MAGPIE

SMART GREEN PORTS

Demo 9. Green Connected Trucking:

Automated driving & hands-free charging of trucks

Funded by
the European Union

This project has received funding from the European Union's Horizon 2020 (MFF 2014-2020) research and innovation programme under Grant Agreement 101036594

contact@magpie.eu +33 2 35 42 76 12 www.magpie-ports.eu

DEMONSTRATION REPORT ON AUTOMATED DOCKING FOR RECHARGING OF ELECTRIC HEAVY TRUCKS D6.3

GRANT AGREEMENT NO.	101036594
START DATE OF PROJECT	1 October 2021
DURATION OF THE PROJECT	60 months
DELIVERABLE NUMBER	D6.3
DELIVERABLE LEADER	DAF
DISSEMINATION LEVEL	PU
STATUS	V1.0 full report for review
SUBMISSION DATE	7-2-2026
AUTHOR	DAF Trucks, Port of Rotterdam, APM Terminals, TNO, Eindhoven University of Technology, Fraunhofer IVI, Rocsys

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036594.

PU=Public, CO=Confidential, only the members of the consortium (including the Commission Services), CI=Classified, as referred to in Commission Decision 2001/844/EC.

Modification Control

VERSION #	DATE	AUTHOR	ORGANISATION
V0.1	10-06-2025	Guus Arts and team	DAF and others
V1.0	08-09-2025	Guus Arts and team	DAF and others

Release Approval

NAME	ROLE	DATE
Maarten Flikkema	Peer-reviewer	09-09-2025
Jaap de Wilde	Peer-reviewer	12-09-2025
Gunnar Platz	WP Leader	30-01-2026
Arne-Jan Polman	Project Coordinator	3-2-2026

History of Changes

SECTION, PAGE NUMBER	CHANGE MADE	DATE
		DD-MM-YYYY
		DD-MM-YYYY
		DD-MM-YYYY
		DD-MM-YYYY

1. Table des matières

Executive Summary

This document presents the results of a technical demonstration conducted under the MAGPIE project, showcasing the integration of automated driving and hands-free charging for electric heavy-duty trucks. The demonstration, held on April 10, 2025, at APM Terminals Maasvlakte II in Rotterdam, illustrates a significant step toward sustainable and efficient logistics operations in port environments.

The purpose of this report is to share insights into the development, implementation, and evaluation of a system where an electric truck autonomously navigates to a charging station, connects to a robotic charger without human intervention, and continues its mission after recharging. This hands-free charging process, developed by Rocsys and integrated with a DAF automated truck, demonstrates how automation can reduce downtime, improve safety, and support flexible energy use—such as charging during off-peak hours.

This demonstration aligns with the broader goals of the MAGPIE (sMArt Green Ports as Integrated Efficient multimodal hubs) project, which is co-funded by the European Union's Horizon 2020 program. MAGPIE aims to accelerate the decarbonization of port-related transport through smart, green, and digital innovations. The automated trucking and charging system is one of ten key demonstrations within MAGPIE, contributing to the project's mission to create scalable, interoperable solutions for future logistics.

The system architecture demonstrated in the MAGPIE project integrates several core components developed by leading partners. Fraunhofer IVI contributed the open-source helyOS framework, which forms the backbone of the Remote Vehicle Operation System (RVOS) responsible for mission planning, dispatching, and monitoring. Eindhoven University of Technology provided advanced localization and high-definition mapping technologies, enabling precise vehicle positioning within the yard. DAF led the development of the vehicle, overall integration and safety protocols, ensuring secure operation and human oversight. TNO played a key role in designing and implementing the dispatcher logic and remote monitoring systems, enabling real-time mission control and safe execution of automated tasks. Together, these components form a robust and scalable architecture for automated electric trucking and hands-free charging in port logistics.

During the live demonstration, the vehicle successfully executed a full mission—from dispatch to charging and parking—without manual intervention, supported by real-time monitoring and robust communication between vehicle and control systems. The event was attended by stakeholders from industry, government, and academia, highlighting the collaborative nature of the MAGPIE initiative.

Looking forward, the MAGPIE project envisions broader applications of the technology in port logistics, industrial zones, and hub-to-hub transport corridors. These innovations are being further developed in related initiatives such as the Dutch CAT4YARDS and European MODI projects, which build on MAGPIE's outcomes to explore automated transport on public roads and across international corridors.

In conclusion, this report underscores the transformative potential of automation in logistics. By integrating vehicle automation with robotic infrastructure, MAGPIE sets the stage for safer, cleaner, and more efficient transport systems—supporting Europe's transition to smart green ports and sustainable mobility.

2. Introduction

2.1 Scope

A significant advancement that can accelerate and enhance the operation of electric heavy trucks is automated transport. Since charging an electric heavy truck should neither disrupt transport logistics nor consume excessive time from the driver, it would be highly advantageous if trucks could recharge themselves autonomously at convenient times with minimal human intervention. Furthermore, to reduce peak demand on the energy grid, it is preferable for trucks to recharge during periods of low overall energy consumption—such as nighttime or when energy prices are lower.

Figure 1: The automated DAF truck and Rocsys hands-free charging system

Automated driving combined with robotic, hands-free charging presents a promising solution, as demonstrated in the MAGPIE project. This project showcased, at a container terminal in the port of Rotterdam, how an electric heavy truck can automatically navigate to a charging station, where a hands-free charging system recharges the vehicle. Once charging is complete, the truck moves to the designated parking spot, streamlining the entire process.

The overall system demonstrated in the MAGPIE project is built upon a collaborative integration of advanced technologies and expertise from multiple leading technology partners. The overall architecture consists of several key building blocks, each contributing essential functionality to enable safe and reliable yard automation.

2.2 Description

In the MAGPIE project a concept is developed to allow vehicles to perform automated tasks. Roughly the system can be separated in automation elements required on the vehicle and the elements that are remote as shown in **Fout! Verwijzingsbron niet gevonden.**. The remote elements can be used to instruct one or multiple vehicles through wireless communication.

The automated vehicle is capable to receive and interpret commands and translate these such that it can perform the automated driving assignment. On the remote side a Remote Vehicle Operation System (RVOS) is required to manage the operations of the automated vehicle. A fleet of vehicles and their individual assignments may be operated by multiple RVOS instances as part of a Remote Operation System. In addition, other acting elements may be coupled via this remote system. This can for instance be a Logistic Planning system for the yard environment or a connection to service elements with which interaction is required to support operation on the yard (e.g., yard services such as gates, chargers, cranes etc.). These yard services can be digital (e.g. checking in at the terminal), but may also contain physical elements such as gates. Additionally, it should be noted that some services may also be accessed directly by a vehicle without intervention of a central remote entity. An example is the hands-free charging system described in chapter 5. The truck can request this service 'on the spot'.

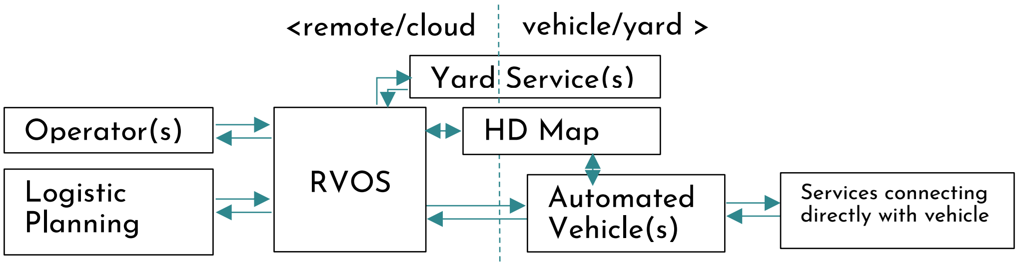


Figure 2: Simplified overview of the elements required for an automation system

Figure 2: Simplified overview of the elements required for an automation system shows on a high level the elements and interactions to take into account when designing an operational concept for a vehicle automation system. In MAGPIE the interactions between these elements are orchestrated by the RVOS of which the helyOS framework described in chapter 3 is an essential part. The RVOS concept has been demonstrated as part of the overall solution. More details on how missions are planned, dispatched and monitored can be found in chapter 4. Details on the developments done on the vehicle can be found in chapter 6. Chapter 7 describes how the vehicle translates the assignment from the RVOS to a driveable path. In order for the vehicle to localize itself, a highly detailed map, environmental perception sensors and accurate localization algorithm are required of which more details can be found in chapter 8.

