A leap towards SAE L4 automated driving features

Assessment of CCAM-implementation along MODI-corridor

23rd February 2026

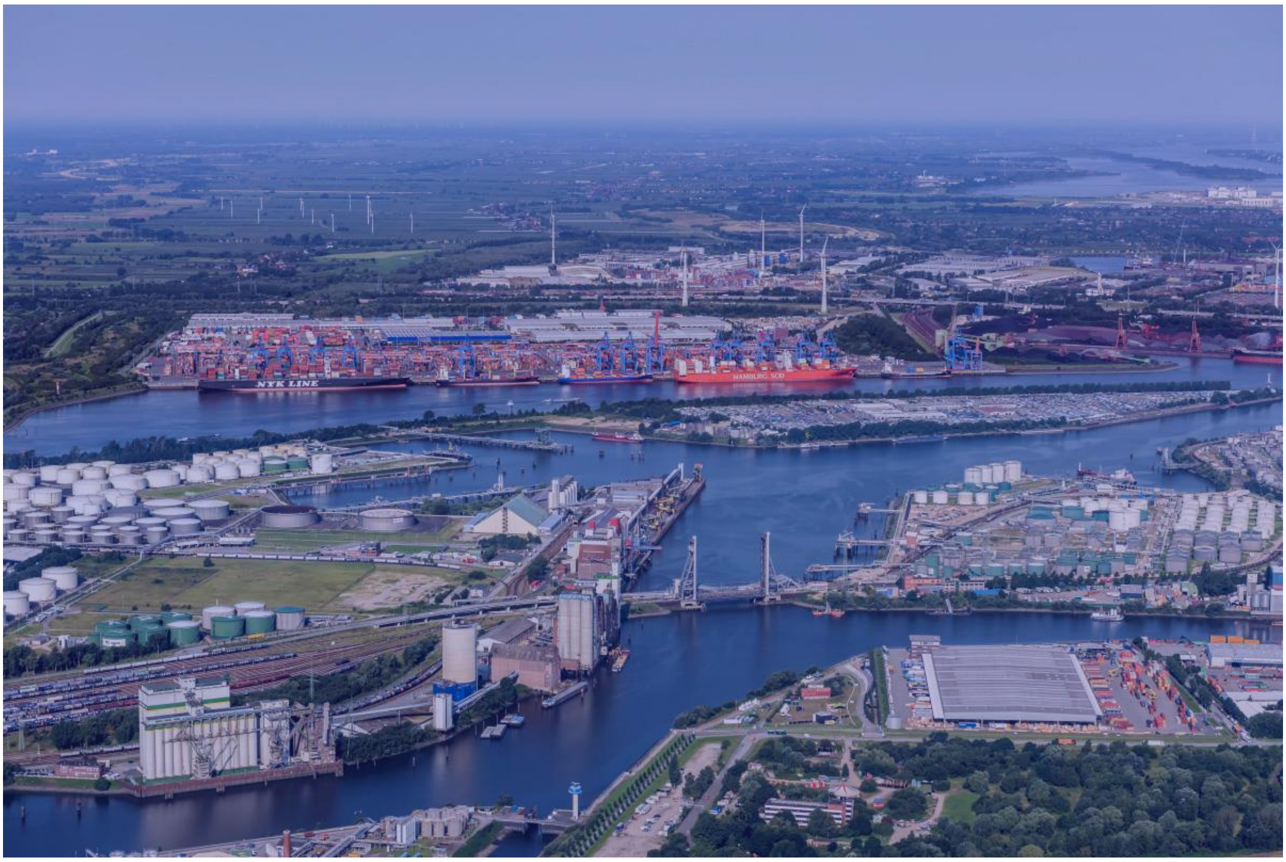

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Table of Contents

List of Figures

List of Tables

Terms and Abbreviations

Term / Abbreviation	Description
5G	Fifth generation of cellular network technology
ADS	Automated Driving System
AFIR	EU’s Alternative Fuel Infrastructure Regulation
AI	Artificial Intelligence
API	Application Programming Interface
BISStra	Federal (German) highway information system
CAM	Cooperative Awareness Message
CCA	Cocreation arena
CCAM	Connected, cooperative and automated mobility
CNN	Convolutional neural network
DENM	Decentralized Environmental Notification Message
DGPS	Differential Global Positioning System
EGNOS	European Geostationary Navigation Overlay Service
EPSG	European Petroleum Survey Group
ESG	Environmental, Social and Governance
FKB	Felles Kartbase (Norwegian)
Galileo HAS	Satellite Navigation System Galileo High Accuracy Service
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GTSRB	German traffic sign recognition benchmark
HAS	High Accuracy Service
HD map	High-Definition Map
IMU	Inertial Measurement Unit
INS	Inertial navigation system
ITS-G5	Intelligent Transport Systems - Wi-Fi standard IEEE 802.11p
LiDAR	Light Detection and Ranging
L4	SAE Level 4 (of automation)
LTE	Long Term Evolution
METR	Management of Electronic Traffic Regulations
MRM	Minimum Risk Manoeuvre
NAL	National Charging Infrastructure Agenda (Dutch)
NRTK	Network Real Time Kinematic
NVDB	Nasjonalt Vegdatabank (Norwegian National Road Database)
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OKSTRA	National Object Catalogue for Roads and Transportation (German)
OSNMA	Open Service Navigation Message Authentication
OSR	Observation Space Representation
PDI	Physical and Digital Infrastructure
PPP-RTK	Precise Point Positioning – Real-Time Kinematic
QoS	Quality of Service
R&D	Research and Development
RADAR	Radio Detection And Ranging
RO	Road Operators
ROI	Region of Interest

RQ	Research question
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTT	Round-Trip Time
SAE	Society of Automotive Engineers
SLA	Service Level Agreement
SNR	Signal-to-Noise Ratio
SSM	Surrogate Safety Measures
StVO	Straßenverkehrsordnung
TCP	(Network) Transmission Control Protocol
TEN-T network	Trans-European Transport Network
UC	Use case
VMS	Variable message signs
WEGGEG	Weggegevens (Dutch Road Data)
YOLO	You Only Look Once

Executive Summary

This deliverable assesses the readiness of the Rotterdam–Oslo corridor for Level 4 (L4) automated freight operations within the MODI project. It combines multi-partner field measurements and desk studies to identify segments and conditions that could potentially constrain L4 operation. The analysis suggests that the corridor could be conditionally suitable for L4 demonstrations if Operational Design Domains (ODDs) are scoped at segment level and strong redundancies across perception, HD maps, digital traffic sign feeds, and positioning are established. However, several of these capabilities are only partially in place, and further development and validation are required before reliable large-scale deployment can be assumed.

Field campaigns show strong but uneven performance across key dimensions. Lane and sign detection work well on straightforward motorway segments, but degrades with complex or temporary markings, dynamic signage, adverse weather, and transitional areas such as interchanges, tunnels, and toll or ferry approaches. Mobile LTE / 5G connectivity is generally robust, with short service losses mainly at borders and in tunnels. High-accuracy GNSS with correction services achieves centimetre-level precision for substantial portions of the route but remains vulnerable to occlusions and reconvergence delays after interruptions. Charging infrastructure coverage is sufficient for single heavy-duty battery-electric vehicles with moderate detours, while scalability under higher simultaneous demand requires further analysis.

