A leap towards SAE L4 automated driving features

D4.3 Report on Optimal designs of physical and digital infrastructures at confined areas

30th September 2024

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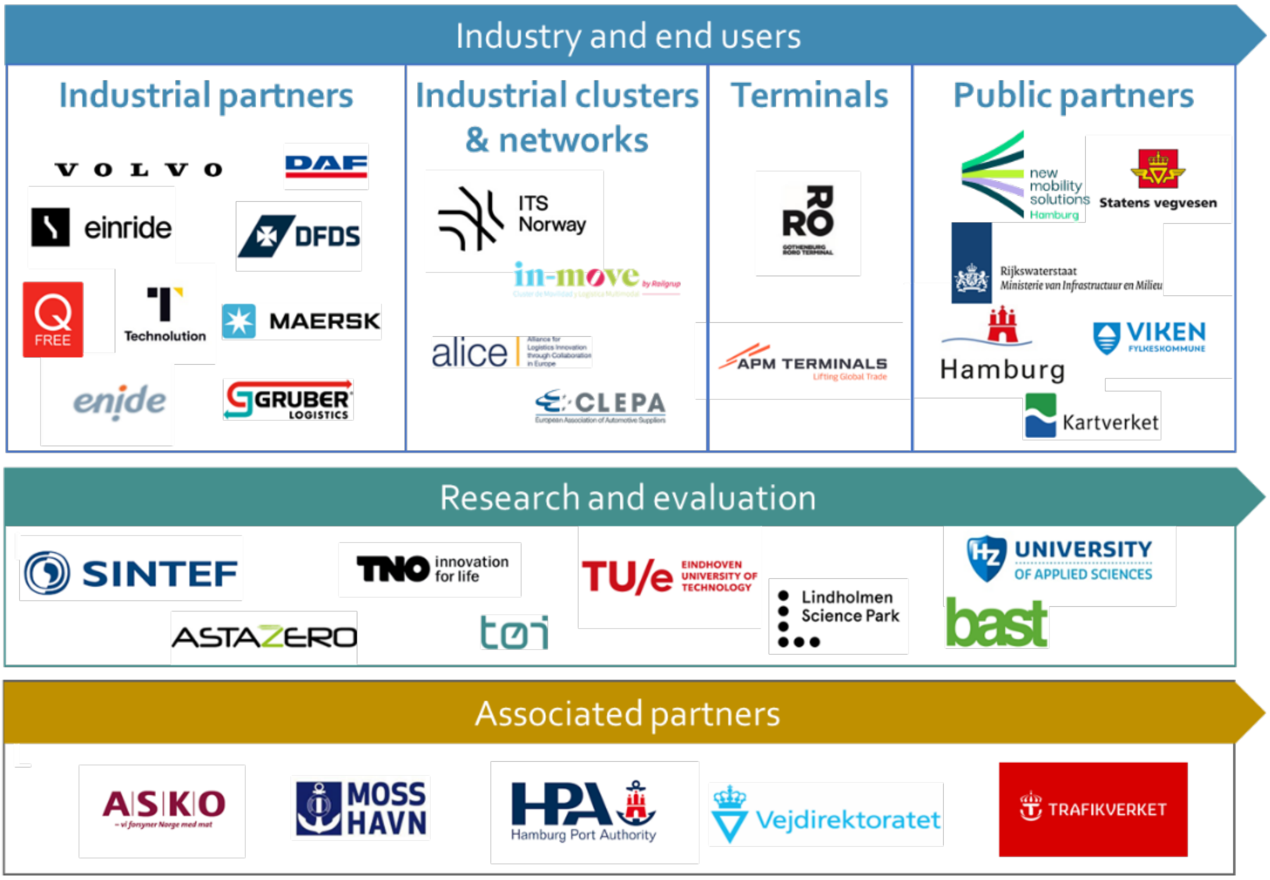

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Terms and abbreviations

Term / Abbreviation	Description
AV	Automated vehicle
CAM	Cooperative awareness message
CCAM	Cooperative, connected, automated mobility
C-ITS	Connected/cooperative-Intelligent transport systems
DENM	Decentralized environmental notification message
MAP	
OEM	Original equipment manufacturer
PDI	Physical digital infrastructure
RAR	Road operator aggregated requirements
SPAT	Signal planning and timing
TAR	Technology developer aggregated Requirements
UAR	User aggregated requirements

Executive Summary

The aim of this deliverable 'Physical and Digital infrastructure on confined areas' is to give the outlines of the necessary adjustments of confined areas to handle automated vehicles/trucks, both from a physical and a digital perspective.

The work that has been carried out in this task is:

- Incorporating of the work of other tasks on the topics:
    - Requirements from road authorities, vehicle OEMs and confined area owners
    - Road geometry guidelines
    - Connectivity requirements and guidelines
    - Logistical processes and derived principles
- Joint design sessions with stakeholders of the task 'public roads [T4.2]' and 'overall architecture for CCAM and logistics [T4.3]'
- Align all information of the bullets above and setting up a scalable, vendor independent design and workflow principles.

A significant part of the design has been used as an underlayer for the MODI use case at APM Terminals in Rotterdam (NL). An automated truck from MODI partner DAF Trucks will fulfil a full automated drive over the terminal. A part of this trip is the swapping of a 30ft container.

The main conclusion – also based upon the pre-tests before the general demo at APM – is that the proposed confined area design principles do work in a field implementation. The usage of connected service in between a 'yard control tower' and automated truck, in combination with standard C-ITS works very well. It lets the benefits of different technology stacks free for all stakeholders while surpassing the several weaknesses of the various communication technology.

Additional work needs to be undertaken in uplifting the usage of technologies into worldwide accepted standards via the different standardization commissions in Europa and other continents. Specific recommendations in these areas are given in the final chapter of this document.

1 Introduction

1.1 Project summary

MODI Ambitions: A leap towards SAE L4 automated driving features

The MODI project aims to accelerate the introduction of highly automated freight vehicles through demonstrations and by overcoming barriers to the rollout of automated transport systems and solutions in logistics. The logistics corridor from the Netherlands to Norway has been chosen for demonstration activities as the Netherlands, Germany, Denmark, Sweden, and Norway are expected to be among the first movers to implement fully automated vehicles in Europe.

MODI comprises five use cases, each describing a part of the logistics chain in confined areas and on public roads. It identifies what is already possible on an automated driving level without human interaction and what is yet to be developed. The MODI objectives are to:

- Implement new technology within the CCAM spectrum.
- Define recommendations for the design of physical and digital infrastructure.
- Demonstrate viable business models for connected and automated logistics.
- Perform technical and socio-economic impact assessments.

Major challenges include regulatory aspects and standardisation, border crossings, access control, charging, coordination with automated guided vehicles, loading/unloading and handover from the public to confined areas.

MODI test sites include a CCAM test corridor from Rotterdam to Oslo with specific use cases at Rotterdam (The Netherlands), Hamburg (Germany), Gothenburg (Sweden), and Moss (Norway).

The ambition of MODI is to take automated driving in Europe to the next level by demonstrating complex real-life CCAM use cases while:

- Showing the local, national, and international context of freight transport with CCAM vehicles, both in confined areas and on public roads.
- Cooperating and co-creating with logistics companies, road operators, vehicle OEMs, providers of physical and digital infrastructure and other stakeholders to bridge the gap between R&D and market readiness.
- L4 solutions for long-distance operational design domains.
- Creating innovative business models and improved business models across the logistics chain.
- Proving that the technology can soon deliver on promised benefits at relatively high speeds and medium traffic complexity, including a coordinated CCAM system to support smart traffic management.
- Paving the way to enable highly automatic transport on important corridors, connecting main ports across Europe.
- Accelerating CCAM in Europe by setting examples of business-wise CCAM integration in logistics.

1.2 Aim of the deliverable

The aim of this deliverable is to define the optimal design for Physical and Digital Infrastructure (PDI), CCAM services for confined areas. This is done in strong alignment with task WP4 4.1 *Definition of an interface for coordinated CCAM* and task WP4 4.2 *Develop optimal designs of physical and digital infrastructures for public roads,* where the general PDI design and interfaces are established and described, as well as several application forms for public road use. This deliverable has a focus on confined areas, and is therefore especially focused on MODI Physical and Digital Infrastructure application within that scope, including required aspects and principles from confined area yard and operational logistics management.

The baseline for the PDI design for confined areas is that the outcomes are applicable cross-border throughout Europe, interoperable with any automated truck and as an open standard applicable for any confined area.

The design serves as a reference for the technical adaptation of CCAM vehicles in the next stage of the MODI project. Moreover, they provide valuable insights for the wider community beyond MODI, which aims to develop connected logistic solutions in the public domain.