3. HelyOS Framework

The helyOS framework, short for Highly Efficient Online Yard Operation System, is a prominent part of the aforementioned Remote Vehicle Operation System (RVOS). It was developed at Fraunhofer IVI with the goal of interconnecting automated vehicles with cloud-based planning services. In MAGPIE, the helyOS framework is used as centralized connector between remote services for dispatching, route- and path planning and the automated vehicle.

3.1 HelyOS framework: description

HelyOS is designed as an open and modular framework that enables developers to efficiently build Remote Vehicle Operation Systems with application-specific components without re-inventing the wheel. When deployed in the cloud, the main component, helyOS

Core, comes with mechanisms to handle the check-in of automated vehicles into delimited automation zones, or yards. Parameters such as kinematic configuration of the vehicle and properties of the yard are exchanged and the vehicle can send status updates for remote monitoring.

To generate and assign missions for automated vehicles, helyOS provides a modular, microservice-based architecture with clean, web-based application programming interfaces (APIs). As discussed in section 4, services such as a dispatcher logic, a route planner and a kinematic path planner are registered as microservices in the helyOS dashboard. Whenever the dispatchment logic triggers the creation of a new task, helyOS takes care of crafting a machine-executable mission by calling the required microservices in correct order according to a so-called mission recipe. As further elaborated in section 4 and 7, in MAGPIE, this includes the calculation of a route from a starting to a target position by the TNO route planner and the calculation of a feasible path along this route accounting to the kinematic constraints of the vehicle powered by Fraunhofer IVI. Eventually, the mission is sent to and executed on the DAF truck. This example clearly shows how helyOS allows to address complex use cases that involve software and hardware produced by various manufacturers. Its open-source licensing model and the compliance with standards such as VDA5050 advocate for true interoperability.

3.2 Scalability and application to other areas

The open, modular architecture of helyOS allows to use the framework in arbitrary scale and for a plethora of application areas.

Under the hood, the use of modern web-technology allows to connect single vehicles up to large fleets of automated vehicles. With well-defined interfaces to external services, helyOS can serve as some kind of application store, in which various providers can offer services for any specific application.

Besides for the automation of trucks in ports and logistics centres, helyOS has already been successfully used for the orchestration of automated buses in depots and for farming robots on agricultural fields.

Figure 3 illustrates the aforementioned options to combine cloud-based planning services (clouds) within mission recipes and depicts possible application scenarios with commercial vehicles and agricultural machinery, as well as examples for required modules on the vehicle side (hexagons).

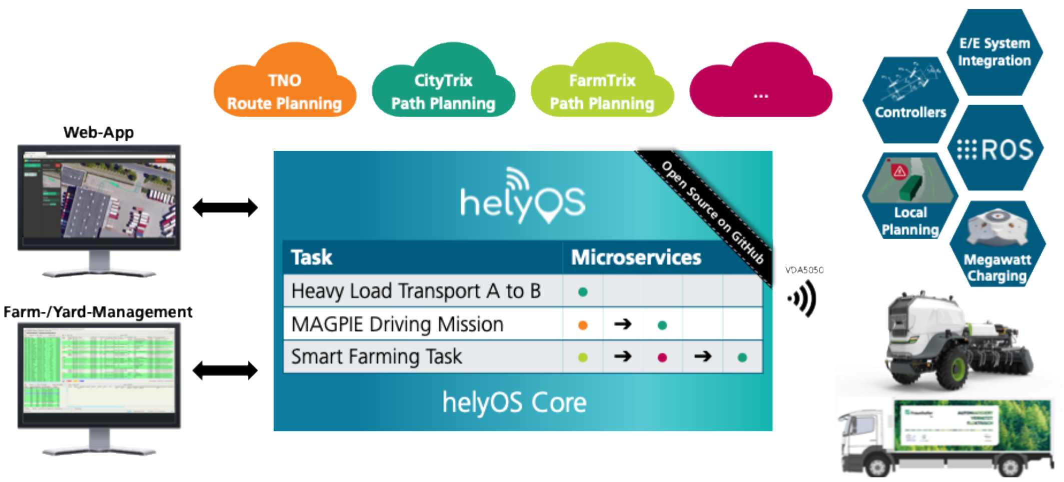


Figure 3: helyOS Architecture and Application Examples

4. Dispatching and monitoring

Automation of a single vehicle or an entire fleet requires effective remote management. Each automated vehicle must receive precise commands to successfully carry out its mission. This necessitates a system capable of fleet management, remote dispatching, and continuous remote monitoring. In the MAGPIE project, the primary focus has been on remote dispatching and monitoring, as detailed in the following sections.

4.1 Dispatcher

The dispatcher is the component of the system responsible for assigning missions to specific vehicles. These missions can vary in type, such as 'charging', 'docking', or 'parking'. Based on the mission specifics, each vehicle can adjust its strategy to effectively complete the assigned task. The dispatcher currently comprises a graphical user interface (GUI) and backend logic that integrates with helyOS (see Chapter 3) to send missions and retrieve vehicle and yard information (see Figure 4).

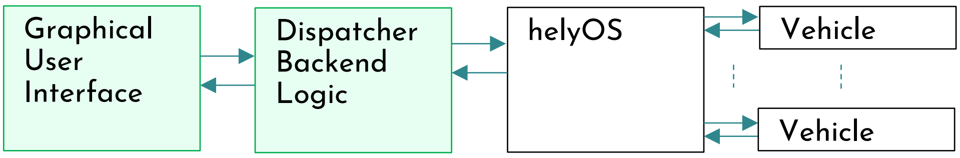


Figure 4: The position of the GUI and Dispatcher Backend Logic relative to the other system components

The Dispatcher Backend Logic retrieves yard information—including the map, destinations, vehicle details, and status—from the helyOS database and presents it on the graphical user interface (see Figure 5). The user interface and backend together enable the assignment of appropriate missions and their specific details. Vehicles and destinations can be selected directly by clicking on them within the interface. Each destination includes details such as orientation and action type, which the user can specify. Once configured, the mission can be dispatched with a single click. The interface also displays the yard map, highlighting the assigned vehicle's route in red. Users can track progress, mission status, and vehicle condition in real time, as well as cancel missions through the interface.