Based on these findings, the report recommends corridor-wide digitalization of dynamic signage and temporary traffic management using machine-readable, lane-specific, harmonized data models. It also calls for standardization of cross-border geodetic harmonization for GNSS services. Furthermore, section- and condition-based ODD engineering should be implemented with defined degraded modes and remote intervention policies. Collaboration between OEMs and road authorities is essential to ensure cost-effective and robust infrastructure for L4 operations.

For business readiness, targeted co-investment models between OEMs and technology providers are recommended, alongside capacity planning and site audits for truck-capable charging stations and additional connectivity infrastructure.

Adopting L4 automation along the Rotterdam–Oslo corridor could offer benefits for logistics stakeholders, including reduced driver dependency, predictable transit times, and improved fleet utilization. Real-time data exchange and harmonized APIs enable dynamic routing and minimize idle time, while scalable charging infrastructure supports decarbonization and ESG goals.

To ensure safe and interoperable deployment, regulatory alignment across EU and national frameworks is essential. Harmonized governance of digital traffic signs, GNSS standards, and cross-border data exchange underpins reliability. EU CCAM [27] and TEN-T [26] directives provide the legislative foundation, complemented by national policies on liability, remote operations, and cybersecurity. These measures collectively advance MODI’s objectives for efficiency, safety, and sustainability, creating a competitive advantage for early adopters.

In summary, no single information layer is sufficiently reliable across all corridor segments and conditions. However, a potential pathway emerges: Targeted PDI improvements, harmonized digital data and APIs, and carefully scoped ODDs could collectively support safer, more efficient, and scalable L4 automated freight operations along the MODI corridor. These insights feed MODI’s Book of Recommendations (D1.5), Impact Assessment (D2.4), and Gap Analysis (D2.5).

1 Introduction

This deliverable provides an overview of the objectives, scope, and structure of the readiness assessment within the MODI project. It begins with a summary of the project context and its relevance to automated and connected mobility. The aim of this document is to outline the prerequisites and methodological approach for evaluating corridor readiness, ensuring alignment with MODI's overall goals and outputs. Additionally, the report explains how this deliverable contributes to the broader project framework and details its internal structure for clarity and ease of navigation.

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 main goal of this deliverable is to provide an assessment of CCAM implementation along the MODI corridor from Rotterdam to Oslo, in line with the overall objective of the use case. This includes a comprehensive data collection and analysis focusing on critical road segments and challenges for automated driving at SAE L4, to verify the readiness of the corridor for this level of technology.

Specifically, deliverable D5.5 aims to:

- Collect and analyse real-world data from the entire MODI corridor using vehicles equipped with relevant sensors.
- Identify and evaluate critical road sections and infrastructure elements (both physical and digital) that are essential for enabling highly automated driving.
- Assess the readiness of the corridor for highly automated road freight transport and logistics, considering cross-border interoperability and harmonization of Operational Design Domains (ODDs).
- Provide insights into challenges and barriers from the perspectives of vehicle manufacturers, logistics operators, and road authorities, and derive recommendations for infrastructure and system optimization.

Ultimately, this deliverable will serve as an input for evaluating the feasibility and requirements of L4 automation in real-world logistics operations, supporting future large-scale deployment and policy development.

It is important to acknowledge that the physical and digital infrastructure relevant for automated driving is evolving rapidly. Therefore, while the findings presented in this report are based on data collected during the project period, certain aspects may change as technologies and standards develop further. Moreover, as the data collection was performed within a defined period and along a specific section of the MODI corridor, the extent to which the findings can be generalised to other road environments or corridors may be limited. Nevertheless, the insights obtained provide a first evidence-based foundation for assessing infrastructure readiness for automated freight transport in Europe.

1.3 Relation to MODI Output

This deliverable primarily contributes to the *Book of Recommendations* (D1.5), which will synthesise lessons learned across the MODI project into actionable guidance for future large-scale deployment of automated freight transport in Europe. The insights, results, and practical experiences documented in this deliverable form a key evidence base for the recommendations on how to design, implement, and operate suitable physical and digital infrastructures for L4 operations.

In particular, this deliverable builds upon and complements the findings of D4.2 (*Optimal Designs of Physical and Digital Infrastructures for Public Roads*). While D4.2 defines the general requirements for physical and digital infrastructures to enable automated freight operations, the present work focuses on testing and validating these requirements in practice. Through experimental demonstrations and field observations by driving the corridor (and several individual stretches), this deliverable investigates whether the identified requirements indeed represent operational challenges and to what extent they impact the functionality, interoperability, and safety of CCAM freight operations (D2.4 – *Impact Analysis*). The results thereby should provide feedback to refine and prioritise the recommendations developed under D1.5.

The outcomes of this work will also support the *Gap Analysis on Technology and Societal Readiness* (D2.5) by offering empirical insights into the real-world feasibility of infrastructure concepts and the maturity of enabling technologies. By bridging the conceptual requirements from D4.2 with demonstrated results, this deliverable should strengthen the evidence base for MODI's overall assessment of readiness levels along the corridor.

Figure 1 illustrates the interconnection between the CCAM use case and the other use cases within the broader MODI project structure. The CCAM use case, documented in this current report D5.5, is not an isolated activity; rather, it is closely linked to specific national use cases implemented in the Netherlands, Germany, Sweden, and Norway. Each of these country-specific use cases produces its own assessment – D5.1 (UC NL), D5.2 (UC GE), D5.3 (UC SE), and D5.4 (UC NO) – which feed into the overall evaluation of the MODI corridor.

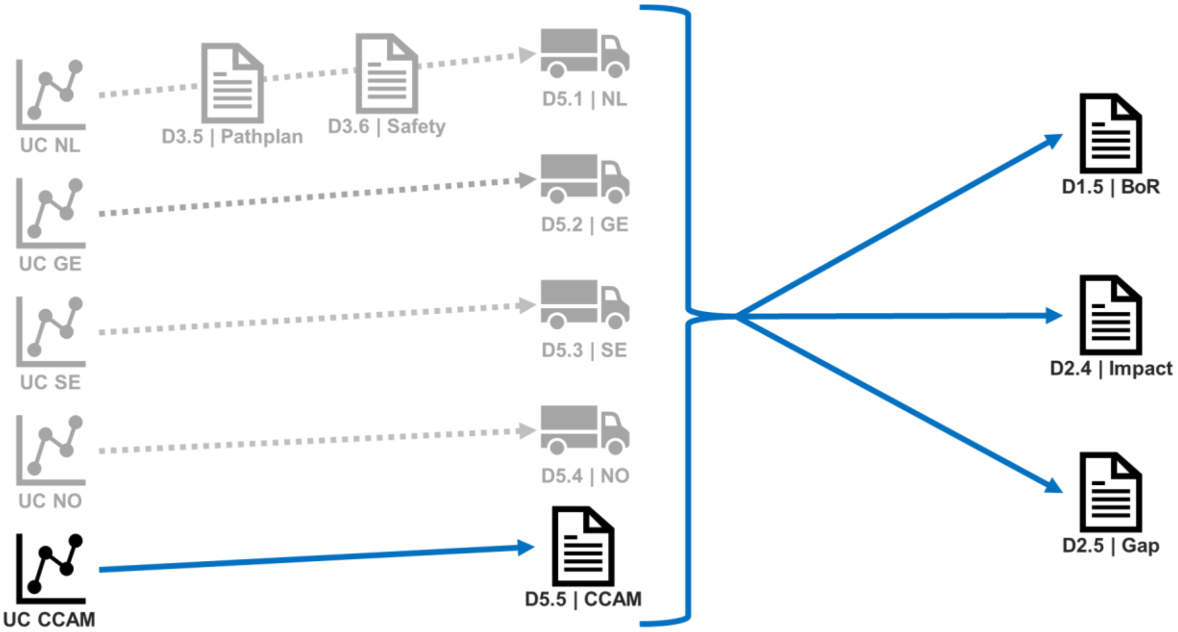

Figure 1: Context of use case CCAM in the overall MODI project

The CCAM assessment consolidates insights from these national evaluations and integrates them into a comprehensive analysis. This synthesis generates critical outputs for MODI's final deliverables, namely:

- D1.5 *Book of Recommendations* – capturing consolidated requirements based on corridor-wide findings.
- D2.4 *Impact Assessment* – evaluating the overall impact of the MODI activities and its use cases.
- D2.5 *Gap Analysis* – identifying remaining gaps and areas for improvement across the European road network.

In addition, the CCAM use case draws on preliminary results from work carried out in WP3, which provides technical foundations for the assessment. Ultimately, this interconnected structure ensures that lessons learned from individual countries contribute to a unified understanding of automated and connected mobility along the entire MODI corridor and beyond.

Together, these outputs contribute to an integrated understanding of how physical and digital infrastructures, vehicle systems, and traffic management can be jointly optimised to support safe and efficient L4 automated logistics.

1.4 Structure of the Report

The report is structured to provide a clear and logical progression from the contextual background to the conclusions and recommendations derived from the readiness assessment. It consists of six main chapters and annexes, each addressing a specific aspect of the work undertaken. The annexes provide supplementary material and chapter 6 contains a comprehensive list of references cited throughout the report to ensure transparency and traceability.

The 1st chapter introduces the deliverable by outlining its objectives and scope. It provides a summary of the MODI project, explains the purpose of this document, and clarifies its relation to other MODI outputs.

Chapter 2 presents the prerequisites for conducting the readiness assessment. It synthesizes requirements identified in preliminary studies and highlights potential infrastructure-related challenges and pain points. Furthermore, it formulates research questions across key domains, including infrastructure, connectivity, positioning and GNSS, unplanned events, and interactions with other traffic. This chapter also defines the MODI corridor, supported by an analysis of available road data, a comparison of relevant databases, and the matching of database attributes with identified challenges. Geospatial visualization using ArcGIS and visual inspections are described as part of the process for selecting critical road sections, followed by conclusions.

The 3rd chapter focuses on data collection and is divided into three thematic areas: Infrastructure, connectivity and positioning, and traffic events. For each area, the relevance of the research questions is discussed, the applied data collection methodology is described, and the results of the analysis are presented. Where appropriate, conclusions are drawn to inform subsequent recommendations.

Chapter 4 provides recommendations based on the findings of the assessment and outlines the requirements for achieving L4 readiness along the MODI corridor. Chapter 5 synthesizes the key insights derived from the data collection activities, with particular emphasis on physical infrastructure (PDI) and vehicle-related aspects.

2 Prerequisites for Readiness Assessment

Before conducting a comprehensive readiness assessment, it is essential to establish a clear understanding of the foundational requirements and potential challenges. This section outlines the critical elements that must be considered to ensure accurate evaluation and informed decision-making. It begins by reviewing insights from preliminary studies, identifying infrastructure constraints, and formulating research questions across key domains such as connectivity, positioning, and traffic conditions. Furthermore, it explains the chosen MODI corridor by analysing available road data, comparing databases, and addressing potential gaps. Visual tools, including ArcGIS mapping and on-site inspections, will support the identification of critical sections, ensuring that the assessment is both data-driven and contextually relevant.

2.1 Requirements from Preliminary Studies

The MODI project aims to assess the CCAM-implementation along a realistic European transport route and to identify challenges and barriers from different stakeholders' perspectives. Thus, vehicle providers, logistics operators, road authorities, and research institutes have elaborated critical parts of the physical and digital infrastructure (PDI) in previous tasks, leading to the validation of those critical parts for automated driving at L4. This current deliverable D5.5 considers the requirements and findings from the previous work carried out in the MODI work packages 1, 2, 3 and 4.

The methodology of MODI follows the European Union Common Evaluation Methodology (EU-CEM) as described in deliverable D2.2 where different evaluation methods of the four impact areas (environment, safety, traffic, and socio-economic impact) were presented. A list of Research Questions (RQs) and suggested Key Performance Indicators (KPIs) has been defined, which led to the data collection plans for all MODI UCs including UC CCAM that is the focus of this current deliverable D5.5.

Based on the analysis of stakeholders' and safety requirements (D1.1 and D1.2), a suitable logistic route has been defined. This MODI corridor is described in section 2.4 in more detail. Deliverable D1.1 provided a robust foundation from interviews with 21 logistic operators, 11 technology developers and 16 road actors for this definition. Among those interviewed were, for example traffic operators and municipalities, passengers and road users, umbrella associations, regulators, and insurance companies. Deliverable D1.2 outlines safety and cybersecurity requirements for automated trucks and their demonstration activities. It highlights the importance of public acceptance and trust, emphasizing that safety must go beyond technical reliability to include transparent communication and risk management. The document stresses the growing relevance of cybersecurity, referencing new regulations like UN R155 and R156, while noting unclear responsibilities between vehicles and infrastructure. These interfaces were the focus of the deliverables of WP4, namely D4.1 (*CCAM interface*), D4.2 (*Optimal designs of PDI for public roads*) and D4.3 (*PDI in confined areas*).

Rising freight thefts show that driverless trucks are vulnerable, prompting a re-evaluation of what constitutes "secure parking." D1.2 recommends combining traditional and technology-based security measures, such as sensors and surveillance. It also calls for contingency plans for emergencies and media handling during trials. Overall, deliverable D1.2 aims to ensure that MODI's vehicles are not only legally compliant but also socially accepted and resilient against emerging threats.

The general requirements from WP1 also supported the technical specifications elaborated in WP3, namely deliverables D3.1 (Connectivity Requirements), D3.2 (Automation Requirements) and the resulting D3.4 (Vehicle Adaption).

Based on the results of the previous activities, the work described in the following sections was then carried out to assess the L4 suitability of European roads, using the MODI corridor as the reference route.

2.2 Potential Infrastructure Challenges

The identification of infrastructure-related pain points was carried out through a consultation process involving multiple stakeholder groups within the MODI consortium, including OEMs, technology providers, logistics operators, national road authorities, and research entities. A pain point refers to an element where it was anticipated that SAE L4 vehicles could possibly face limitations within their Operational Design Domain (ODD), due to characteristics of surrounding infrastructure, traffic, or indirect influences such as charging or regulations.