1.3 Relation to MODI output

This delivery is part of the MODI work package 4 (WP4) *Coordinated CCAM interface and optimal physical, digital infrastructure*, which is delivering a total overview for infrastructural architecture and interfaces in order to facilitate automated road transport throughout Europe. To achieve this goal, collaboration has been setup with the other work package tasks in order to come to a generic design for infrastructure. Within the context of this deliverable on PDI for confined areas, input has been used from WP4 - task4.1 *Definition of an interface for coordinated CCAM* [3] and WP4 task 4.2 *Develop optimal designs of physical and digital infrastructures for public roads*[3] , as well as confined area-related requirements from users and stakeholders (WP 1 task 1.1 *User and stakeholder requirements*) and several confined area-related use cases (WP2 *UC definition and impact assessment*). The outcomes of this deliverable, as well as the other WP4 deliverables, will be used in use case applications related to confined areas in WP5 *Market applications demonstrated*.

1.4 Structure of the report

This deliverable is structured in several chapters, addressing the task 4.3 (*Optimal design of physical and digital infrastructure, CCAM services at confined areas*) research process, the several perspectives on PDI for automated trucks and the role of confined area PDI within this scope, and the description of the confined area PDI design in all it's different aspects.

The task 4.3 research process is described in chapter 2 as a means of describing how the applicability, scalability and interoperability of the PDI for confined areas was ensured by aligning with the several requirements as defined within MODI, as well as continues alignment with MODI use case descriptions and alignment with other WP4 PDI design activities.

Chapter 3 establishes the PDI for confined areas perspective in comparison to the other perspectives on public road (task 4.2 *Develop optimal designs of physical and digital infrastructures for public roads*) as well as vehicle-oriented perspectives (WP3 *Vehicle sub-system development*).

Chapter 4 describes the PDI design for confined areas, including all relevant aspects such as truck handling, physical road infrastructure, digital infrastructure and mapping.

2 Research Process

The design of physical and digital infrastructures required for confined area L4 freight operations is no stand-alone exercise and is strongly integrated with research and design activities both within and beyond the MODI project. This chapter describes how the work performed in designing confined area PDI is related to these several other related activities, and which interdependencies exist.

2.1 Requirements

Confined area L4 Freight operations in general are very diverse in nature, given the large variety in confined area characters (e.g. warehouses, terminals, other private logistical areas), L4 freight logistical segments (e.g. on-site yard mobility, heavy duty trucks, exceptional cargo) and operational natures (e.g. 24/7 vs. daytime operations, roll-on roll-off vs. Container terminals). Designing PDI with an application value for the large majority of these confined areas therefore very much relies on setting uniform and scalable requirements for this PDI architecture. Within MODI Work package 1 *Requirements, business models and recommendations,* valuable work is performed on requirements and business models, defining requirements from the viewpoints of users and stakeholders (D1.1 *User and stakeholder requirements*) as well as safety and security requirements in L4 Freight operations context (D1.2 *Safety and security requirements*). These requirements set the baseline for the overall PDI design for scalable L4 Freight operations, and thus for application in the several MODI use cases across the MODI corridor. These recommendations are considered during the PDI design phase, and therefore also for the design of PDI for confined areas. The requirements within these reports are described over the axes of User aggregated requirements (UAR) consisting of logistics stakeholders such as transporters, carriers, terminals, etc., Technology Developer Aggregated Requirements (TAR) and Road operator aggregated requirements (RAR), all relevant for scalable PDI design.

These MODI use cases are a basis for demonstrating in real practise a selection of the requirementens, in which several use cases contain a ‘confined area’ aspect. These use cases and their ambitions are more elaboratively described in paragraph 2.2

2.2 Use Cases

The MODI project focusses on demonstrating L4 freight in several representative use cases across the MODI corridor. These five use cases and related sub-use cases are described in detail in D2.1, and several of these use cases are implemented in a confined area context. The PDI Design for confined areas should enable deploying these use cases within and towards confined areas, and therefore are vital input for the design work performed in task 4.3 and described within this deliverable report. The use cases (partly) performed upon confined areas are shortly described below and more elaborately described in the deliverable for use case definition (D2.1) as important input for confined area PDI design. Within the D2.1 deliverable the implemented services, PDI constraints and challenges, and relevant technological and physical objects are listed per (sub) use-case.

The MODI use case operated within the Netherlands contains the on-terminal automated driving sub-use case in which a freight vehicle will be demonstrated to operate upon the private APM terminal and integrate into existing logistics operations. In a series of interactions between the vehicle and the terminal control tower the vehicle will perform actions such as gate-entrance, parking, lane merging and entering/exiting a transfer lane for container pick-up and delivery. In another related sub-use case in the Netherlands, the vehicle will perform a near-site drayage route between the APM terminal and a nearby warehouse across public road and eventually arriving at the warehouse confined area where the vehicle should also be able to operate.

In several MODI (sub) use cases in Sweden a confined area will host the use cases as well, such as gate access with two vehicles at a terminal gate, automated charging and automated loading and unloading of vehicles, where vehicle-to-vehicle and vehicle-to-object interactions are enabled through the confined area control tower.

Despite the cross-border use case between Norway and Sweden being largely on public terrain, the customs area where vehicles could be sent to when crossing the border could be seen as a 'publicly owned' confined area in which the customs and other authorities could serve as control tower to local vehicles.

2.3 Vehicle subsystem

In order to enable and demonstrate L4 Freight vehicle operations within a confined area, the vehicle will need to be guided by one or more local entities (e.g. local control tower) in charge and aware of the local situation and operations. This brings the need for connectivity and mutual understanding between the confined area PDI and the vehicle sub-systems it connects to. Within Work package 3 subsystem development work is performed on the design of vehicle-side systems capable of sensing, reasoning and acting in order to perform L4 automated tasks, as well as capabilities to interact with a variety of external supporting digital systems including the confined area PDI. Within deliverables from work package 3, especially D3.1 and D3.2 on connectivity and automation requirements, several aspects of PDI design are mentioned crucial for PDI design for both public and confined area operations.

The connectivity requirements include relevant C-ITS standards such as Cooperative Awareness Messages (CAM), Decentralized Environmental Notification messages (DENM), Signal Phase and Timing Messages (SPAT) and Map Messages (MAP), as well as communication means, several sensor standards and more. The automation requirements report consists of requirements for automated operations by trucks, as well as requirements for actions such as charging and remote operations.

3 Infrastructure and automated vehicles

The PDI design for confined areas is a synchronised effort with the design of the several use cases, and the several other important PDI aspects such as the vehicle and the public road PDI. In order to understand the interdependencies and complementary design of these system segments, the perspectives from a vehicle and the perspective from a road operator during public road L4 Freight operations are described within this chapter. Consequently the parallels between these perspectives and the perspective from a confined area are described, bringing together the context in which the design of confined area PDI should be seen.

3.1 Perspective from a vehicle journey

When L4 Freight operations in MODI are seen from the perspective of a vehicle, in its very essence an automated freight vehicles will perform the same basic tasks as their traditional vehicle counterparts. These vehicles are used to ship cargo from location A to location B, possibly via location C. When considering the MODI use cases these A to B trips could potentially cross international borders such as shown in Figure 1, where a trip is depicted along the MODI corridor from Rotterdam (NL) to Oslo (NO). Along this route, the vehicle will come across a range of traffic control centres operated by public and private road operators as well as one or more yard control applications run by confined area operators, all (partly) responsible for guiding the vehicle across specific parts of its route.