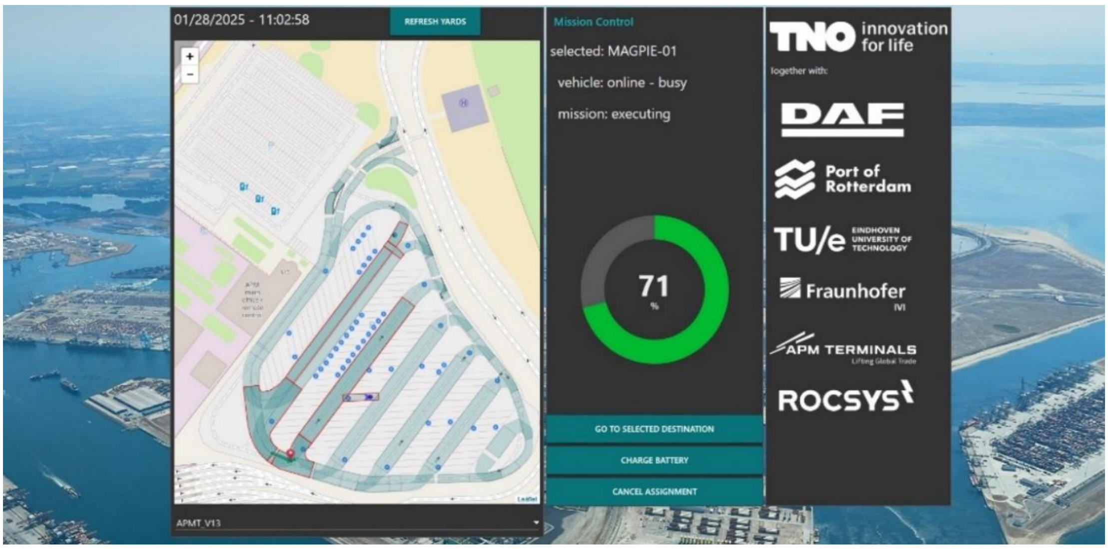


Figure 5: Snapshot of user-interface while the vehicle is performing a mission at the APMT parking lot

4.2 Route planner

In the MAGPIE concept the route is planned by a dedicated route planner that is located in the RVOS in the cloud. As the RVOS gets information from the yard, the vehicles and other actors on the yard, it can get a good overview of the yard and its traffic situation. One advantage of a centralized route planning is that the vehicles can be provided with routes adapted to the traffic situation at the yard.

The route planner uses an OpenDRIVE map that represents the yard environment. Using this map, it calculates a route from the vehicle's current position to the selected destination. The planner considers factors such as driving direction and destination-specific details to determine the optimal approach for the vehicle. Additionally, it can plan routes that include intermediate waypoints, enabling intelligent and flexible vehicle routing.

As shown in **Fout! Verwijzingsbron niet gevonden.**, the route planner is implemented as a microservice within the helyOS framework, where it delivers its results as a helyOS assignment to the vehicle. It communicates the selected route using unique identifiers corresponding to road elements. The vehicle, which operates using the same online available yard map, uses these identifiers to obtain geometrical details of the road layout of the elements, e.g. lane width, and translates this into drivable space. This drivable space is then used to compute a navigable path to the destination within the road boundaries defined by the map.

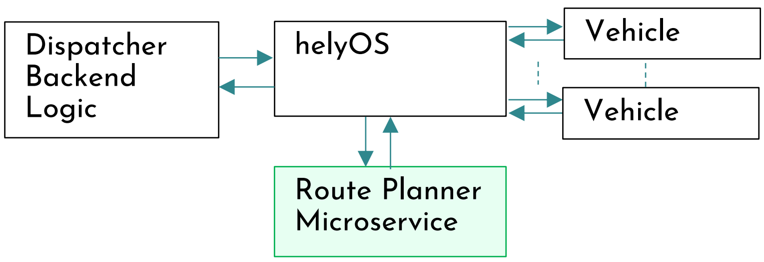
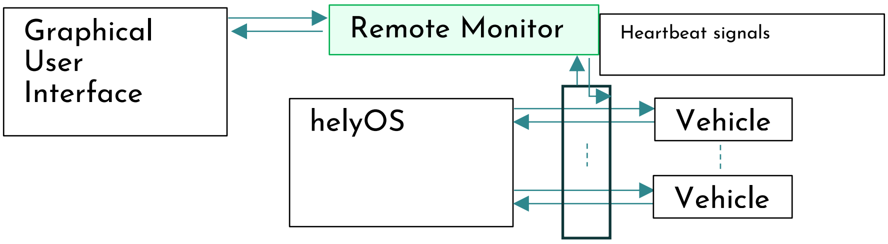


Figure 6: The position of the Route Planner Microservice relative to the other elements in the system

4.3 Remote Monitoring

A remote monitor has been developed to ensure the safe operation of automated vehicles within the yard. Since a remote operator cannot watch all vehicles simultaneously, automated monitoring is essential. Monitoring takes place both in the vehicles and remotely. The remote monitor can halt vehicle operation if problems are detected, whether by the monitor, the vehicle, or an operator. Notably, vehicles can also stop themselves automatically whenever they encounter a problem, reporting their status back to the system.

During a mission, the remote monitor tracks communication between the vehicles and helyOS by sending a regular "heartbeat" signal (see



).

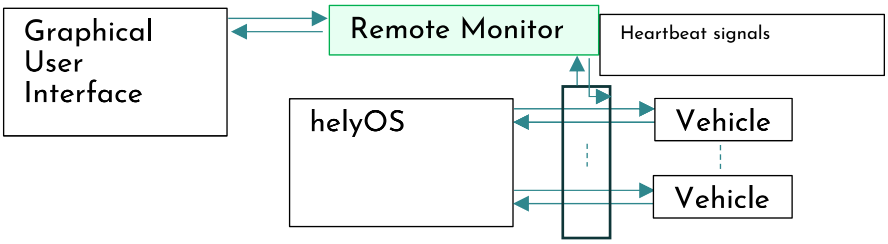


Figure 7: The position of the monitor relative to the other elements in the system

The monitor receives details about each vehicle's assigned mission and ongoing status updates, allowing it to verify that the vehicle remains connected and is progressing as expected. The monitor also checks that the vehicle stays within its assigned route boundaries and that message data (such as timestamps) is accurate. When everything is normal, the monitor grants the vehicle permission to proceed on specific sections of the route by sending access to those road elements. If any abnormality or alarm occurs, the monitor revokes this access, causing the vehicle to perform a safe, controlled stop.

Alarms can also be raised or cleared via the graphical user interface. For enable this the remote monitor and the Graphical User Interface are interconnected.

4.4 Challenges and scalability

The MAGPIE route planning and dispatching application is still under development and has only been deployed in prototype systems for testing and demonstration with a single automated vehicle. It is designed with built-in flexibility to accommodate various mission types and variations. However, future work is needed to determine whether the system can support a wider range of operations and destinations, as well as manage multiple vehicles simultaneously.

At present, mission dispatching is performed manually by an operator through the user interface. This approach suits the current development stage, where testing has involved only a single vehicle and different missions can be assigned easily. In the future, however, the Dispatcher Logic could integrate with a logistics planner to automatically manage and dispatch missions for an entire fleet. Although operators will still be necessary, the system will become more scalable as vehicle monitoring becomes automated, limiting operator intervention to exceptional situations or emergencies.

Currently, only a subset of the fault-detection mechanisms envisioned for a fully automated system has been implemented. Further work is required to define how operations should resume after a vehicle stops due to a detected issue. In some cases, recovery may be automatic; in others, manual intervention—such as remote assistance or remote driving—might be necessary. Additionally, the precise thresholds for monitored parameters must be established to ensure safe and reliable operation with multiple vehicles.

Testing so far has involved up to two vehicles, with robust performance demonstrated during trials and demonstrations. While the system's design supports multiple vehicles performing automated tasks simultaneously, its performance under such conditions remains to be evaluated. This will likely require optimization of the monitoring system and thorough testing of the communication network to ensure it can handle the necessary data traffic. Furthermore, when multiple vehicles operate in the same area, a fleet management algorithm will be essential to optimize traffic flow and prevent vehicles from being delayed while waiting for one another.

5. Hands-Free Charging

5.1 The hands-free charging concept

Charging infrastructure today is primarily designed for manual operation, requiring human intervention to connect and disconnect electric vehicles (EVs) for charging. However, as automated vehicles become increasingly prevalent, logistics operators are seeking comprehensive end-to-end solutions that extend automation beyond driving to include the entire charging process.

Hands-Free charging addresses this need by enabling the automatic connection and disconnection of the EV charger to the vehicle without any human involvement. This fully automated process is facilitated by an Automated Connection Device (ACD), which precisely aligns and engages the charging connector with the EV's inlet, ensuring safe, efficient, and seamless charging. By integrating Hands-Free charging into automated vehicle fleets, operators can significantly improve operational efficiency, reduce downtime, and support continuous, around-the-clock vehicle use, paving the way for smarter and more sustainable logistics systems.