A common template was distributed to collect feedback on real-world challenges for automated driving at SAE L4, asking stakeholders to describe critical road elements, conditions, and traffic scenarios that were likely to pose difficulties for automation, such as tunnels, variable signage, merging lanes, and adverse weather. These qualitative inputs were consolidated and discussed within UC CCAM and the Co-Creation Arena (CCA) in Copenhagen, a collaborative workshop where experts jointly explore ideas and develop solutions, to ensure that both technical and infrastructural perspectives were represented.

The resulting list of pain points serves as an input to several subsequent project activities. It supports the definition of the UC CCAM route, the formulation of research questions and derivation of hypotheses for the consideration of what data should be collected and analysed along the route. Moreover, the pain points provide a foundation for structuring the data collection strategy and prioritising physical and digital infrastructure requirements.

Table 1 summarizes potential infrastructural challenges, that were identified in the beginning of the MODI project, on a very general level. The complete list includes an evaluation of the concrete difficulties, the degree of challenge associated with a specific pain point, and suggestions to mitigate difficulties.

Table 1: Potential Infrastructure challenges

Challenge	
Infrastructure	tunnels, underpass, signs, variable message signs, road markings, railroad crossings, road without divider, junctions, roundabouts, tolling stations, customs, traffic lights, merging lanes
Connectivity	especially cross border connectivity, C-ITS message availability
Traffic	mixed traffic, emergency vehicles, vulnerable road users, merging lanes, heavy traffic, movement of other traffic
Weather condition	snow, rain, wet, fog, sun, ice
Unplanned events	speed changes, accidents, road works, police hand signal and law enforcement vehicles, robbery
Regulation	national and European rules and regulations, harmonization of communication protocols

In the CCA in Copenhagen in 2023, the table listed above were echoed as important parameters to consider both on short and long term with respect to deployment of L4 vehicles. In addition, charging infrastructure for electric vehicles, availability of accurate map objects (e.g. for use in HD maps), and GNSS were considered as important. The full lists can be found in Annex I: Challenges and Pain Points.

2.3 Deriving the Research Questions

To ensure that the data collection within UC CCAM effectively supports the overall assessment of CCAM readiness along the MODI corridor, a set of targeted research questions (RQs) has been formulated. These questions serve as the backbone of the data collection strategy, translating the project's broader objectives into concrete and measurable investigation areas.

Building upon the previously identified infrastructure challenges and pain points, the discussions within the CCAs, and insights from earlier survey iterations, some key thematic categories have been developed. These represent both the fundamental areas of interest and those that can be practically addressed through data collection along the MODI corridor. The selected key thematic are:

Infrastructure

This focus area investigates the condition and quality of the physical and digital infrastructure along the MODI corridor. It includes aspects such as lane markings, signage, map accuracy, HD map availability, and charging infrastructure. HD maps (High-Definition map) are highly detailed digital maps that provide precise information about road geometry, lane markings, traffic signs, and other static features. These maps are used to complement vehicle sensors to enable accurate localization and safe navigation for autonomous vehicles.

Connectivity

Connectivity plays a key role in enabling cooperative and connected driving at SAE L4. This area examines the availability and quality of mobile networks (LTE / 5G) and short-range ITS-G5 communication along the route. It also investigates how network performance could affect data exchange between vehicles, infrastructure, and traffic management systems.

Positioning (GNSS)

This topic focuses on assessing the quality and robustness of GNSS signals along the corridor, including the availability of correction services. It aims to identify areas with reduced signal quality or coverage gaps that could affect vehicle localization and overall navigation performance.

Unplanned Events

Unplanned events such as accidents, roadworks, or unexpected obstacles may impact automated vehicle operation. This category is designed to identify and characterize events that serve as examples of sudden changes in the legally permitted maximum speed along the corridor. Although numerous types of events may occur, this category focuses specifically on speed-related changes as representative cases.

Other Traffic

Automated freight vehicles will need to interact with conventional road users under diverse traffic conditions. This area focuses on observing the behaviour and movements of surrounding traffic to identify potentially challenging interactions or traffic dynamics that could affect L4 automated driving performance.

These thematic areas cover the critical aspects influencing the operational performance of L4 automated freight vehicles. Within each of these domains, specific research questions have been defined to guide the measurement activities and align data collection efforts among partners. The following sections present the defined research questions.

2.3.1 Infrastructure

The infrastructure RQs are divided into five sub-categories: detection of lane markings and signage, availability of accurate map data, digital twins / HD maps, and charging.

Table 2: Infrastructure related research questions

Category	Sub-category	RQ
Infrastructure	Lane markings	Under which conditions do lane markings or related road surface issues (e.g., damage, reflective repairs) fail to support reliable detection by camera-based systems compared to map data or manual verification?
Infrastructure	Signage	Under which conditions do traffic signs fail to be reliably detected – or are misinterpreted – by camera-based systems compared to map data or manual verification?
Infrastructure	HD maps	To what extent is it possible to create an HD map of route segments of sufficient quality to be used for simulation-based verification of L4 functions?
Infrastructure	Accurate map data	What is the availability of quality map data along the route, e.g. for use in HD maps?
Infrastructure	Charging	What is the availability of charging infrastructure along the route?

2.3.2 Connectivity

The connectivity part is divided into RQs either for mobile connection (LTE / 5G) or ITS-G5 availability.

Table 3: Connectivity related research questions

Category	Sub-category	RQ
Connectivity	LTE / 5G	How is the mobile data (LTE / 5G) availability distributed along the route?
Connectivity	LTE / 5G	What empirically determined circumstances have a negative impact on mobile service quality?
Connectivity	LTE / 5G	How is the mobile data (LTE / 5G) availability on border crossing along the route?
Connectivity	ITS – G5	How is the availability of CAM / DENM (ITS-G5) along the route distributed?

2.3.3 Positioning / GNSS

For this category, the focus was on global positioning, i.e., satellite availability and the Quality of Service (QoS) that results along the corridor, preferably using both uncorrected and corrected services.

Table 4: Research questions related to positioning

Category	Sub-category	RQ
Positioning / GNSS	Positioning / GNSS	How is the GNSS quality distributed along the corridor?
Positioning / GNSS	Positioning / GNSS	What empirically determined circumstances that have a negative impact on GNSS quality?

2.3.4 Unplanned Events

Sudden speed change events were analysed based on GNSS and velocity data, and data on pedal position.

Table 5: Research questions for unplanned events

Category	Sub-category	RQ
Unplanned events	Unplanned events	What kind of unplanned events occur during driving the route?
Unplanned events	Unplanned events	What is the occurrence frequency of unplanned events?

2.3.5 Other Traffic

The aim of this RQ is to register relevant movement of other traffic around the vehicle, to identify challenging behaviour or important aspects of other traffic that an automated vehicle needs to consider.

Table 6: Research questions related to other traffic

Category	Sub-category	RQ
Other traffic	Other traffic	How do other traffic participants behave around an (automated) ego vehicle?

2.4 Defining the MODI Corridor

This section consolidates and streamlines the background, data sources, methods, and findings for the MODI corridor from Rotterdam (Netherlands) to Oslo (Norway). The corridor was selected based on its alignment with the Trans-European Transport Network (TEN-T) core network, its strategic role in European freight logistics, and the diversity of road sections that present both “easy” and “difficult” scenarios for L4 automated driving. The objective is to identify infrastructure-related challenges that may impede automated driving functions and to inform empirical drives and subsequent data collection for UC CCAM.