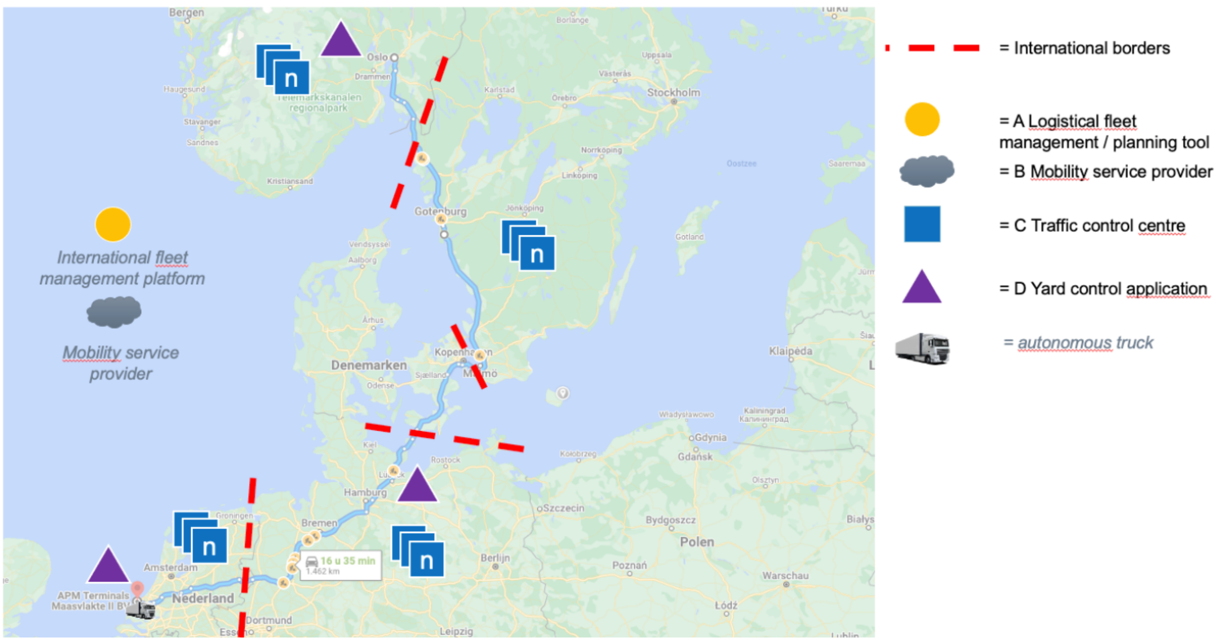

Figure 1: Example of an international truck journey

When assuming such a long-distance freight transport route the logistics partners will find a suitable route and path for the planned transport through three levels of consideration, shown in Figure 2 Different levels of route finding from a truck perspective. These levels differentiate in time-horizon, geographical scope and level of detail in which planning and operational decisions are made: a strategic level, a tactical level and an operational level.

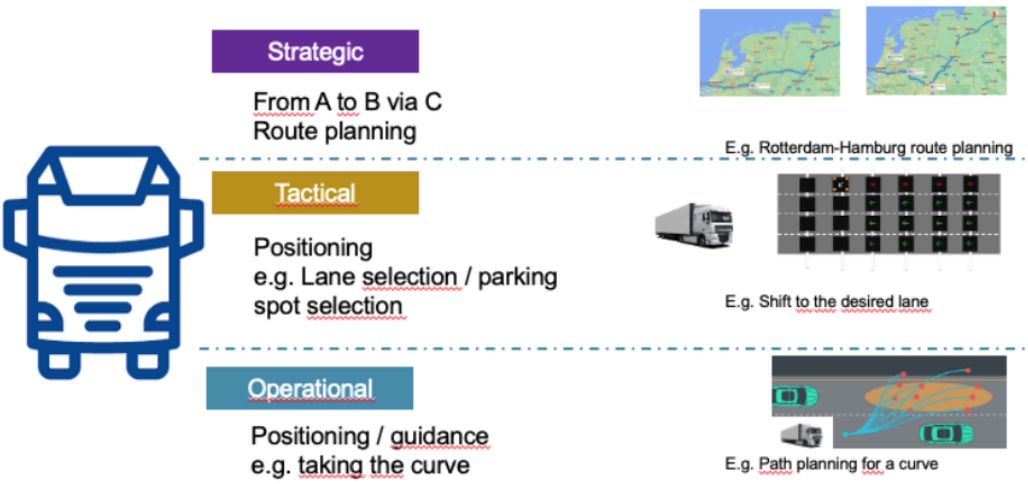

Figure 2 Different levels of route finding from a truck perspective

As shown in figure 2, where the planning and operational considerations on strategic level are on a kilometre-scale as well as a hours-ahead time horizon, the operational level is on centimetre-scale as well as a seconds-ahead time horizon. When translating these levels into a related technical architectural context for the required functions per level, these have been described in the SAE J3016 standard as shown in figure 3.

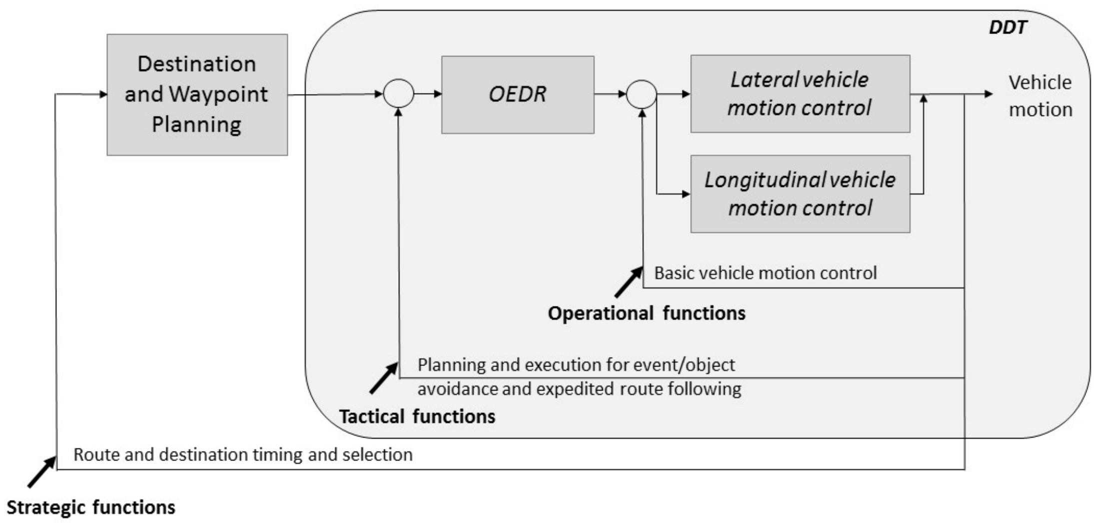

Figure 3 Schematic view of driving task showing DDT portion

Based on the architectures as described in SAE J3016, a fully automated freight vehicle does have the technical capabilities to perform the complete dynamic driving task (DDT) as described in Figure 3. Within MODI work package 3 on vehicle subsystems the implementation of these systems is worked out more extensively, however the foundations for performing these tasks have been constructed through use of these standards.

3.2 Perspective from a road authority

Road authorities and operators are responsible for the construction and maintenance of public roads. The size of a road authority may vary from large organisations with hundreds of employees like national road authorities like NPR(Norway), Rijkswaterstaat (Netherlands), Trafikverket (Sweden) to small local organisations like the municipality of Wageningen (Netherlands) or the municipality of Frederiksberg (Denmark).

Especially the larger organisations do often fulfil a so-called 'operational traffic management task' by making use of ITS (Intelligent Transport Systems). The goal is to improve the transportation system by making it more effective, more efficient and safer [2]. Note that this service is not per definition car-centric, nowadays a multimodal approach which takes bicyclists and pedestrians into account is more logical given the worldwide challenge around environmental issues.

Despite these operators not having responsibility for confined areas, the vehicles will have to be able to switch from public to confined terrain, and therefore switch from Road operator to local operator. This brings C-ITS technology and related standards for public road as relevant subjects for Confined area PDI design.

Interventions that a traffic operator can take when managing traffic across its (road) network focus on two kinds of events (expected and unexpected) and two intervals (regular/daily and irregular/incidents).

Traffic management interventions do focus on two kinds of events (expected and unexpected) and two intervals (regular/daily and irregular/Incidents). Examples within the constructed quadrant are shown in Figure 4 Traffic management interventions categories.

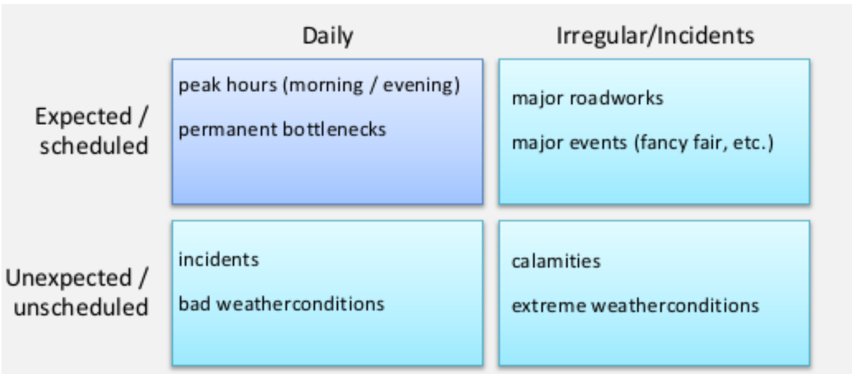

Figure 4 Traffic management interventions categories

Specific requirements for road authorities can be found in deliverable document "MODI D1.1 *User and stakeholder requirements*" within the RAR category.