Figure 8: Rocsys ACD – ROC-1, used in the Magpie demo

Figure 9: Set up as used in the Magpie demo at APM Terminals MVII in April 2025: DAF Automated vehicle, Rocsys ACD ROC-1, PACCAR charger with CCS2 connector

5.2 Hands-Free Charging Process

The Hands-Free Charging system enables fully automated connection and disconnection of an electric vehicle (EV) to a charging station, eliminating the need for human intervention. The process consists of two main phases: plugging in to start charging, and unplugging once charging is complete.

Plugging In

1. The automated vehicle (AV) drives toward the charging bay and parks itself with an accuracy of approximately 30 cm.
2. The AV disables its drive train and sends a wireless signal to the Automated Connection Device (ACD) to initiate a charging session.
3. The Rocsys ACD receives the request and prompts the AV to open its charge port cover.
4. The AV opens the charge port cover and confirms this to the ACD.
5. Using its vision system, the ACD locates the charge port inlet and determines its precise position.
6. The charging connector, permanently attached to the ACD, is compatible with any standardized connector—such as the CCS2 standard used for DC charging in Europe. The ACD carefully moves the connector toward the vehicle and inserts it into the inlet.
7. Once physically connected, the charging process begins automatically, just as it would if a human had plugged in the connector manually.

Plugging Out

8. When the vehicle is fully charged or the RVOS determines the battery has sufficient charge for its next task, the AV stops the charging session.
9. The AV then sends a request to the ACD to unplug the connector.
10. The Rocsys ACD retracts the connector from the vehicle inlet and moves it back to its resting position, notifying the AV that the process is complete.
11. The AV closes the charge port cover, re-engages the drive train, and proceeds to its next mission.

5.3 Communication with the vehicle

Communication of the hands-free charging system with the vehicle is implemented in accordance with international standards wherever possible to ensure compatibility and interoperability. For the charging infrastructure, the relevant standards are IEC 61851-27 and IEC 61851-28, while for the vehicle side, ISO 17409-5 is applied. At the time of the demonstration, both sets of standards were still under development and not yet fully finalized. Therefore, this project adopted the most current versions of these standards available as of the first quarter of 2025. This approach allowed the system to align closely with emerging industry norms while maintaining flexibility to adapt to any future updates or changes in the standards.

5.4 Robustness and scalability to other vehicles and areas

The ISO and IEC standards mentioned before have been developed through the collaboration of a wide range of industry experts from various relevant sectors, including numerous automotive manufacturers and charging infrastructure companies. Several initiatives contributed to this effort, such as the ROCIN-ECO project in Germany, which involved key automotive players including Audi, BMW, Ford, and Porsche. Additionally, Ionity—operator of one of Europe's largest fast-charging networks—also played a significant role in shaping these standards.

Figure 10: The ROCIN-ECO consortium driving the global standards for robotic charging

The IEC61851-27/28 and ISO5474-5 standard have been designed to accommodate a wide range of vehicles such as passenger cars, commercial vehicles, public transport buses, trucks for the public road as well as for vehicles for gated areas – such as terminal tractors, forklifts and similar equipment used in ports and distribution centres.

MAGPIE was the first project to publicly demonstrate Hands-Free charging of an electric truck in Europe. By adhering to these international standards, the system is prepared to charge automated vehicles from other manufacturers and for other applications, creating an interoperable eco system, similar to what the CCS2 charging standard is for charging electric vehicles in Europe.

6. Vehicle development

6.1 Vehicle concept and system integration

At the system level, mission management and orchestration are coordinated via the RVOS (see Chapter 3), which allows operators to interact with multiple automated vehicles and provides human oversight when needed. The TNO dispatcher and Fraunhofer's open-source HelyOS framework perform the mission management and route planning, utilizing a multilayer high-definition map supplied by Eindhoven University of Technology. The university also delivers high-precision vehicle localization by combining data from dual lidar sensors with the HD map, ensuring the vehicle can manoeuvre accurately within the yard and achieve precise docking—essential for tasks such as hands-free charging with RocSys.

A core activity within the project is the seamless integration of these components into the vehicle platform. DAF leads this integration effort, ensuring that the various systems (Figure 11: Overall system diagram and related vehicle functions) work together smooth and reliable. DAF's role extends beyond integration: it encompasses the development and implementation of the key vehicle functions required for automated driving, as well as the assurance of overall safety. For this purpose, DAF has developed and integrated several essential functions:

State Logic & Plausibility: This module manages the interaction between the vehicle's Yard Automation function, the driver, the RVOS, and external systems such as the charging robot. It supports safe transitions between manual and automated driving and continuously monitors the correct operation of all automation functions. Status and diagnostic information are reported back to the RVOS for remote monitoring.

Path Follower: The path follower receives the planned trajectory from the path planner and translates it into precise setpoints for the vehicle's motion systems. It continuously compares the desired path with the actual position of the vehicle, ensuring accurate tracking and smooth navigation even in complex yard environments.

Vehicle Motion Controller: Responsible for both longitudinal and lateral control, the motion controller actuates the driveline, braking, and steering systems to execute the commands from the path follower. It also processes sensor data to detect obstacles and other road users, to avoid any collision with other road users.

Safety Assurance: Safety is embedded throughout the system. DAF has implemented multiple layers of functional safety measures, including system monitoring, redundancy in critical controls, and mechanisms to safely transition between manual and automated modes. The architecture ensures that in the event of any irregularity—such as sensor inconsistency, unexpected obstacles, or loss of communication—the vehicle can respond appropriately, for example by slowing down or stopping to prevent unsafe situations. This is described further in the next section.

By integrating these components and functions, DAF enables the automated vehicle to execute complex yard missions with high precision and safety. The result is a reliable, coordinated system that combines contributions from all partners while maintaining robust control and oversight.

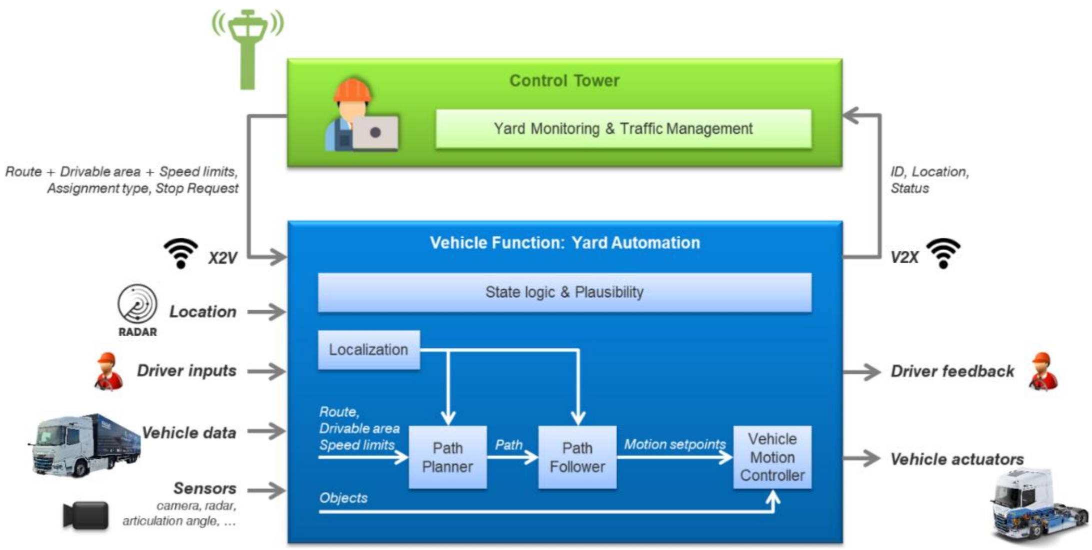


Figure 11: Overall system diagram and related vehicle functions

6.2 Safety

Ensuring safety is a central focus of the automated driving system developed in the MAGPIE project. Functional safety requirements define a safe and controlled proof-of-concept evaluation with a safety driver on board. The safety process systematically identifies hazards and risks, establishes safety goals, and implements a range of measures to mitigate those risks.

