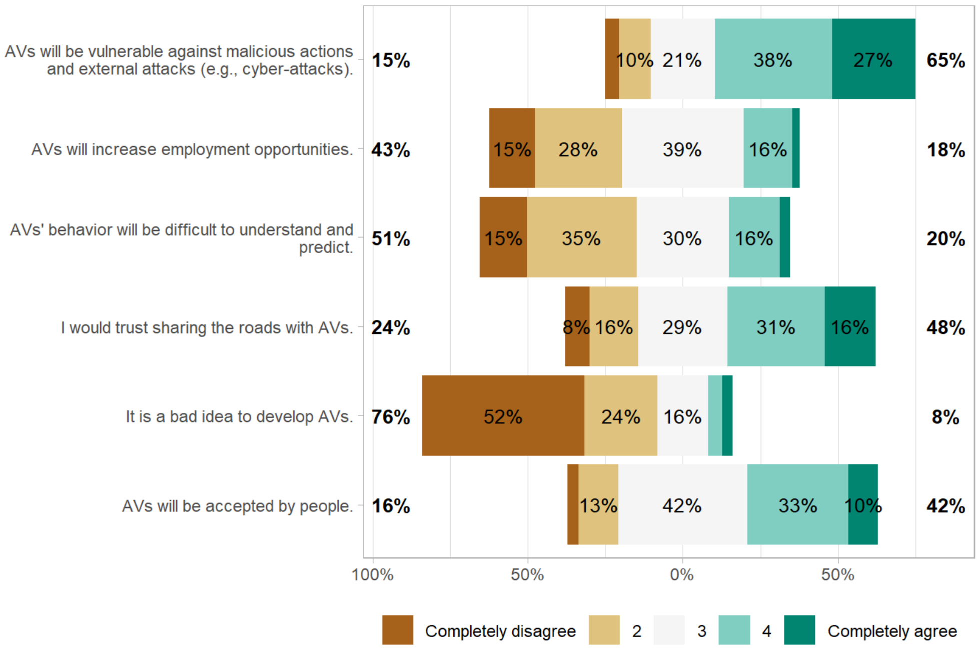


Appendix Figure 2: Familiarity of participants with AVs

Approximately one-fifth of the participants had a connection to the AWARD project. Appendix Figure 3 and Appendix Figure 4 show participants' responses (from completely disagree to completely agree) to different statements regarding the effects of automated vehicles on different aspects.



Appendix Figure 3: Participants' evaluation of the effect of automated vehicles (first part)



Appendix Figure 4: Participants' evaluation of the effect of automated vehicles (second part)

Summary scores for selected related items, derived from the ARTLAM Model were calculated. The resulting dimensions are ease of use, perceived usefulness, safety, security, effects on employment, trust and acceptance. The summary scores were calculated so that higher numbers must be interpreted as more positive results towards AVs.

Overall, the expectations regarding the effects of AV were more towards the positive side on most dimensions. We found negative correlations between age and trust ($r= -0.15$, $p = < 0.05$). This implies that the older the respondents, the lower the trust towards AVs.

Positive correlations were found between age and security ($r = 0.16$, $p = < 0.05$), familiarity with AVs and ease of use ($r = 0.21$, $p = < 0.01$), perceived usefulness ($r = 0.21$, $p = < 0.01$), safety ($r = 0.32$, $p = < 0.001$) effects on employment ($r = 0.16$, $p = < 0.05$), trust ($r = 0.24$, $p = < 0.001$) and acceptance ($r = 0.17$, $p = < 0.05$). Concerning security, the results show that the older participants were, the less vulnerable to malicious actions they considered the AVs to be. The other results indicate that the more familiar the respondents were towards AVs, the higher was their perception about the ease of use, usefulness, safety, employment opportunities, trust and acceptance of AVs.

The ratings on the different dimensions are very similar in the different gender and age groups, no noticeable patterns can be detected.

Some relevant observations also emerged from participants' answers to the open question. As this was not a mandatory question, not all participants answered. In total, 79 answers were collected and analyzed. The main insights are hereby reported. In general, the main topics that emerged from their answers loosely reflect the structure of the survey and the ARTLAM model.

Safety, security, and reliability were considered top priorities. Particularly, several participants brought up questions and doubts about how AVs will handle mixed traffic situations alongside human drivers, as well as detect pedestrians. Their ability to perform reliably in all weather conditions was also questioned. Then, concerning security, the main hurdle identified by participants concerned their susceptibility to hacking. Taken together, these challenges demand significant investments to be made to ensure not only that AVs are deployed when truly mature, but also that their potential in terms of efficiency and usefulness can be fully realized.

Public acceptance was an important part of the survey and participants brought it up repeatedly. Among the main points, they stressed how communication, for instance about data protection, AVs' safety and potential to improve transportation efficiency, is crucial to develop trust. Participants also highlighted how potential losses of jobs in the transportation sector due to automation will play a key role in shaping acceptance. They also expressed mixed feelings about the environmental impact of AVs. While some believed AVs will lead to a more efficient transportation system, others were concerned about energy and resource (e.g., rare materials) consumption.

Regarding supporting conditions, participants identified infrastructure upgrades as a key enabler for AVs' efficiency potential. These include smart roads and standardization of street signs. Regulations, clear legal frameworks around accidents and liability, and standardized protocols across national borders and industries were also deemed crucial.

Overall, participants expressed cautious optimism about AVs' potential to revolutionize transportation, not only in the context of logistics operations, but also in terms of broader adoption. However, the various challenges and concerns regarding safety, security, privacy, environmental impact and so on need to be promptly addressed for AVs' successful integration into society.

A6. Scaling up

In this section dedicated to Scaling up, our strategy entails a thorough examination of the obtained outcomes, commencing at the business level and extending towards broader geographical dimensions. Initially, we conduct a detailed statistical analysis pertaining to specific business categories, scrutinizing their prevalence within distinct geographic entities, including cities, countries, the European region, and globally. Subsequently, the scaling-up process is initiated by multiplying these findings by the number of enterprises in each respective geographic unit. This strategic step is designed to efficiently extrapolate the impact assessment results to larger contextual frameworks.

To enact a robust scaling-up methodology for impact assessment outcomes across varying scales, an array of established approaches is at our disposal. One notable methodology involves the integration of bottom-up results derived from GIS-based models. This integration serves to characterize and assess factors such as building stock energy performance at the city level, providing a resilient foundation for assessments on a broader scale [8]. Additionally, GIS modeling proves instrumental in scaling up sustainability assessments from neighborhood to city levels, as exemplified in the context of LEED-ND assessments [9].

Through the adept utilization of GIS and other pertinent methodologies, our approach remains systematic and data-driven, ensuring the effective scaling up of impact assessment results with precision and dependability across diverse geographical extents.