3.3 Perspective of a confined area

A confined area within the context of MODI is seen as a privately owned area where automated freight vehicles will have to be able to operate. In most cases, these areas will not be publicly accessible (due to gates, barriers or other forms of access control), and will have a logistics/freight-related function (e.g. terminals, warehouses, etc.). Within the context of L4 freight operations the entity owning and managing the confined area is responsible for local operational safety (but not for the safety of the functionality of individual vehicles and their functional safety), guiding the vehicle to fit within running (logistics) operations, and could in that context be seen as a 'local road operator'. Given the fact that the L4 vehicles will operate within public road context as well, interoperability between 'confined' and 'public road' context is key. Moreover, given that much standardisation work has been performed within C-ITS public road context the confined area operator could benefit from the available technology and apply these in a lean fashion on confined area as well.

What automated transport could bring for confined areas is still a topic of discussion. L4 freight operations could help improve operational safety by lowering the number of humans present at the site. Furthermore, these vehicles could be a means of improving logistical throughput, enabling 24/7 operations and faster on-demand transportation. Finally, these vehicles could contribute to solving driver shortage problems.

The Physical and Digital Infrastructure (PDI) required for guiding and providing local context to L4 freight vehicles will be a specialised set of technical capabilities focussed on confined area operations within the overarching MODI PDI infrastructure.

4 Design for infrastructure for confined areas

This chapter describes the PDI design elements which are needed to support L4 driving on confined areas. The research results described in this chapter are the result of earlier mentioned alignment with MODI requirements, other PDI perspectives and the Use Case descriptions. An important annotation regarding the meaning and scope in which this confined area PDI is designed must be noted:

The focus on the design which is described in this document is on supporting L4 driving in *mixed traffic* situations on confined areas. In other words: the possible presence of automated vehicles *together* with manned vehicles at the same time at the confined areas. This choice has been made as it is foreseen for many years ahead that a mixed situation will be the standard. When reaching a point that all vehicles would be fully automated, a redesign of the content in this document will be required.

4.1 Truck handling on confined areas

A confined area in the context of logistics covers areas as ports, warehouses, cross dock facilities (road to ship- and/or air transport). In practice these confined areas might have a large variety in physical design, facilities for loading and unloading and exit and entrance procedures. However, L4 vehicle operations upon those confined areas can be brought down in its essence to two basic enabling competencies a vehicle needs to be able to cover its required operations within such confined areas. These competencies can be described as follows

1) Driving capability to reach the desired position(s) in the confined area.

A very basic and obvious competence for an L4 freight vehicle regardless of it being within a confined area or a public road regards its driving ability to reach a certain destination across a certain route. Upon a confined area this is also the case, be it on a private area where the vehicle must be able to reach for example a docking facility through a route starting at the confined area entrance or vice versa.

2) Technical features to support the loading and unloading of proposed cargo, passing a certain checkpoint or charging operations.

Apart from a L4 vehicle having the capability to reach its destination upon these confined areas, the vehicle should also have to be able to play a part in the loading and unloading of cargo. Without the interaction to enable these actions the validity of an L4 vehicle at the confined area is quickly lost, and should therefore be included. The need in this category depends on the type of cargo. For example, where container operations require twistlocks management, liquid cargo requires hose connectors, and pallet goods require a hose connector to enter the trailer floor. Currently it is generally the vehicle driver or personnel at the confined area site that operate the different systems around the truck (or mostly: the trailer) to guide the process. Within MODI it is not yet completely detailed out how the support of the loading and unloading process should or will work. According to MODI stakeholders known with these processes, there are different scenarios possible such as:

1. Fully automated scenarios which requires trucks/trailer combinations of infrastructure intelligence which can support the entire loading/unloading without human interventions.

2. Scenario’s involving (partly) manual support by supporting personnel human actions, e.g. open trailer doors or connect hoses to a tanktrailer.

As for automated connections between trucks (or trailers) and the loading/unloading operations, for many of the different variants automated solutions are already (or becoming) available. For example, for hose connections as well as automated charging of vehicles robotic systems are available capable of locating and (dis)connecting these devices without direct human intervention. It does however still remains a question from the viewpoint of involved confined area operators and logistics stakeholders if and how these investments will give a return as these kinds of solutions are not profitable with a small percentage of automated trucks and with limited standardisation developments on the several variations of interconnections.

When considering the current state of affairs where drivers operate a freight truck upon a confined area, the driver has several other responsibilities next to driving the vehicle. Examples of such responsibilities are:

1. Responsibility of check-in / check-out procedure for the truck at the (virtual) gate or entrance of a confined area.
2. Responsibility for managing and handing over the correct paperwork belonging to the cargo.
3. Responsibility for securing the cargo in the truck or do the check that the load has been secured properly by others. The responsibility for safely transporting the goods remain with the driver at all times both on public and on confined terrains.

In order to transition towards L4 freight operations without a driver in the loop (or even in the vehicle) these responsibilities will also have to be shifted to other responsible actors than the driver. The MODI project leaders acknowledge the need for solving these issues before stepping towards full L4 driving, and possibly the need for adequate PDI in supporting these use cases, however in the current PDI design these use cases are not incorporated. The PDI for confined areas, as for the other PDI aspects within the MODI projects, relate to the driving and mobility aspect of the driver and vehicle, including the several use cases required for making that transition.

In order to address the confined area Physical Digital Infrastructure, the description of the confined area PDI is structured in four main categories related to four core aspects that should be well aligned in order to enable an L4 vehicle to operate upon confined areas. These categories are:

1. **Physical Road Infrastructure:** The road body with its geometric design, extent and paving, including physical road safety equipment, physically visible signs, and road markings. See paragraph 4.2.
2. **Communication/Connectivity/CCAM:** All infrastructure for digital communication, including but not limited to road equipment (sensors, signs and other RSUs) set up for online communication with vehicles, traffic rules and regulations, and positioning services. See paragraph 4.3.
3. **Positioning:** This category includes requirements for positioning services and the positioning of roadside units and road data. Not detailed further in this deliverable.
4. **Data Types for HD-Maps:** This category outlines the specific data types needed for creating detailed and accurate HD-maps, which are essential for L4 vehicle navigation and decision-making. See paragraph 4.3.2.

4.2 Physical road infrastructure

The physical aspect in the PDI design for confined areas concerns all required physical aspects and objects required to support L4 operations within confined areas ranging from road body design and paving to physical signage, road markings and other physical equipment.

Road geometry

The physical road design upon confined areas in Europe are in many cases aligned with physical road design guidelines for public road geometry in the area the confined area is located. An example of such a guideline is the [CROW ASVV201 Aanbevelingen voor verkeersvoorzieningen] in the Netherlands which includes detailed design patterns for areas with a significant number of large vehicles. An illustrative example of how the turning radius of a freight vehicle should be considered when designing confined road geometry is given in the picture below:

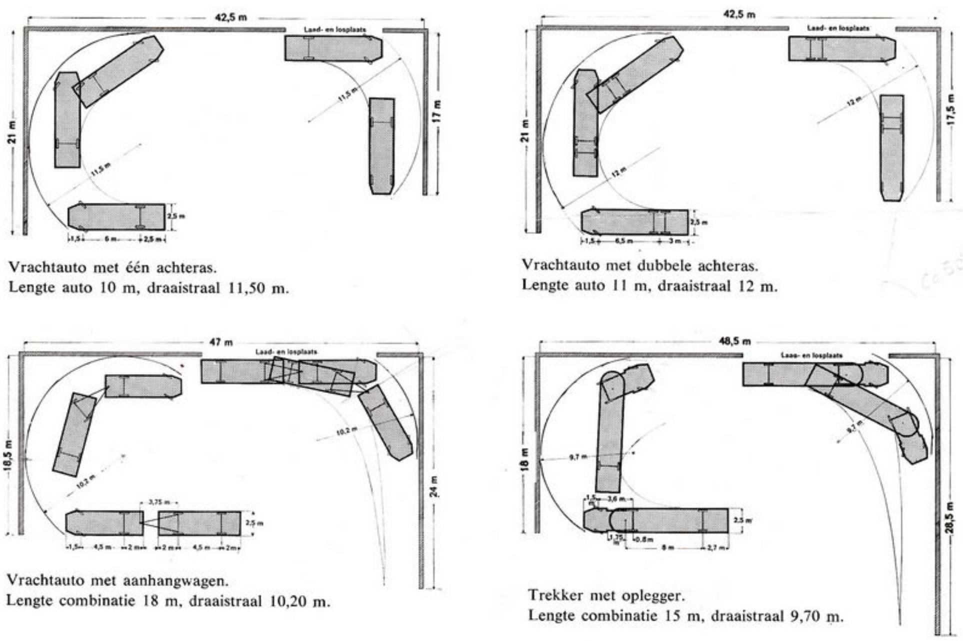

Figure 5: Example of design guideline for road geometry design for trucks

Vehicle providers/OEMs involved in the MODI project and participants in the vehicle adaptation work package stated that there is no direct need for alternative geometry guidelines on confined areas as automated trucks can navigate over current roads accurately enough, given that accurate digital maps of the environment are available. An extensive list of requirements and recommendations for road geometry are incorporated in the deliverable 4.1 PID for Public roads [4]. Therefore, the physical road geometry of confined areas should be aligned as much as possible with surrounding public road design guidelines to reduce any potential discrepancies for L4 vehicles in interpreting public and private road segments.