Key safety measures include requiring redundant actions by the safety driver to activate automated driving mode and automatically disabling the system if the driver is no longer seated or if the cab door is opened. Collision avoidance systems provide warnings and automatic braking at both the front and rear of the vehicle. The safety driver receives an alert before the vehicle starts moving, while external indicators notify other road users whenever the vehicle operates autonomously. Additional software checks ensure the vehicle remains within a safe (predefined) area, limits the speed to a maximum of 15 km/h, and actively reduces speed ahead of corners. Communications from the RVOS are continuously verified, and the vehicle stops immediately if any discrepancies occur.

Together, these measures create a robust safety framework that minimizes risks and ensures the protection of all participants and other road users during the demonstration.

6.3 Stepping-stone to other automated driving applications

Robotic charging represents a promising minimum viable product within the evolving landscape of automated driving in Europe. This solution is carefully designed around key use cases, emphasizing safety, logistical efficiency, and seamless integration with existing infrastructure. By automating the charging process, logistics operators can reduce downtime and optimize vehicle utilization, laying a strong foundation for broader applications.

Building on this foundation, ongoing research and development efforts—such as those in the MODI project—explore expanding the vehicle's capabilities beyond charging. These expansions include automating tasks like automatic gating and container handling within confined industrial areas, with the longer-term vision of enabling safe, automated driving on public roads within industrial zones. Such "drayage" applications promise to further streamline logistics operations by automating repetitive and constrained driving tasks.

Achieving these advancements requires close interaction between vehicles, infrastructure, and logistics systems, all while navigating the complex legal frameworks governing automated operations in Europe. Maintaining a careful balance between technological innovation, regulatory compliance, and operational practicality is essential for successful deployment.

Technological enhancements play a critical role in this evolution. Incorporating Vehicle-to-Everything (V2X) communication, adding advanced sensors to improve perception in public environments, and refining localization techniques for precise docking are key areas of focus. Together, these technologies enable vehicles to operate safely and efficiently in increasingly complex and dynamic environments.

Ultimately, these developments empower logistics operators by automating routine vehicle tasks, allowing human drivers to focus on activities where their skills and judgment are most valuable. This collaboration between automation and human expertise drives greater productivity and safety across the logistics sector, supporting Europe's transition towards smarter, more sustainable transportation systems.

7. Path Planner

Within the MAGPIE project, the vehicle's route is provided through the cloud-based Remote Vehicle Operating System (RVOS), on a precise path planner on the vehicle level remains essential to calculate waypoints, simulate the vehicle's trajectory, and apply local adjustments when necessary. Fraunhofer IVI has developed a robust path planner based on their CityTrix solution, which is described in the following paragraphs.

7.1 Path planner concept

The CityTrix path planner starts with detailed environmental information from an OpenDRIVE map. This map describes the area and road network in great detail and serves as the foundation for the subsequent planning steps. While the overall route that the vehicle should follow is given by the RVOS, OpenDRIVE breaks the route down into lanes and lane sections. The planner must decide which specific lane and which lane section the vehicle should use at every point along the route. This task is handled by the so-called NAVI-Planner. It creates a smooth connection, a so-called clothoid curve, between the vehicle's starting point, its target position, and the surrounding road network as depicted in **Fout! Verwijzingsbron niet gevonden.**.

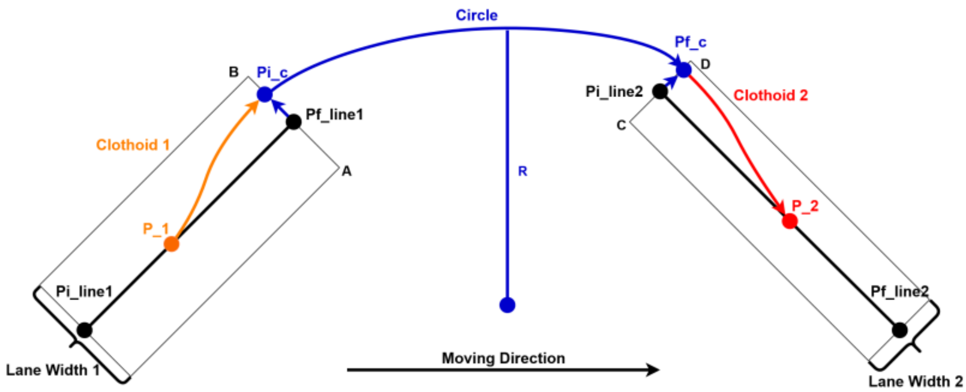


Figure 12: Clothoid connections for smooth transitions between path segments

Once this connection is established, the NAVI-Planner goes through each road segment in the initial route, determining the exact lane sections and lanes to be used. It then generates a list of centerline points along the path which the vehicle should follow. Next, the so-called SIMU-Planner takes these centerline points and uses a detailed model of the vehicle's shape, size and kinematics to simulate the vehicle moving along this path. If the simulation is successful with no collisions or constraint violations reported, the SIMU-Planner calculates the vehicle's heading angle (direction) at each point and outputs a smooth path, called a spline, that the vehicle can follow to begin driving.

However, because the NAVI-Planner strictly follows the centerline of lanes, the exact path it generates might sometimes be physically impossible for the vehicle to follow due to its size or turning limits. When this happens, the SIMU-Planner detects collision points or other infeasible segments during the simulation. Using this feedback, the path planner performs local adjustments to the waypoints, optimizing the path to respect the vehicle's physical limitations while still trying to fulfill the original route request.

By working together, these three planners form a feedback loop as illustrated in **Fout! Verwijzingsbron niet gevonden.**. This loop ensures that the planned drive is not only feasible but also safe and executable, thanks to the physical simulation carried out before the vehicle actually moves.

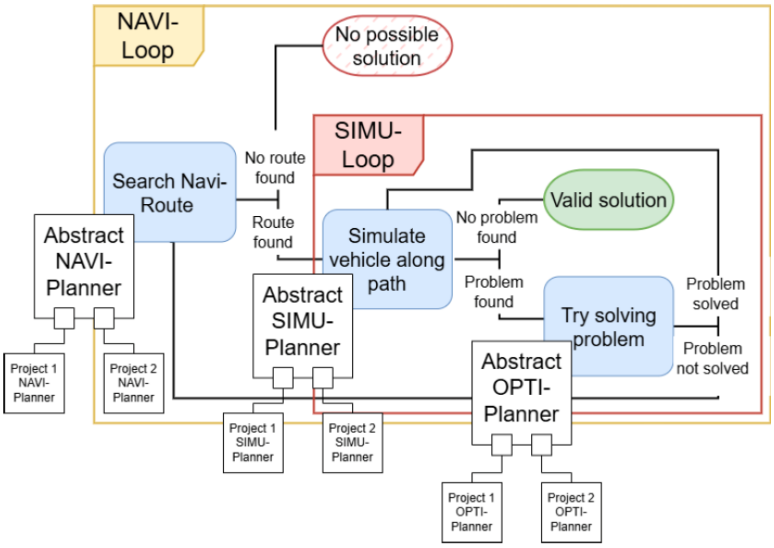


Figure 13: CityTrix module architecture

Additionally, a GeoJson map defines the physical boundaries of the yard, ensuring that even when the planned path deviates from the lane centerline, the vehicle stays within allowed areas. Thanks to this coordinated planning system, we can guarantee that no drive will be executed that would cause the vehicle to leave the premises or exceed its physical limits. If such a maneuver is impossible, the system marks the plan as failed in the helyOS platform, preventing unsafe or infeasible drives.

The result of a successful path planning along a route provided by the upstream planner introduced in section 4.2 is depicted in Figure 14.