2.4.1 Route Selection

The Rotterdam – Oslo route was defined by combining:

- Core TEN-T road network coverage
- Importance and realism for freight flows
- Inclusion of a variety of road sections (both complex and straightforward)

Figure 2 illustrates the defined corridor. For country-specific rationale and alternatives considered, see Annex II: MODI Corridor by Country and [1].

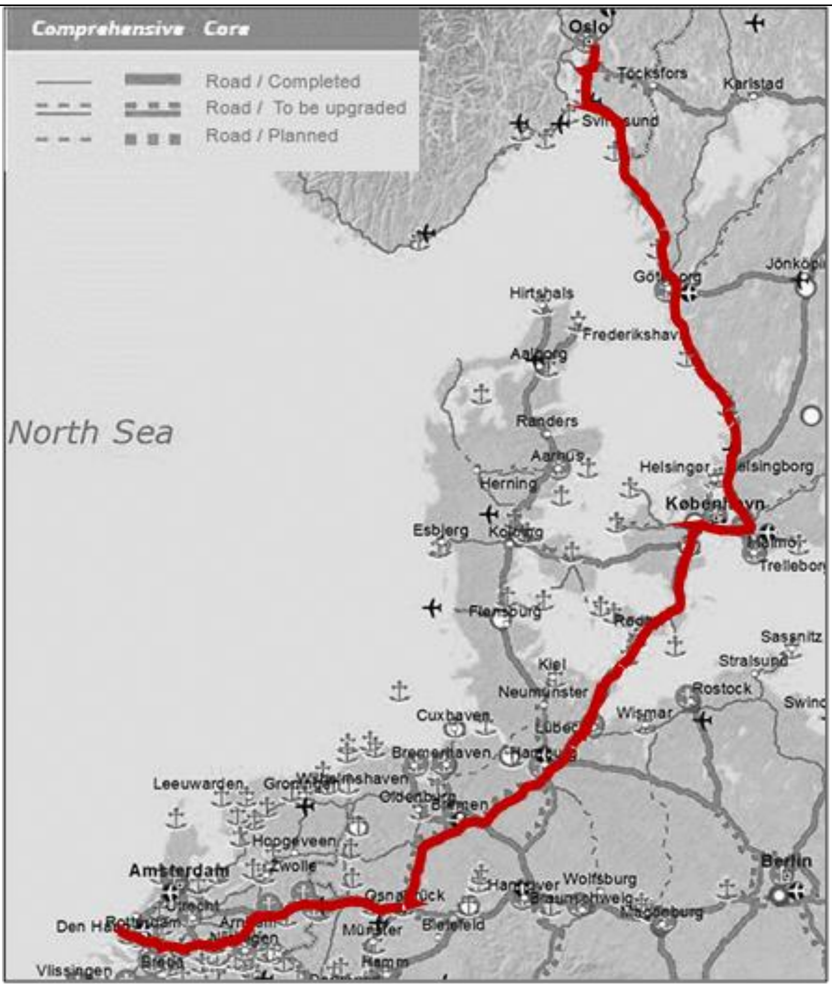

Figure 2: Defined route Rotterdam–Oslo

2.4.2 Data Availability on Road Characteristics

This subsection provides a brief overview of the available data from databases or comparable sources in the different MODI partners' countries.

Denmark

Spatial data for Denmark is available from the Danish Road Directorate's data exchange platform. The Data Exchanger is the Danish National Access Point (NAP). Here, a user account is required to access the data in the portal.

Germany

In Germany, the Mobilithek is the platform for exchanging digital information from mobility providers, infrastructure operators, transport authorities as well as information providers and is the national access point for mobility data. The Federal highway information system (BISStra) and the National Object Catalogue for Roads and Transportation (OKSTRA) extend the data infrastructure with additional datasets.

Norway

Norway's National Road Database (NVDB), maintained by the Public Roads Administration, offers extensive road network data and hundreds of related attributes. Most of this data is freely accessible and can be exported in various formats via the NVDB Read API, including spatial data for mapping and analysis.

Sweden

Data for Sweden is available on the “Lastkajen” portal. Lastkajen is an e-service provided by the Swedish Transport Administration – Trafikverket, where both companies and private individuals can download open data about Sweden's road and railway networks. Sweden, like Norway, has an NVDB.

The Netherlands

In the Netherlands, the WEGGEG dataset from Rijkswaterstaat provides detailed administrative and visually surveyed data on national roads, updated monthly or quarterly. It includes road numbers, segment details, and visual attributes like lane count, pavement type, and lighting. This data supports traffic safety analysis, road network management, GIS applications, and more. Additionally, traffic sign locations from NDW (Nationaal Dataportaal Wegverkeer) complement the dataset.

2.4.3 Comparison of databases

Data quality varies across countries due to factors like update frequency, collection methods, and data storage. For spatial data, the type of geometry used is critical – lines or polygons for features like bridges and tunnels provide meaningful information about their extent, unlike simple points which lack detail on length, width, or height. Table 7 lists the attributes used in the desk study, provided by the national road authorities.

Table 7: Overview of data elements available per country

Attributes	Norway	Sweden	Denmark	Germany	Netherlands
Road number	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Tunnel	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Intersections	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Roundabouts	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Bridges	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Road shoulder	*Yes*	*No*	*No*	*No*	*Yes*
Merging lines	*Yes*	*No*	*Unsure*	*Unsure*	*Yes*
Speed limit	*Yes*	*Yes*	*Yes*	*No*	*Yes*
Signage	*Yes*	*No*	*Some*	*No*	*Yes*
Number of lanes	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Rush hour lanes	*Yes*	*No*	*Yes*	*No*	*Yes*
Bus lanes	*Yes*	*Yes*	*Unsure*	*Unsure*	*Yes*
Markings category	*Yes*	*No*	*No*	*No*	*Feature engineering*[1]
Markings quality	*Unsure*	*No*	*No*	*No*	*No*
Signage category	*Yes*	*No*	*Unsure*	*No*	*Feature engineering*
Signage quality	*Unsure*	*No*	*Unsure*	*No*	*No*
Geometry severity	*Yes*	*No*	*Unsure*	*No*	*Feature engineering*
Dynamic signs category	*Yes*	*No*	*Unsure*	*No*	*Yes*
Dynamic signs availability	*Unsure*	*No*	*Unsure*	Partly	*Yes*
Variable message signs	*Yes*	*No*	*Unsure*	*Yes*	*Yes*
Construction on road	*No*	*No*	*No*	*No*	*Yes*
Overtaking restrictions	*No*	*No*	*No*	*No*	*Yes*
Speed limit time constraints	*No*	*No*	*No*	*No*	*Yes*
Signals	*No*	*No*	*No*	*No*	*Yes*
Advised speed limit	*No*	*No*	*No*	*No*	*Yes*
Noise barrier	*No*	*No*	*No*	*No*	*Yes*
ITS devices	*Manual input(G5-station)*	*No*	*No*	*Yes*	*No*

Potential Challenges for Automated Driving

Database Analysis

National datasets were interrogated for attributes mapped to predefined challenge categories: markings, signage, geometry, dynamic signs, tunnels, bridges, entrances/exits/interchanges, and “other” . Some issues were directly identifiable (e.g., tunnel presence, dynamic signs), while others relied on proxies (e.g., rush-hour lanes implying continuous-line crossings). Limitations include the absence of attributes for marking quality (e.g., reflectivity/contrast) and temporary roadworks in all five national datasets.