Loading and unloading facilities

Much in line with road geometry, when considering loading and unloading facilities upon confined areas comparable principles apply. Also, for generic facilities such as design of loading docks or other (un)loading facilities guidelines are established that have served as the standard for current facility design. MODI consortium partners have established that there is no need for a separate design for (un)loading facilities as steering and sensing capabilities of automated trucks are accurate enough to execute the docking process for these facilities safe and fast enough.

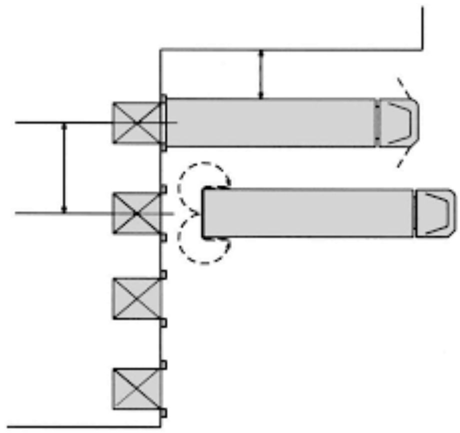

Figure 6: example of design of loading/unloading dock facilities, source: dockequipment [6]

In order to take the step from (partly) manual (un)loading at these facilities, detailed and reliable localisation and manoeuvring becomes of increased importance. In order to overcome these challenges and enable exact manoeuvres for docking, digital anchor points are needed to instruct and support the automated vehicles. The requirements for enabling this process are described in paragraph $4.2.1

Road markings, Safety zones and Parking facilities

The aim of road markings for automated trucking is supportive for validation of the digital map. According to all vehicle providers/OEMs, automated vehicles will navigate primarily on digital maps ($4.3). Physical assets such as road markings need to be clear but more important not confusing as they should be relatable to the digital equivalents. This need obviously already is the case for drivers, but it is key for automated vehicles. Road markings are an important backup along the digital map in order to calibrate the position and heading, and serve as fallback scenario if communication is somehow lost and the vehicle has to perform a safe manoeuvre to not obstruct or harm other road users. More information about requirements, road markings and standardization is described in MODI deliverable 4.2 on optimal PDI for Public roads [3].

When it comes to safety zones and parking facilities, these can be designed in a conventional way following the reasoning as described in the road geometry paragraph.

Traffic rules and signing

A specific category of physical road infrastructure requirements relates to traffic rules and associated (physical) signing. A very delicate and complex topic, which is being worked on by a range of stakeholders and initiatives such as NAPCORE, the EC ITS Delegated Act, RTTI and the DATEXII community. Addressing these requirements is deemed essential for automated driving as a whole and so for automated trucks.

In its essence two main challenges are to be overcome under the scope of traffic rules and signing for L4 freight vehicles.

1) Standardization of traffic rules where possible.

In order to be able to interpret traffic rules and regulation by human drivers, especially for cross-border mobility, a range of initiatives are ongoing to standardize traffic rules across the European Union, such as aligning the implementation of Urban Vehicle Access Regulations (UVAR), maximum speeds and related road layouts, and standardisation of roadmarks and route signage. These initiatives are paving the way for L4 vehicle interpretation of active and local traffic rules and regulations by use of visual sensors interpreting these signs. Adaptations will be required for exact scalable interpretation by L4 vehicles, however the basis is being constructed for this already.

2) Digitalize traffic rules and location in order to integrate them into digital maps.

Another important requirement for human drivers already, let alone for automated vehicles, is alignment between what drivers are shown on the street and what information is being given to the driver through the onboard unit based on digital maps. Not only is this a challenge from the viewpoint of constructing a digital twin of active traffic rules and regulations, but only a challenge in maintaining that digital twin every time that these rules and regulations are (if only temporarily) adapted. Especially around roadworks this is a known challenge. Ongoing initiatives such as the EC ITS delegated act and the NAPCORE project support the alignment of digital and physical traffic rules and regulations already.

In general traffic rules at confined areas are as much as possible aligned with the regulations and signing on surrounding public roads infrastructure in order to ease the transition between public roads and confined areas for drivers, and consequently for L4 vehicles. Therefore, the extended R&D results on this topic have been included in deliverable 4.1 PID for Public roads [4] as well.

4.3 Digital design

As described in paragraph 4.1 the key feature for the transition towards L4 freight vehicles within the scope of MODI is these vehicles being able to drive around Europe on both public road and confined areas. Nowadays driving instructions from a confined area operator will be communicated verbally to the truck driver. These instructions need to be digitalized. From a more high-level point of view a truck gets driving instructions from its operationally responsible stakeholder (e.g. the fleet manager, Transport Management System, owner, OEM). This will be instructions in a sense of ‘get from your current location [Rotterdam] to [Hamburg] to pick up a cargo on the confined area of [company X]. It could pass international border crossings in meanwhile. An example of a trip has been depicted in the Figure 7 below.

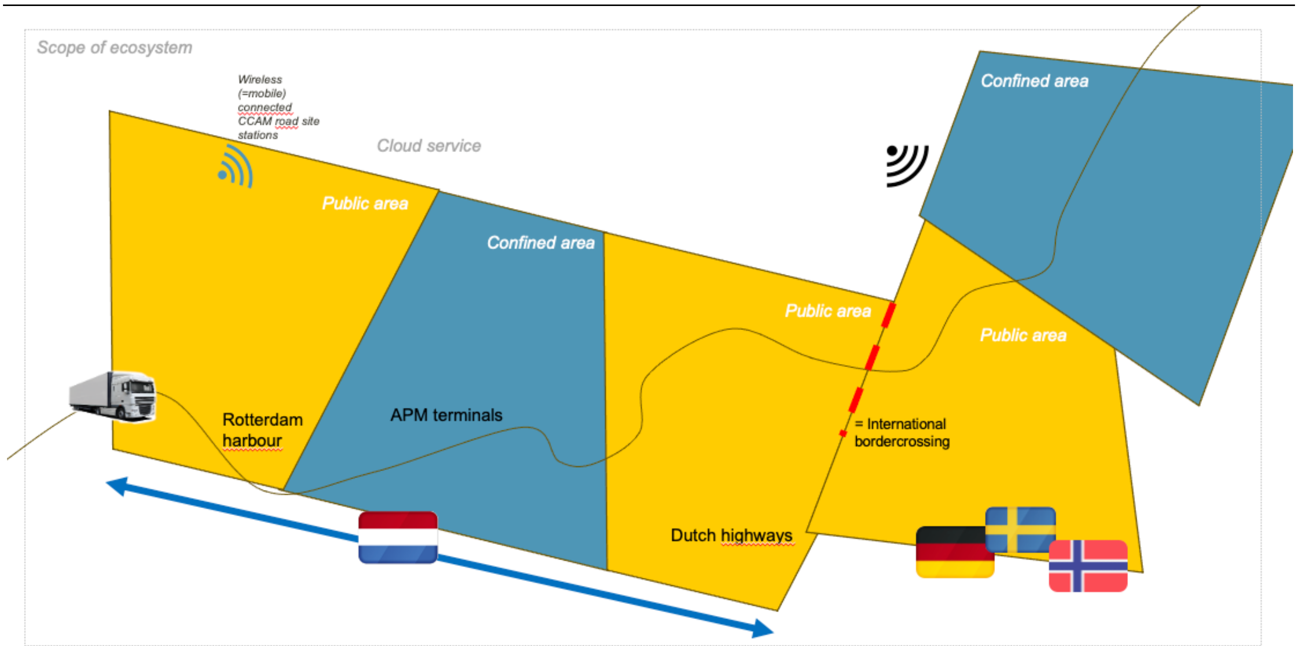

Figure 7: Virtual trip from a truck that goes from public roads to confined areas and vice versa.

Once arrived at a confined area, it is not in the interest or sphere of influence of the fleet manager how a truck will follow its path on the area. This stakeholder provides the requirements on, for example, unloading, pickup or swap the cargo within the agreed, or expected, time frames, in line with the goal of the visit. It is then up to the confined area manager (or operator) what kind of routing is devised in order to execute the belonging cargo task. Mostly these instructions consist of one or more consequent destinations on the confined area that the drivers should head for (e.g. "park at parking bay C4", "Reverse park at Dock 4"). Although in general there is one primary or obvious (marked and/or signed) route towards those destinations, the driver remains in charge of deciding and driving the actual route between the entrance and these subsequent destinations.