Figure 14: Example result of a drivable path at the APM Maasvlakte II terminals along a route provided by the upstream route planner

7.2 Application to other areas

The proposed planner can be used in any scenario that requires the calculation of kinematically feasible paths along an existing route network. Thanks to its modular architecture featuring interfaces for abstract planners as depicted in Figure 13, the actual implementation of the NAVI-, SIMU- and OPTI-planner can vary throughout different projects and each component can be tuned to the individual application scenario.

Thus, it can be used to calculate drivable and safe paths along a route proposed by an upstream planner like in the MAGPIE project, but can also serve to find optimal paths from a starting to a target position in a route network.

The kinematics-informed and swept-area-aware planning in the SIMU-planner can also be used for unconstrained path planning from a starting to a target position independent from a route network to evaluate, whether a long, articulated vehicle can fit through a narrow passage at all. With this, it can be used to digitally assist the approval process for heavy load transports.

Furthermore, the technology can be adopted for the development of local planning algorithms for obstacle avoidance in future work, where the vehicle needs to leave a globally planned path to drive around obstacles before safely returning back to the original path. Again, a unique selling point compared to other solutions on the market is the compatibility with complex vehicles such as long, articulated truck-semitrailer-combinations.

8. Localisation & HD Map

8.1 Localisation concept description

A real-time, accurate, and robust vehicle localization system is the backbone of automated vehicles. It is the basis for environment perception, path planning, and automated decision making. Traditionally, Global Navigation Satellite System (GNSS) based solutions are used, but they often suffer from reliability issues originating from satellite visibility, multipath error, atmospheric, and ionospheric delays. To overcome these issues, LiDAR sensors are used to create a high-resolution 3D map of the environment and localize in it.

TU/e developed and integrated a localization system for automated trucks that is accurate, robust, and runs real-time. **Fout! Verwijzingsbron niet gevonden.** represents a high-level architecture diagram of the localization system used. The system uses point cloud data from two LiDAR sensors and vehicle kinematics data from the truck's ECU to localize itself in the point cloud layer of an HD (High Definition) map. The system has an accuracy of around a few centimetres. Figure 16 depicts a truck being localized in a point cloud map, where the white coloured point cloud represents the point cloud layer of the HD map, and the coloured point cloud represents the data from the two lidars mounted on the truck.

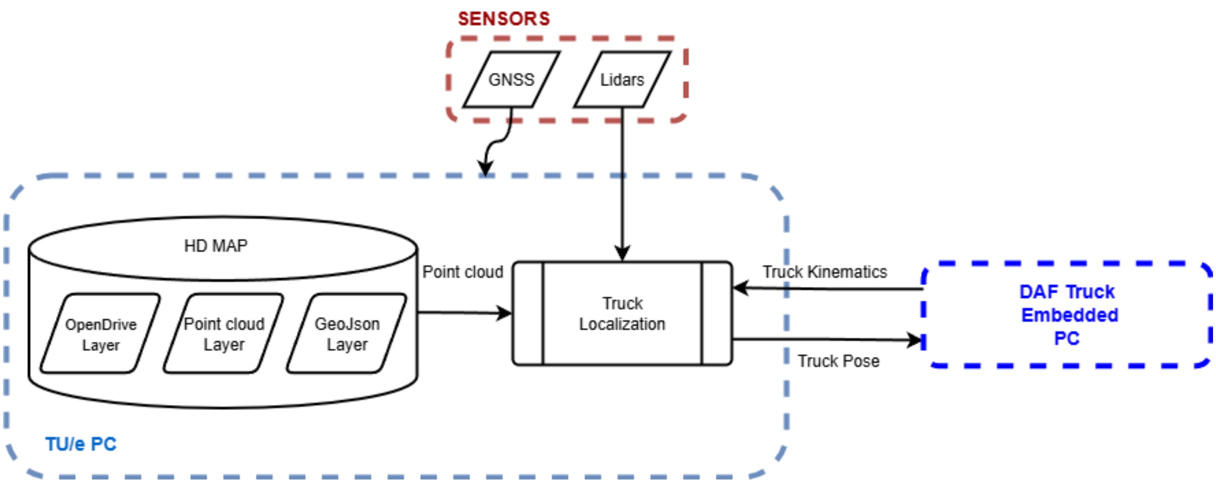


Figure 15: High level architecture of the localization system

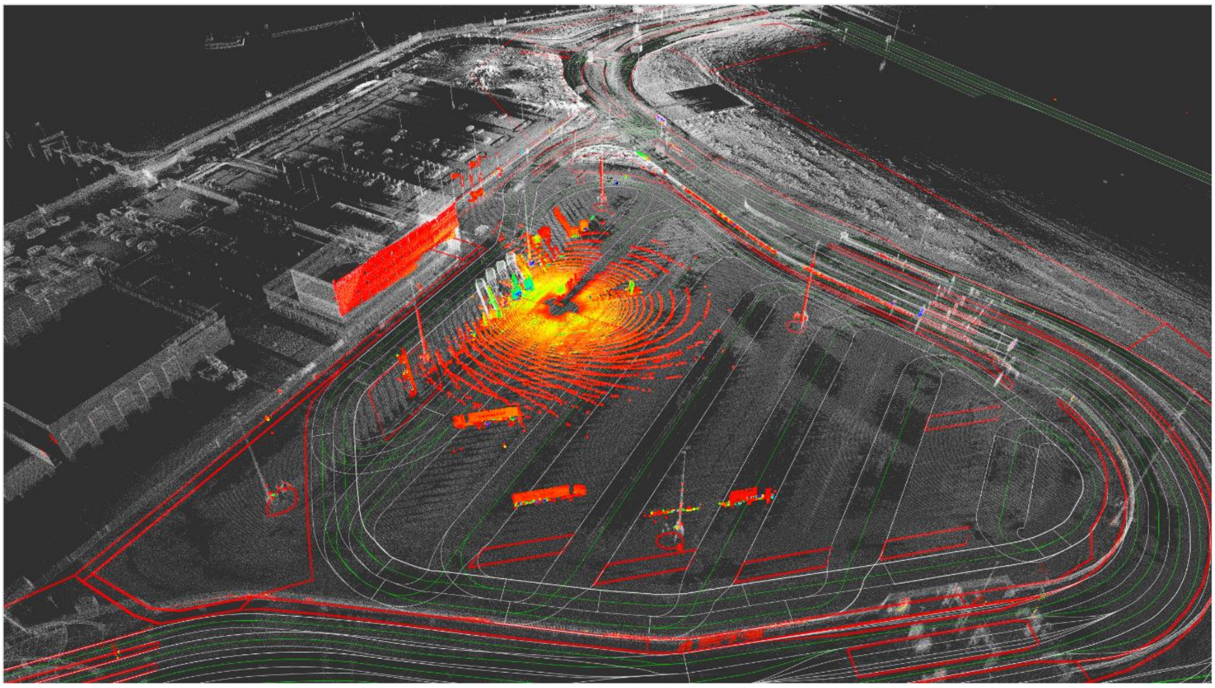


Figure 16: Truck localization on a point cloud map. The white point cloud represents the map and the coloured point cloud represents the lidar data.

8.2 HD Map

TU/e is providing the HD (High Definition) maps for the project. These maps consist of three different layers. Figure 17 depicts the different layers of an HD map. Each layer provides specific functionalities as mentioned below:

Point cloud layer: This layer consists of a 3D point cloud scan of the environment, and it is used to accurately localize the automated truck inside it using live LiDAR data.

OpenDrive layer: This layer contains information about the road and lane geometry of the environment, along with static traffic information, used for route and path planning.

GeoJson layer: This layer contains information about the drivable and non-drivable regions in the environment. The path planner uses it as a hard threshold to compute a path for truck manoeuvring that requires it to deviate from the centre line of the lane.