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[1] Feature engineering’ indicates that the element is not directly available but can be derived from existing data.

Visual Inspections to Define Critical Road Sections

Because databases differ and could not be fully harmonized, complementary visual inspections were performed and integrated into the ArcGIS map as a dedicated layer.

- **Denmark**: Walkthrough from Rødbyhavn to the Øresund Tunnel entrance (early 2024) using internal mapping tools and Google Street View. Focus on signage, markings, distances, and complex merges (e.g., scenarios comparable to those near Nijmegen). Findings documented in ArcGIS.
- **Norway** (NPRA): Review of high-resolution road images (May 2024). Emphasis on worn markings, unclear signage, and lane merges (including interactions with public transport lanes). Findings added to ArcGIS; informed upgrades such as METR for digital dynamic speed signs. Static imagery basis: dynamic conditions excluded.
- **Sweden** (Trafikverket): No dedicated field inspection; insights via expert consultations. Route along the E6 (Svinesund to Öresund Bridge) assessed for deteriorating markings under heavy traffic, complex lane changes in Gothenburg, congestion (Gothenburg/Malmö), left-side exit ramps, VMS, short entrances, toll stations, tunnels, and high coastal bridges. Winter conditions (snow, wind, slipperiness), notably in Hallandsåsen, add risk.
- **Netherlands** (Rijkswaterstaat): Hands-on drives (May–June 2023) from Rotterdam to the German border and back. Structured logging for geometry and signage; full-route video captured. Identified dynamic signage (red crosses, variable limits), complex intersections, and layout issues.
- **Germany** (BASt): Review of road images from national data base and open-source repository as preliminary visual data source for infrastructure elements (early 2024). Furthermore, Demo Drives as part of UC Germany with focus on Connectivity and Positioning (small portion of the German route).

Across all countries, inspections sought elements that can confuse human drivers or be misread by vehicle sensors. Most evaluations reflect static conditions (daylight, dry weather, light traffic), but additional challenges may appear in darkness, adverse weather, or heavy traffic.

2.4.4 ArcGIS Mapping and Visualization

Findings from database analysis and visual inspections were consolidated into an interactive ArcGIS environment. The corridor line is color-coded by challenge likelihood / severity, and an example of the area around Gothenburg is shown in Figure 3:

- **Green** no potential challenges identified
- **Yellow** minor challenges or uncertainty
- **Red** potential challenges based on available data

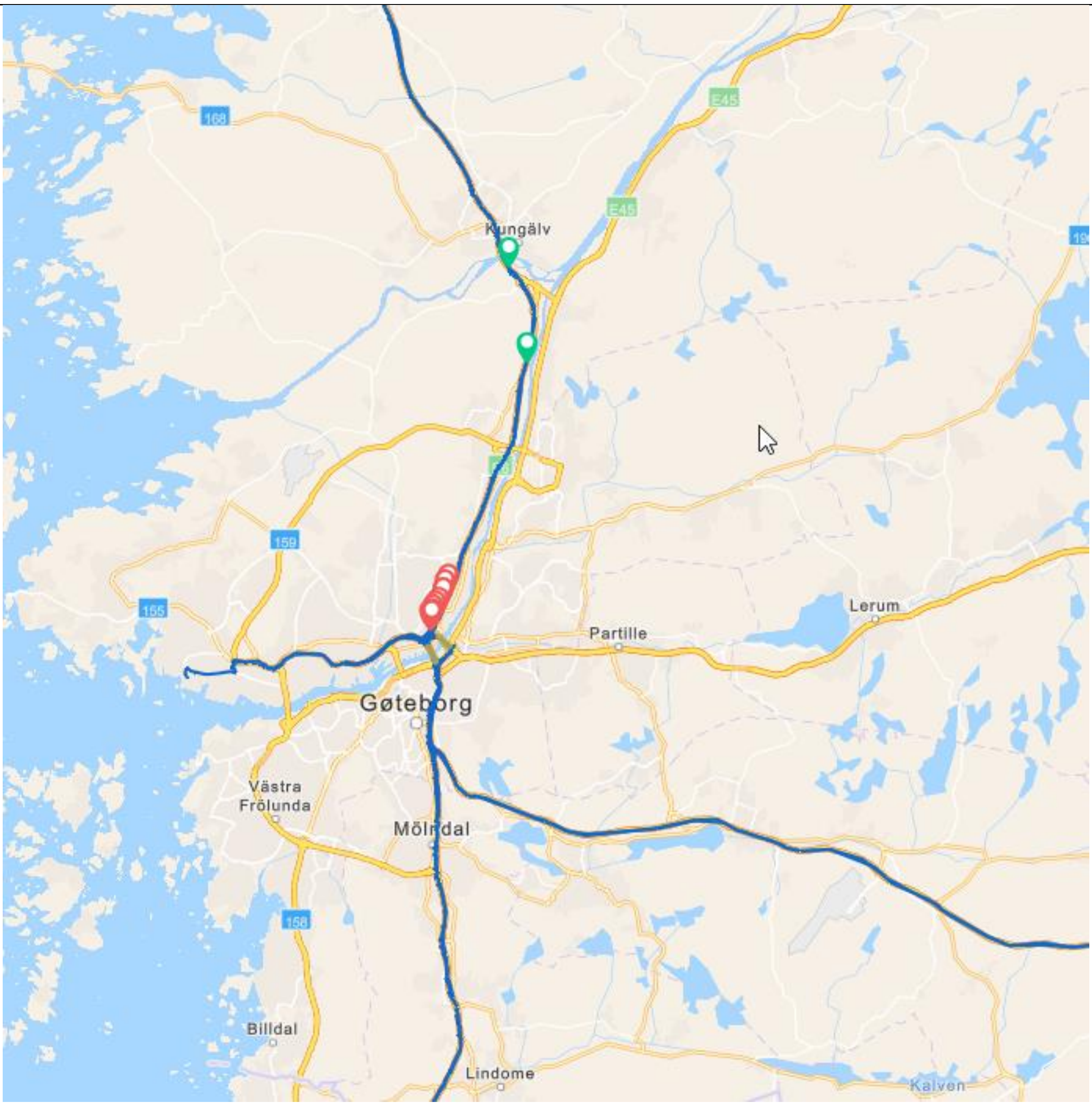


Figure 3: ArcGIS map with identified potential challenges around Gothenburg

Users can toggle thematic layers corresponding to challenge categories (Markings; Signage; Road geometry; Entrances/interchanges/exits; Dynamic signage; Tunnels/bridges/toll stations/ferries; Other) to identify which characteristics contribute to the corridor's risk profile.

Interactive resources:

- StoryMap overview: https://storymaps.arcgis.com/stories/343210bf9eb347498a2bd7f8b07ffdb2
- Pain Points dashboard: https://experience.arcgis.com/experience/655944607b05406ebf045c0adc3bcc4b/page/Pain-Points-

Substantial portions of the route illustrated in Figure 4 for the Netherlands example appear red due to dynamic overhead signs (red crosses; variable limits of 50/70/90 km/h), which challenge automated interpretation.