From a conceptual perspective digitising these instructions could be interpreted as a form of 'valet parking' where a car owner will hand over the keys to a specific driver to park the car. Once back at the gate the 'virtual keys' from an automated vehicle will be handed over to the fleet manager again to follow its path on (mainly) public roads towards the next destination of a confined area.

The concept of valet parking has been used as a main approach to develop the handling of trucks on confined areas within MODI. This approach is primarily based upon input and ongoing work from different logistical facilities stakeholders within MODI, as well as a related former European R&D program - Magpie - which developed an architecture for performing such 'valet parking' like activities within confined logistical environments.

In this paragraph the aim and working of the interface B has been described. The interface B is an interface under the umbrella of the "CCAM interface" which has been described in MODI deliverable task 4.1 [3]. More information could be found in that deliverable. An overview of the CCAM interface architecture is shown in Figure 8 below:

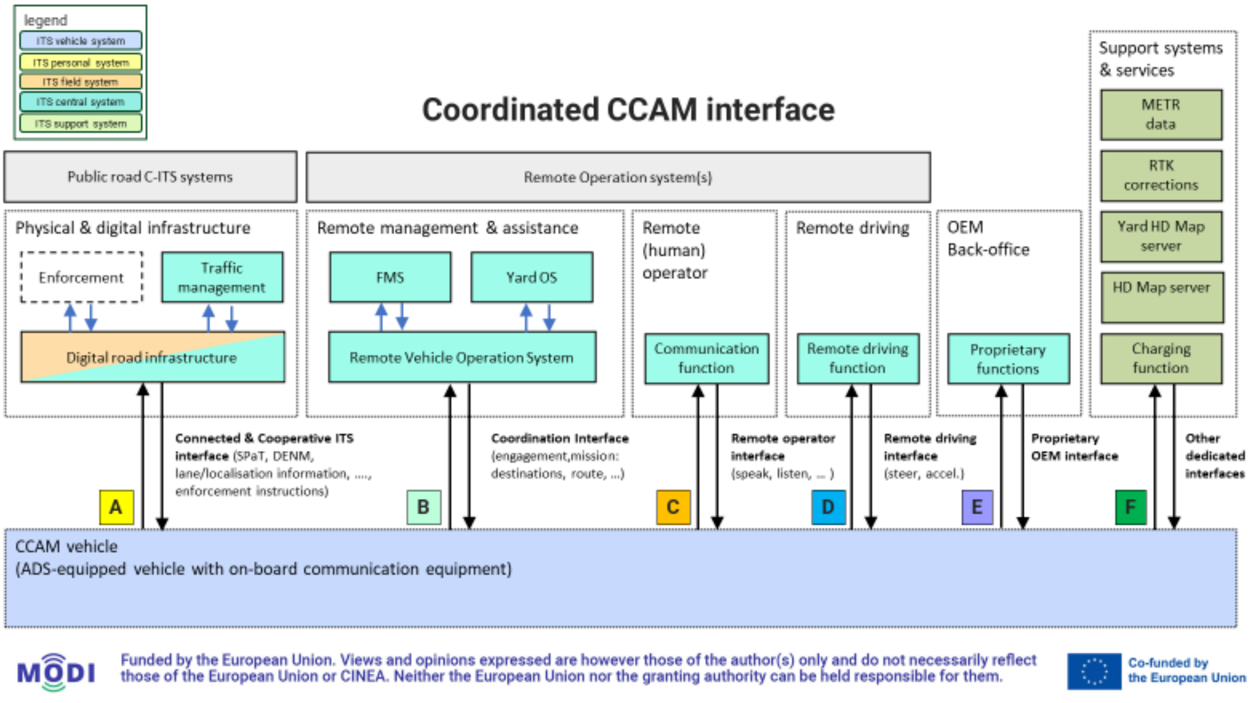

Figure 8: MODI CCAM interface

The interface B can provide the vehicle with an assignment containing the destination and route to the destination for both the Fleet manager and the Confined Area Manager. The design of this interface is described according to several prominent use case features that are included in several of the MODI use cases and are representative of many other conceptually comparable actions on confined areas. These features regard:

1. Gate Access (§4.3.1)
2. Routing and Mission Management (§4.3.2)
3. Freight Documentation (§4.3.3).

Once interface B is established, this chapter describes interface A as the way in which infrastructure could support automated trucking with C-ITS reporting in a scalable and interoperable manner between public and confined areas.

4.3.1 Gate Access (interface B)

The moment where an automated vehicle will leave the public roads and enter a confined area is covered by the so-called Gate Access process. Within this process, the 'gate' concept does not have to be a physical movable gate, but also movable barriers, as well as merely 'virtual' gate concepts where this serves as a way of guiding the entry, authorisation process. This process could be seen as the process where a regular truck driver (or vehicle) will register upon arrival at a reception / front desk and get further instructions were to go within the confined area. The front desk has been (partly) replaced by a Yard OS (Yard operating system) which has digital capabilities via the standardizes interface B to interact with AVs and related fleet management system. More information about this process has been described in MODI deliverable 4.1 reference [3].

In the digitalizes Gate Access process:

1) The AV that arrives sends a message to the Yard OS it has arrived at the dedicated confined area entry location (gates).
2) The AV shows a visitID which is required at the yard before the trip started, and enables the authorisation procedure of the Yard OS.
3) The AV switches to 'valet parking' mode as it awaits further detailed routing instructions from the YardOS where to go and how to perform that task (speeds, local regulations, etc.)
4) AV is enabled to exchange digital freight documents from the moment of entry at the confined area entrance.

The Yard OS

1. Checks whether the arrived AV is allowed to go on the terrain based upon the visitID and related procedure.
2. Gives the first route and mission to the AV where to go.

An example of this procedure with details is given in the Figure 9. Please note that this example is tailored for application in the Rotterdam MODI use case, and is designed for availability of the APM Terminals backend services.

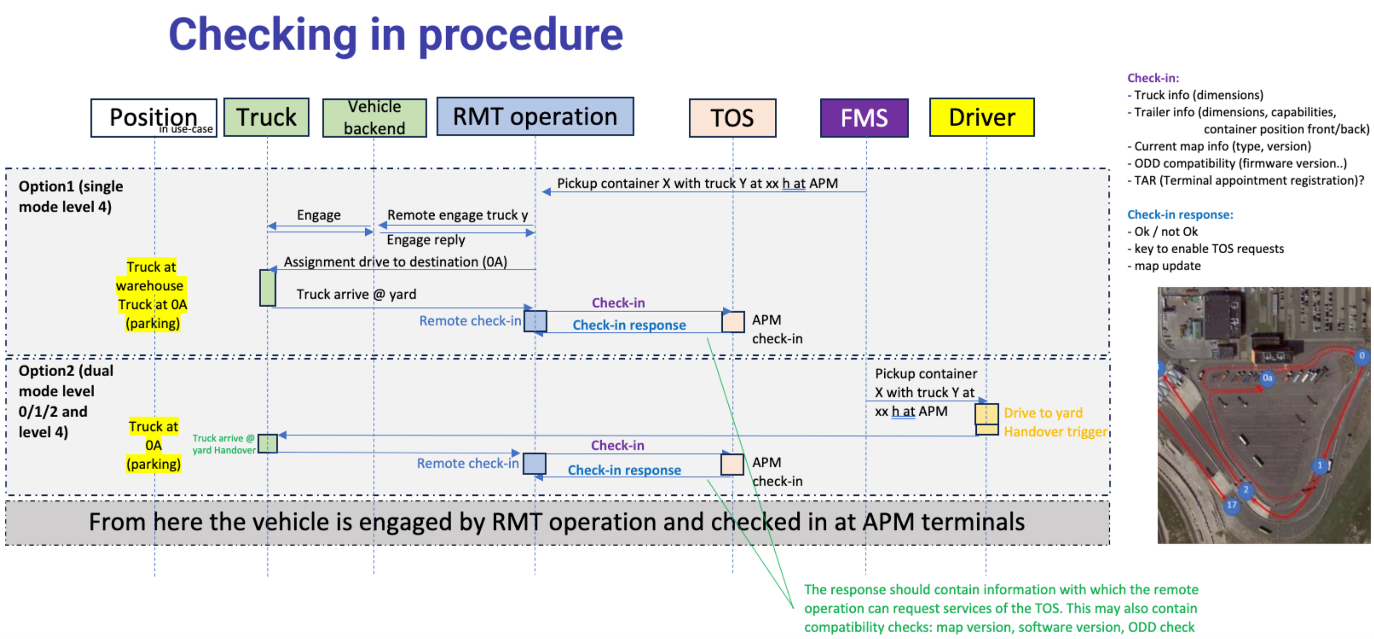

Figure 9: Gate Access procedure – example for APM terminals in Rotterdam

4.3.2 Routing and mission management (interface B)

Once entered the confined area the aim of routing and mission management is centred around route assignment and destination assignment. This information is exchanged through interface B.