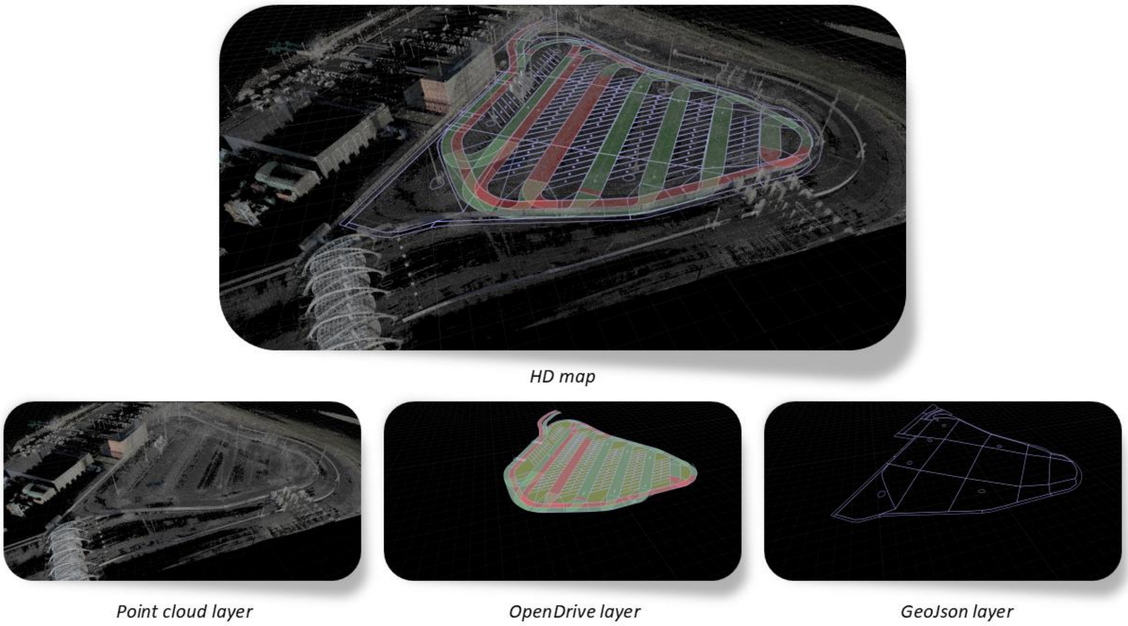


Figure 17: The HD map of the APMT parking area with its three different layers.

8.3 Challenges and scalability

The LiDAR-based localization system is accurate and robust in most scenarios, but there are still some challenges to overcome. One of the key requirements for the system is the availability of HD maps. Furthermore, LiDAR sensor generally work poorly in heavy rain, dense fog, and snow. These types of systems will also fail if the LiDAR's get fully occluded when the vehicle is parked between other trucks with trailers. Therefore, a more robust localization system will require fusion of RTK GNSS and lidar. RTK GNSS can be used to initialize the LiDAR-based localization system, and it can take over when the lidar sensor fails or its visibility is obstructed.

The scalability of the proposed localization solution has significantly improved over the years. The primary bottlenecks were HD map creation and maintenance; however, these processes have become increasingly automated through the use of user-sourced data.

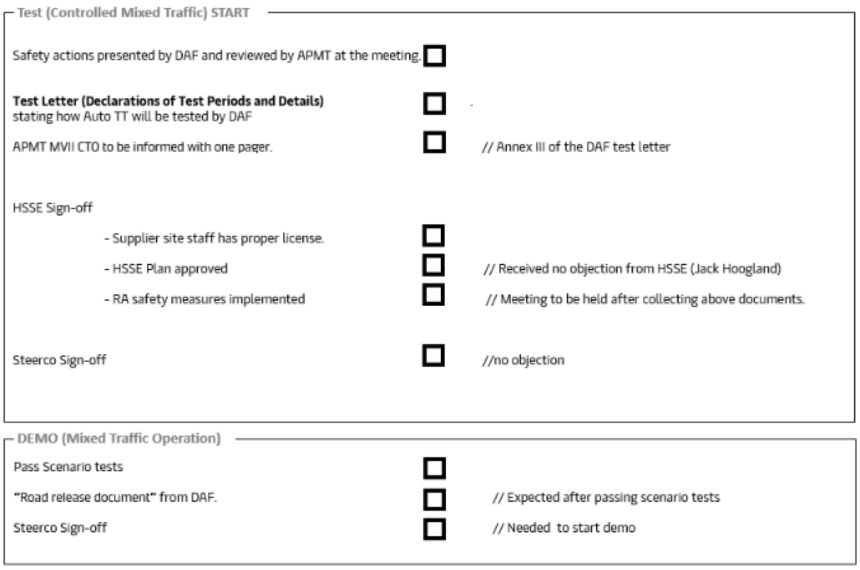
9. Application & Safety

9.1 Application at the terminal

At APM Terminals Maasvlakte II, automated electric trucks are redefining safety in port logistics. By reducing dependency on human drivers at high-traffic yard operations, the risk of accidents is significantly reduced. These trucks follow a closed-loop route—drop-off, parking, robotic charging, and pick-up—within a controlled environment, monitored in real time. Built-in safety protocols, including automated abort procedures and pre-tested routes, ensure reliable performance. This innovation not only enhances operational efficiency but also aligns with APMT's commitment to zero-harm workplaces and sustainable automation. The MAGPIE project proves that safety and innovation can go hand in hand in the future of terminal operations.

9.2 Safety

Safety is paramount: key safety case elements have been developed, including risk assessments, supplier safety plans, and independent safety advisor reviews. Internal approvals have been secured from HSSE (Health, Safety, Security, and Environment) and the Steering Committee, with no objections raised for controlled testing phases. The pilot includes scenario-based validation, road release documentation, and phased acceptance criteria, culminating in a live test with external truck drivers. These measures ensure that automated operations meet stringent safety and regulatory standards. For APMT, this represents a strategic leap—enhancing yard safety and preparing for scalable automation.


Test (Controlled Mixed Traffic) START

Safety actions presented by DAF and reviewed by APMT at the meeting. ☐

Test Letter (Declarations of Test Periods and Details) stating how Auto TT will be tested by DAF ☐

APMT MVII CTO to be informed with one pager. ☐ // Annex III of the DAF test letter

HSSE Sign-off

- Supplier site staff has proper license. ☐
- HSSE Plan approved ☐ // Received no objection from HSSE (Jack Hoogland)
- RA safety measures implemented ☐ // Meeting to be held after collecting above documents.

Steerco Sign-off ☐ //no objection

DEMO (Mixed Traffic Operation)

Pass Scenario tests ☐

"Road release document" from DAF. ☐ // Expected after passing scenario tests

Steerco Sign-off ☐ // Needed to start demo

Figure 18: Operational Safety Approval Checklist

9.3 Outlook: vision on automated electric trucking and hands-free charging at APM

Looking ahead, APM Terminals envisions a gradual and carefully managed integration of automated electric trucking and robotic charging into its operations. These technologies offer promising opportunities to enhance safety, reduce emissions, and improve operational consistency—particularly in repetitive, low-speed yard movements. The MAGPIE project has demonstrated that such systems can operate reliably within controlled environments, supported by robust safety protocols and human oversight.

However, APMT recognizes that automation is not a one-size-fits-all solution. The introduction of automated systems will be guided by operational needs, regulatory frameworks, and close collaboration with workforce representatives. Human expertise remains essential—not only in supervising automated systems but also in managing exceptions, ensuring safety, and maintaining service quality.

Robotic charging, in particular, offers a practical step forward. It reduces manual handling of high-voltage equipment and enables more flexible charging schedules, especially during off-peak hours. As APMT continues to explore these technologies, the focus will remain on complementing—not replacing—human roles, while building a safer, more sustainable terminal environment. The long-term vision is one of coexistence, where automation supports people in delivering world-class logistics performance.