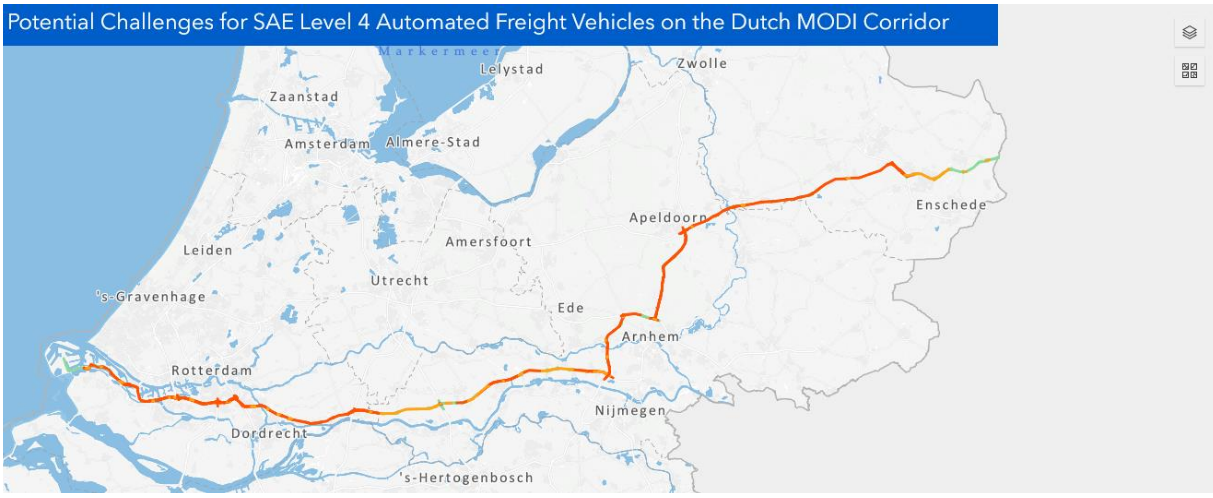
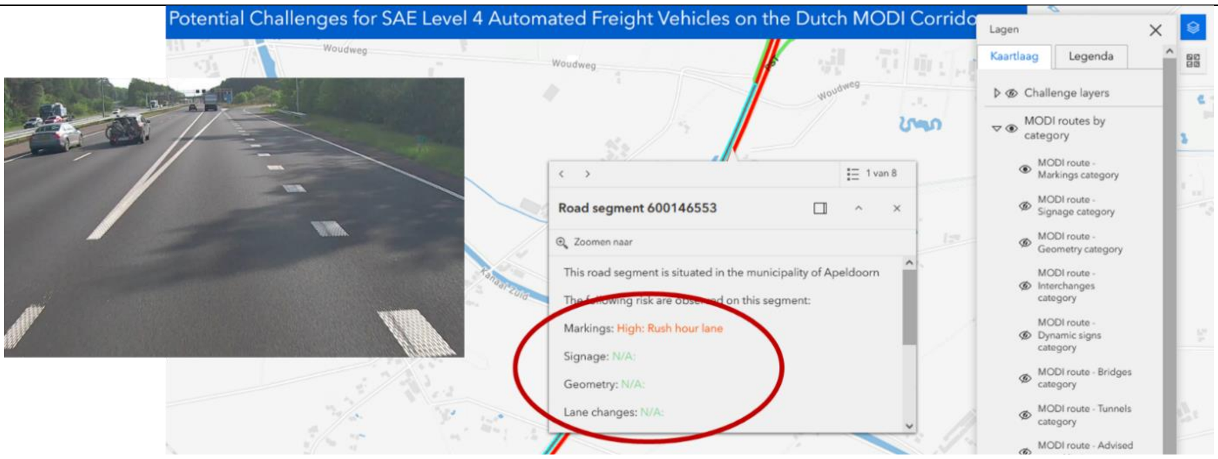


Figure 4: ArcGIS map with identified potential challenges in the Netherlands

When filtering for “Markings category,” the Arnhem–Apeldoorn segment remains red while other parts turn green (no potential challenges, see Figure 5).

Figure 5: ArcGIS map with potential challenges on markings in the Netherlands

Figure 6 zooms in on a road segment along the red-marked route, showing that the rush hour lane markings present a potential challenge. The photo illustrates that vehicles must cross a continuous line to use the lane – particularly relevant for trucks, which typically drive in the rightmost lane, often the rush hour lane when active.



Road segment 600146553

This road segment is situated in the municipality of Apeldoorn

The following risk are observed on this segment:

Markings: High: Rush hour lane

Signage: N/A:

Geometry: N/A:

Lane changes: N/A:

Figure 6: Complex markings due to peak hour lane

2.4.5 Key Observations

Dynamic overhead signs, such as red crosses and variable speed limits, remain among the most frequent and high-impact challenges along the corridor, particularly in the Netherlands. Additionally, complex road markings – such as rush-hour lanes and certain merges near ramps – can create situations where crossing continuous lines becomes necessary, which may confuse automated perception systems. The heterogeneity of national databases further complicates the situation, as full harmonization is not possible; critical attributes like marking quality and temporary traffic management measures are missing across all five countries. Environmental and operational conditions, such as night-time driving, winter weather, and congestion, are likely to exacerbate these risks beyond what is observed under static, daytime conditions. Furthermore, infrastructure elements such as bridges, tunnels, toll stations, and ferries demand geometry-aware representation using lines or polygons to enable accurate interpretation by automated systems.

To address these challenges, several steps were recommended to be in the scope of the data collections in use case CCAM. First, targeted data collection for UC CCAM should focus on attributes absent from national databases, such as marking retro reflectivity and temporary traffic management. Second, ArcGIS layers should be enhanced with harmonized schemas and metadata to improve cross-country comparability. Third, sensor-perception validation drives should be conducted under varied conditions, including night-time, adverse weather, and peak traffic, particularly along segments marked as high-risk. Fourth, collaboration with road authorities is essential to standardize dynamic sign encoding and to explore digital sign feeds, such as METR, for machine readability. Finally, country-specific edge cases, including left-side exits, short ramps, and interactions with public transport lanes, should be documented to enrich scenario libraries for automated driving systems (ADS).

3 Data Collection

The data collection activities within MODI were designed to provide the empirical foundation for evaluating automated freight transport along the defined corridor from Rotterdam to Oslo. The objective was to gather relevant information to support the analysis of connectivity, positioning, perception, infrastructure readiness, and interactions with other traffic participants. Therefore, a coordinated series of measurement campaigns was conducted across various parts of the corridor. The campaigns included vehicle-based recordings as well as complementary infrastructure and mapping data. Table 8 provides an overview of the data collections conducted. In total, seven distinct types of data collections were carried out, some of them repeated to examine whether the corridor has undergone changes, for example through the implementation of additional connectivity infrastructure.

Table 8: Overview data collections

Data collection responsible	Data types / focus
BASt	LiDAR and camera recordings focusing on traffic movements, interactions, and traffic signs
NMA and Q-Free	Connectivity and GNSS (HAS, OSNMA, RTK, etc.), ITS-G5, camera
DAF & Gruber Logistics	Lane markings and sign detection
Road Authorities and research institutes	Infrastructure mapping, including markings, signage, and pain point references
Volvo	Perception, connectivity, GNSS and energy data
Einride	Connectivity and GNSS
HERE	Digital infrastructure and HD map evaluation

The data collection section is structured into three main parts: infrastructure, connectivity, and traffic events. The first part focuses on the physical and digital infrastructure of the corridor, including road markings, signage, and digital mapping data. The second part addresses connectivity aspects, covering measurements of LTE / 5G, ITS-G5, and GNSS performance along the route. The third part concentrates on traffic events, including recordings of vehicle movements and interactions, providing insights into the operational environment for automated driving.