Route assignment

The concept of route assignment is in the essence based on a digital map of the confined area. All links (road segments) and nodes (intersections) on the confined area are digitalized in the map. The

Yard OS needs to give a certain route by giving all the desired routing ID's to the AV. Figure 10 gives an impression of a route via different segments and nodes and the corresponding ID's.

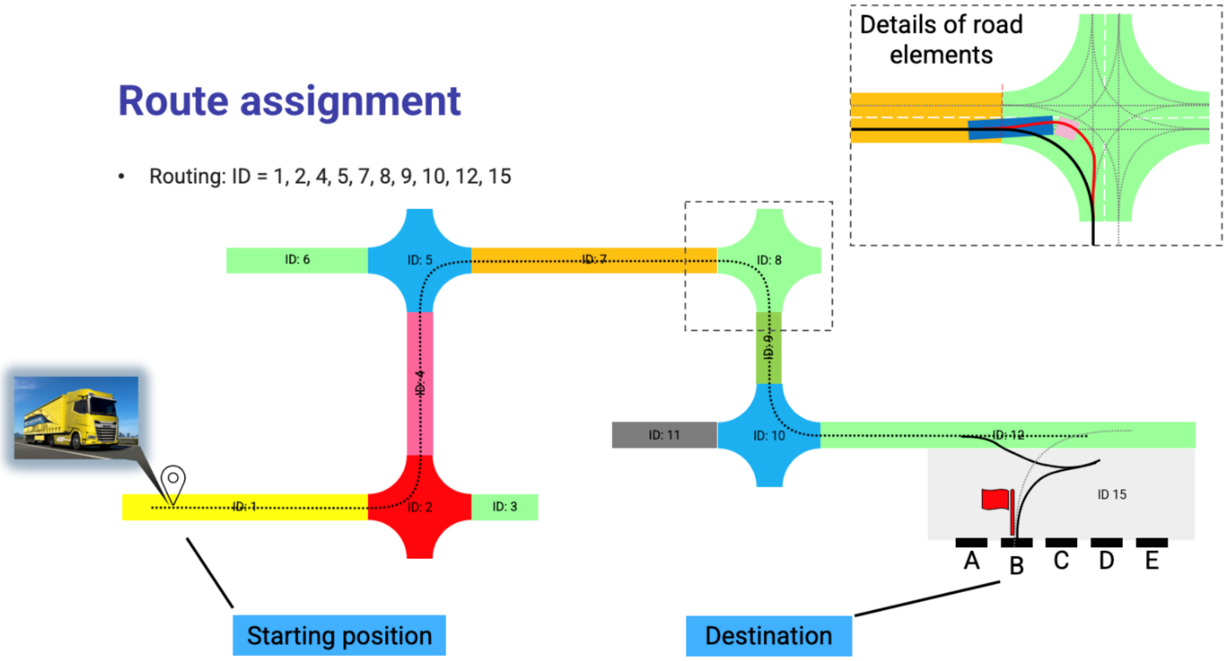

Figure 10: Route assignment via digital map and corresponding route ID's

Digital maps for public roads are available as commercial services from companies e.g. TomTom, Here or Inrix. However, for confined areas they are not always available or accessible. The main reason for this is commercial limitations for private companies to drive around upon confined areas in order to make digital versions of such areas. Moreover, the need for such maps is strongly related to the development in connected and automated driving, and therefore, this need has emerged only recently. From a technical point of view, it is a relatively simple task to create a digital map of a confined area, especially with all experience and active parties in digitizing public roads already. Moreover, apart from availability of these maps, there is no international widely adopted standard to create digital maps. This hurdle must be taken if the wide adoption of AV's is a common goal. This is work in progress and undertaken by organisations such as TISA, but progress in this field is currently insufficient for supporting large scale deployment of automated vehicles in logistical chains related to confined areas.

In order to support the required functionalities for shorter term AV deployments in confined areas, High Definition (HD) maps are created for the terminals and other confined areas. These HD maps consist of three static layers as depicted in the Figure 11.

- The point cloud layer contains an accurate georeferenced point cloud map of the environment. It is mainly used for vehicle localization.

1) The road geometry layer contains the road geometry information, which is provided in ASAM OpenDrive format. It is used to plan routes and compute the path for the vehicle to follow.
2) The environment geometry layer contains information about the drivable and non-drivable areas in the map. It is used for path planning, and it is supplied in GeoJson format.

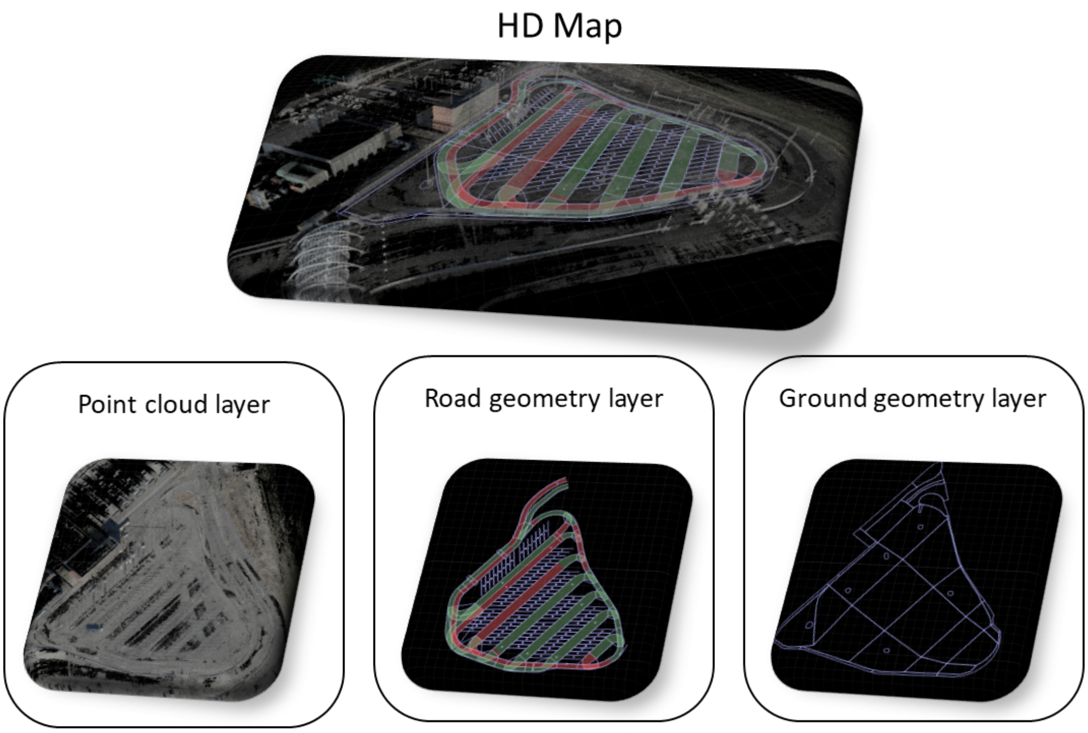

Figure 11: HD map of the APMT parking area, consisting of the point cloud layer, road geometry layer and ground geometry layer.

The HD map is generated in three stages. Firstly, data is recorded on the environment to be mapped using a mapping vehicle with a state-of-the-art RTK GNSS INS system and Lidar. The recorded sensor data are post-processed with the point cloud map generation pipeline to create an accurate georeferenced point cloud map. Then the road geometry and environment geometry layers are annotated manually and are registered to the point cloud layer.

Destination assignment

A route assignment is the instruction required for an AV to understand the route how to go from A to B. In the context of AVs for logistics and the aim of loading and unloading of cargo, it is important to reach the destination in a dedicated way to support the loading and unloading actions as much as possible. Therefore, a specified way of parking an AV is a necessity.