10. Demonstration & Findings

10.1 Demonstration of the concept at APM Terminals

After the development of the concept, a technical implementation of the automation system was made. This implementation was demonstrated at the 10th of April 2025 in Rotterdam on the premises of APM Terminals.

Figure 19: Two pictures of the demo runs during the demo day at the parking of APM Terminals

In the demonstration a vehicle could be dispatched to the selected parking spot in the area. by clicking on the desired destination on the operator interface (see **Fout! Verwijzingsbron niet gevonden.**, left). Once dispatched, the remote operation system planned the route for the vehicle to take and this information was sent to the vehicle. The vehicle planned the path based on the route received and drove to the destination, constantly updating its positions using the localization system. Once the vehicle was parked near the charge robot, the charging assignment was dispatched to start a hands-free charging session. Although a safety driver was present during the demonstration, it could be executed fully by the automated system without human interventions in the execution.

10.2 Evaluation of the Automated Driving System

This section presents an evaluation of the automated driving system, which comprises the Remote Vehicle Operating System (RVOS), the vehicle itself, and the supporting infrastructure equipment. During the demonstration and testing phases, the overall technical concept was assessed, and recommendations for further improvements were identified. The following examples illustrate key observations and findings from the evaluation.

System Monitoring and Remote Operation

Throughout the demonstration, the vehicle's motion and assignment progress could be continuously tracked via the vehicle interface, with the dispatcher being able to monitor these activities on a map in real-time. Remote dispatching, route planning, and monitoring functions operated reliably and without issues, confirming the robustness of these core features.

The RVOS included a monitoring component that continuously evaluated incoming information from the vehicle. Basic checks were performed, such as verifying message reception and ensuring that the vehicle's status and position aligned with its assigned mission. Importantly, the monitor did not need to intervene to stop the vehicle at any point, indicating that the vehicle remained on its planned route without significant deviations. This also reflects the stability and reliability of the communication link between the vehicle and RVOS, which experienced no major interruptions.

Infrastructure Considerations

The system demonstrated consistent capability in positioning the vehicle within the required margins relative to key infrastructure elements, such as the hands-free charging system and other designated spots. It is, however, important to ensure that chargers and similar infrastructure are positioned carefully to avoid risks—specifically, the trailer's large oversway beyond the drivable space resulting from minor deviations of the vehicle position should not result in collisions.

Recommendations for System Enhancements

While the current error handling and recovery mechanisms in the RVOS monitor provide basic functionality, these need to be expanded in future development cycles. Enhancements could include more detailed error and alarm messages that precisely identify the type of issue encountered, along with clear and standardized recovery procedures for each error type. Such improvements would strengthen system resilience and operational safety.

Future Development Directions

Looking forward, it will be valuable to explore the requirements and challenges associated with managing multiple automated vehicles operating simultaneously within the same environment. This scenario would offer insights into the system's performance under increased communication loads and complexity. Moreover, future applications will likely require the system to interact seamlessly with other actors and services on the yard, such as cranes, docks, and security systems. Although the helyOS platform and RVOS concept are designed to support such integrations, detailed design work remains necessary to define how these interactions will be realized. This area is currently being investigated further in the MODI project, which focuses on the integration of automated vehicles with broader logistics systems and infrastructure.

11. Outlook to scaling of automated driving in logistics operation

11.1 Automated driving & hands-free charging as minimum viable product

A key objective and achieved result of the project is the technical demonstration that showed that automated driving and hands-free charging of heavy-duty trucks has reached a level of technological maturity that brings practical application and implementation within reach in a logistical (port) environment. This underscores that automated driving and hands-free charging are no longer conceptual or speculative solutions, but rather viable technologies. Consequently, this serves as a clear signal to accelerate progress and take subsequent steps in further development.

11.2 Potential integration in future logistic concepts

Automation, robotics, and digitalization offer significant potential solutions to both emerging threats and opportunities within (port) logistics. The sector faces substantial challenges in areas such as sustainability, efficiency, safety, and human capital. For road transport —whether on terminals, private premises, within port areas, regional zones, or hinterland corridors— the demonstrated capabilities of automated driving and hands-free charging represent a precursor to promising use cases where these technologies can be integrated into logistical processes.

These use cases are already beginning to materialize through concrete pilot projects with clients, focusing on automated driving within terminal premises and along the Rotterdam Port Container Exchange Route (CER), which interconnects the container terminals at Maasvlakte II and facilitates efficient inter-terminal container traffic.

In parallel with the MAGPIE project, the Dutch CAT4YARDS initiative is exploring how the concept of automated transport can be embedded within terminal logistics, including the logistical interface between terminals and adjacent industrial zones. This includes the transition toward automated transport on public roads, which introduces additional complexity regarding mixed traffic environments, regulatory frameworks (vehicle approval), and the involvement of road authorities.

Simultaneously, the European MODI project is investigating automated transport not only within terminals and industrial zones but also along international transport corridors, focusing on hub-to-hub operations. As part of the MODI project, a demonstration is prepared for automated driving between the APMT Terminal Rotterdam and a warehouse at the Maasvlakte II in the port area of Rotterdam. For this demonstration of automated transport at an industrial zone, the results, experience and the actual automated truck of MAGPIE project are being used and further developed. This way, the outcome of the automated transport demonstration in MAGPIE is an important result in itself and a basis for next steps in the development towards more complex and extensive applications of automated driving in practice.

Also in the Netherlands, a hub-to-hub approach is being pursued within the MIRT freight transport corridor South, which aims to identify a sub-route suitable for large-scale trials and pilot implementations.

All these initiatives aim to foster experiential learning and practical insights, enabling incremental progress and building confidence in the deployment of automated road transport. This requires collaboration among all relevant stakeholders to establish a cohesive ecosystem. The success of these efforts is driven by attractive and viable logistical use cases and business models from the demand side. The availability and applicability of regulatory frameworks are essential preconditions that will significantly influence the pace and success of implementation.

12. Conclusions & Recommendations

The MAGPIE demonstration has shown that automated driving combined with hands-free charging is a technically feasible and operationally beneficial solution for logistics environments such as ports. The integration of an automated electric truck with a robotic charging system enables fully automated missions—from dispatch to charging and parking—without human intervention. This not only reduces downtime and manual labor but by enabling more flexible charge planning it also allows for flexible, off-peak energy use, contributing to more sustainable and efficient logistics operations. Importantly, the hands-free charging system, developed by Rocsys, is not limited to automated vehicles; it can also be applied to conventional electric trucks, offering immediate benefits for existing fleets by reducing the need for manual handling of high-voltage connectors and enabling safer, more ergonomic charging processes.

Despite the successful demonstration, several technical limitations remain before large-scale deployment is possible. The current system has been tested with a single vehicle in a controlled environment. Scaling to multiple vehicles will require robust fleet management algorithms, improved communication infrastructure, and more advanced monitoring systems to ensure safety and efficiency. Additionally, while the localization system—based on LiDAR and HD maps—proved highly accurate, it may face challenges in adverse weather or when the sensor vision is blocked by surrounding trucks. To address this, future systems will need to integrate redundant technologies such as RTK GNSS for improved reliability.

The dispatcher logic and mission control, developed by TNO, currently rely on manual input. For real-world applications, integration with logistics planning systems is essential to enable automated mission assignment and dynamic routing. Furthermore, the system's error handling and recovery mechanisms need to be expanded to support automated decision-making in case of faults or unexpected events.

To move toward deployment, further development is needed in several areas: regulatory alignment for automated operations and validation of safety systems under diverse operational conditions. Projects like MODI and CAT4YARDS are already building on MAGPIE's results to explore these next steps, including automated driving on public roads and integration with broader logistics networks.

In conclusion, the MAGPIE demonstration provides a strong foundation for the future of automated electric trucking. With continued development and collaboration across industry and government, these technologies can play a key role in creating safer, cleaner, and more efficient logistics systems.