Within the MODI project this challenge is overcome through the usage of goal points and anchor points. The Figure 12 describes this process:

![MODI logo]

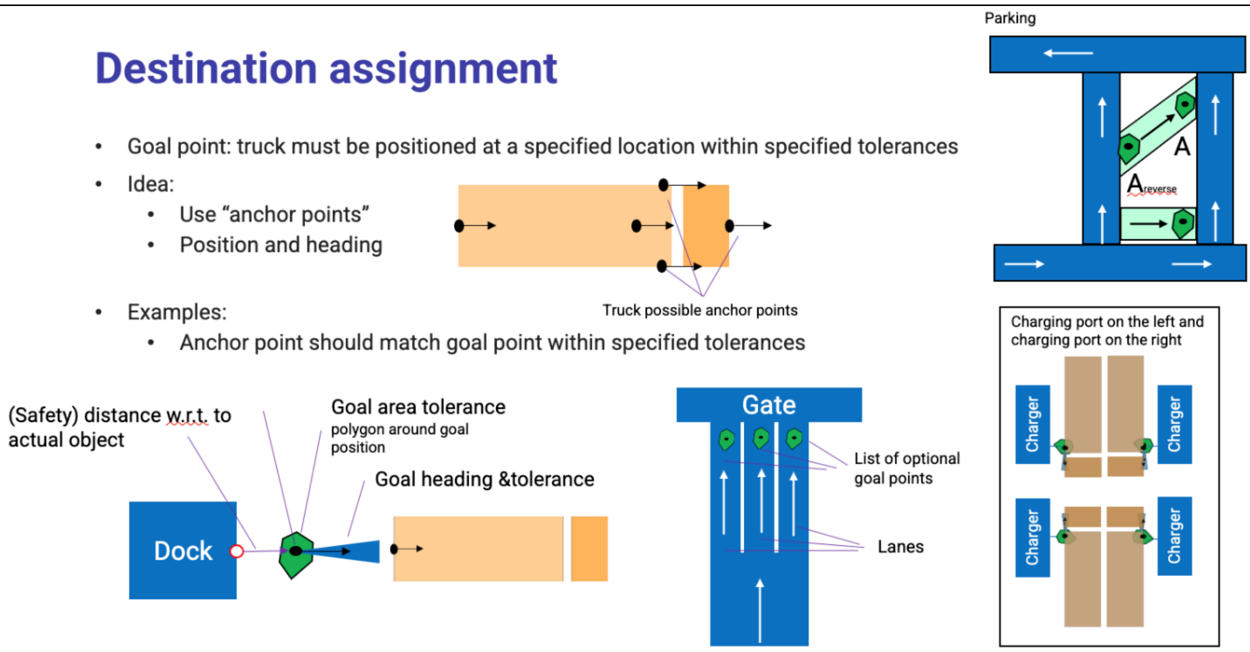

Figure 12: Positioning of a truck with goal point and anchor points

The specific goal points and related anchor points for docks or other loading and unloading facilities, needs to be part of the digital MAP as needed for the route assignments. In this way, not only will the AV understand where to go and how to go there, but also know in a precise manner how and where exactly to come to a standstill for performing or undergoing specific processes such as loading/unloading, connecting/disconnecting trailers, charging and regular parking. For further information on this process see MODI D4.1 [3].

4.3.3 Freight documentation (interface B)

Apart from the driving capabilities, a driver task comprises more than solely driving the vehicle. Taking care for the freight documentation is also a task for the driver. Another task that needs to be digitalized in operationalizing autonomous transport. Freight documentation needs to be available complete digitally in the context of automated trucks. The application of digital documentation is a common property nowadays (e.g. digitally signed pdf files which have a legal status nowadays. In the context of logistics, it is not primarily a technical question that needs to be solved. It is a challenge how to give place do freight documentation in an ecosystem in order to give insight in the documents to the right stakeholders. Stakeholders in this perspective are e.g. the fleet owner, the origin/destination yard or warehouse but also governmental enforcement services as the police.

Within MODI, it has been decided to not invest our time into this subtopic as there are other EU R&D projects which are figuring out how to deal with digital documentation (e.g. Smart Urban Traffic Zones).

4.3.4 C-ITS infrastructure supportive services (interface A)

In general, autonomous vehicles are equipped with an impressive number of sensors like radars, cameras and lidar facilities. Whatever the setup is, physical sensors do have a certain range in which they are able to detect things. Apart from that, in some situations some sensor technologies will work poor or not at all. Think about video sensor capabilities in the case of foggy weather. This is where C-ITS comes in. Through interface A Cooperative Intelligent Transport Systems (C-ITS) information can be exchanged. C-ITS is about vehicles interacting with the digital road infrastructure and with each other. The idea is that sharing information can improve road safety, traffic efficiency and comfort of driving by providing information sensors cannot (always). C-ITS is also one of the domains the European Telecommunications Standards Institute (ETSI) has been focussing on. Many standards regarding C-ITS are already available for various applications, e.g., V2X message set definitions for sharing traffic light information (Signal Phase And Timing (SPAT) messages), information to create awareness (Cooperative Awareness Messages (CAMs)) or alerting road users about traffic events (Decentralized Environmental Notification Message (DENM)). Basic principle behind the exchange of these messages is that these are available to anyone who can receive them. Thus, in principle messages are “open”.

Also, C-ITS is in principle communication technology agnostic. Different technologies are available to realize the needed connectivity. Often C-ITS deployments use short-range communication (e.g. ITS-G5, Cellulair-V2X), long-range communication (e.g. cellular 4G/5G) or a combination of the technologies (hybrid solutions). The used communication technology will also set certain requirements for the specific security solutions. Best practice is to follow the available security standards from the used connectivity technologies.

As C-ITS has been standardized and described in extensive documents which can be found in the open, this deliverable is not deepening out the details of this full operational piece of technology. A bit more detail and the aim of C-ITS messages, can be found in MODI deliverable “D3.1 Connectivity requirements” [5]. The application of C-ITS messages for the MODI use cases are described in deliverable “D4.1 Validated interface for Coordinated CCAM”.

5 Conclusions

The MODI project aims to accelerate the introduction of highly automated freight vehicles by contributing with different blueprints from different angels (technical, economical, societal, etc.) and demonstrations in order to contribute to overcoming barriers to the rollout of automated transport systems and solutions in logistics. In this deliverable, the focus has been to explore the needs for confined areas for being a welcoming and reliable host for automated vehicles.

In the very essence, a truck in a confined area needs to go to one or more destination points, load unload or swap cargo before exiting the area. Communication nowadays happens via the truckdriver which isn't there in an automated vehicle.

Within MODI a 'Remote vehicle operating centre' design has been made to guide automated trucks (or vehicles) successfully over the yard. This includes the necessary gate access process and supportive C-ITS services. MODI pre-tests (before the final demonstration) show the proposed confined area design principles do work in a field implementation. Obviously, different elements need to be prepared and maintained in confined areas in order to support automated transport. The items could roughly be divided into the topics: Physical (markings, signs, …), Digital (connectivity, messages, back-office, ...) and Map/positioning (HD, map/position services, …).

Driving the truck is one task for a truckdriver nowadays. Other tasks, like handling of the freight documentation, assisting with the loading and unloading process and securing the cargo are activities which could be automated as well but require quite some investments at the side of the truck/trailer combination or the confined area. A more in-depth R&D project on the non-driving aspects is required to give a boost to the standardization of these items.

However, while more steps need to be taken, our conclusion within the context of MODI is that we could have made huge steps toward the aim of L4 driving!

5.1 Recommendations

Within MODI a solid basis of technology for confined areas to handle automated vehicles has been demonstrated. Further research and developments are necessary on the following topics (Table 1):

Table 1 Table with recommendations

ID	*Topic*	*Description*	*Potential front runners*
T4.1-R1	Standardisation of Digital maps for confined areas	Digital maps are available for public roads but not confined areas. From a technical point of view it is possible to create digital maps but an international accepted (technical) format is not in place.	Map creators like TomTom, Here and Inrix.
T4.1-R2	Standardisation of routing instructions for AV's/trucks	Within MODI the concept of giving route instructions to a AV has been implemented and tested successfully. The lessons learned should be uplifted towards technical standards which can be adopted by OEMs worldwide. Please note that there is an overlap with concepts which has been defined in the area of	Truck manufacturers like DAF and Volvo but also in the area of passenger cars like Toyota and Ford to support valet parking concepts.

ID	*Topic*	*Description*	*Potential front runners*
		Valet Parking. ISO standards in this area are available.	
T4.1-R3	Standardisation for load/unload handlings for trailers	Mostly a truck driver prepares a truck for the loading and unloading process like opening trailer doors, connecting hoses or control a pallet truck. In full automated environments these activities need preferably automated as well. There are some solutions going around but they are far from mature for large scale rollouts.	Trailer manufacturers

6 References

[1] J3016_201609 Surface Vehicle Recommended Practice - Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles – SAE

[2] Regional and sustainable traffic management: methodology and applications, Henk Taale ea 2003

[3] MODI D4.1 Validated interface for Coordinated CCAM, TNO ea 2024

[4] MODI D4.2 Optimal designs of physical and digital infrastructures at public roads, Kartverket ea 2024

[5] MODI D3.1 Connectivity requirements

[6] Dockequipment designguidelines and technical specifications, Dockequipment 2015

[7] https://www.magpie-ports.eu/magpie-project/magpie-deliverables/ - Deliverable D4.1 Digital platforms and services