3.1 Infrastructure

This chapter details the methodology, execution, and subsequent analysis of the data collection activities focused on the PDI along the MODI corridor. These efforts were designed to provide empirical validation of the corridor's readiness for highly automated driving features conforming to SAE L4. The data collection activities were guided by the infrastructure-related Research Questions articulated in Section 2.3.1, specifically targeting the functional limitations and potential challenges posed by road signage, lane markings, and the availability of accurate map data.

The core objective of this data collection was to assess the functionality and robustness of vehicle-borne perception systems when confronted with real-world infrastructure conditions on European trunk roads. Empirical evidence was sought to verify the severity of infrastructural shortcomings identified during preliminary studies and stakeholder consultations (Section 2.2), such as issues related to complex road geometry, dynamic signage, and the overall quality and consistency of lane markings.

3.1.1 Relevance of the Specific Research Question

The reliable detection and interpretation of road signs and lane markings are foundational components of the ODD for L4 automated vehicles, as these elements serve as critical inputs for the perception and decision-making systems. In order to evaluate the L4 readiness of the corridor, the five RQs as listed in Section 2.3.1 have been formulated:

1. RQ: Under which conditions do lane markings or related road surface issues (e.g., damage, reflective repairs) fail to support reliable detection by camera-based systems compared to map data or manual verification?

This research question is relevant because it examines the robustness of vehicle perception systems that use lane markings to determine the drivable area and road geometry. The functionality of automated vehicles depends on the quality and consistency of several physical road elements in different environments. Evaluating the accuracy and reliability of lane detection systems under varying conditions (e.g., integrity, complexity, or visibility) is important for identifying limitations within the ODD and for determining potential needs for redundancies or infrastructure standardization.

2. RQ: Under which conditions do traffic signs fail to be reliably detected or misinterpreted by camera-based systems compared to map data or manual verification?

This inquiry addresses the criticality of regulatory compliance and contextual awareness for L4 freight operations. Road signs provide essential information regarding speed limits, vehicle restrictions (such as height or weight limits), and traffic flow mandates, which are particularly important for heavy-duty logistics. The relevance lies in identifying if specific sign types, placement, or environmental conditions impede the automatic detection systems. A key secondary relevance is the evaluation of data integrity within road sign databases concerning missing or erroneous records, which would compromise the redundancy capabilities provided by digital maps.

3. RQ: To what extent is it possible to create a HD map of route segments of sufficient quality to be used for simulation-based verification of L4 functions? **and**
4. RQ: What is the availability of quality map data along the route, e.g. for use in HD maps?

Depending on the design of L4 automated driving features, they might be reliant on HD maps for accurate localization and robust path planning. This RQ is relevant since the development of L4 functions often necessitates simulation-based verification using highly accurate map data of the specific ODD.

5. What is the availability of charging infrastructure along the route?

EU's alternative fuel infrastructure regulation (AFIR) [2] provides deployment targets for charging stations along the Trans-European Transport Network (TEN-T). For heavy-duty vehicles, one target is that there should be charging stations with a minimum output of 350 kW installed every 60 km along the TEN-T network. This evaluation is critical for ascertaining if the current infrastructure can support both initial demonstrations and the necessary mass adoption and scaling of automated electric logistics.

3.1.2 Data Collection Methodology

The empirical assessment of the PDI along the MODI corridor involved a multi-faceted data collection strategy, integrating both qualitative expert input from Road Operators (ROs) and quantitative field data acquired by project partners utilizing equipped vehicles. This methodology was structured to address the research questions pertaining to the detection performance of infrastructure features, the integrity of digital map data, and the availability of critical services such as charging facilities as described.

The operator-led assessment produced a comprehensive map of potential challenges. The subsequent vehicle-based campaigns were designed to empirically test these hypotheses, quantify the performance degradation associated with these "pain points," and uncover dynamic challenges invisible to static database analysis. The following subsections detail the specific methodologies applied to assess lane markings, road signage, and charging infrastructure.

DAF / Gruber Logistics Methodology

The data collection that was jointly executed by DAF and Gruber Logistics was conducted between June 6th and June 18th, 2024, involved driving a test truck across the majority of the Rotterdam-Oslo corridor. The following data streams were acquired:

1. In vehicle data, i.e. CAN-bus and vehicle camera system, and
2. An external Video Recording: A continuous feed from a stand-alone Blackvue DR900x camera, utilized for verification across the entire route, complementing the limited segments recorded by the internal camera system.

The data analysis was bifurcated into two specialized procedures [3]:

Road Sign Detection Analysis

The primary procedure involved retrieving the coordinates of a sign observation in Norway and the Netherlands based on the vehicle’s position at the moment a given sign ID was first detected in the log files. These log-derived positions were systematically compared against digital road sign databases (e.g., NVDB in Norway and opendata.ndw.nu in the Netherlands). Manual verification using dashcam footage was deployed to resolve detected deviations. Registered deviations were subsequently tagged into standardized categories, such as 'False detection,' 'Missing detection,' 'False database record,' and 'Missing database record'.

Lane Marking Detection Analysis

This procedure focused strictly on segments where the vehicle's lane departure warning system was logged as 'Unavailable' (approximately 407 km of 3014 km total travel distance), indicating a failure to detect lane markings of sufficient quality. The methodology consisted of generating "snapshots"—one video frame for every 5 meters of travel within continuous 'Unavailable' segments. These snapshots were then analysed manually by visual inspection to classify the causes of system failure based on observed characteristics of the road environment, such as marking condition (e.g., poor, missing, complex, confusing), tunnels, lighting effects, or wet surfaces. The systematic categorization provided the empirical foundation for quantifying infrastructural impediments

Volvo Methodology

The data collection undertaken by Volvo utilized battery-electric Volvo FM 42T trucks to conduct measurements along stretches of the MODI corridor between Hamburg and Oslo. The collection was executed during two primary periods in 2025:

1. January 2025: Segments recorded included the route between Gothenburg and Oslo, and the reverse journey from Oslo to Gothenburg.
2. May 2025: Segments recorded included the route between Hamburg and Gothenburg, or alternative segments related to this direction.

The empirical data collected covered the following specific cross-border segments, logged over an approximate total distance of 1192 km:

- Sweden to Norway (January 12, 2025).
- Norway to Sweden (January 15, 2025).
- Germany to Denmark (May 22, 2025).
- Denmark to Sweden (May 22, 2025).

It is pertinent to note that the collected routes represent approximately two-thirds of the total MODI corridor.

Lane Marking Detection

With regards to the lane detection, the data collection prioritized measuring the vehicle's geometric relationship to the road infrastructure, capturing six distinct lateral distance measurements: the left and right road lines, the outer left and right road lines (for multi-lane roads), and the left and right road edges. All measurements were recorded within the vehicle's coordinate system, where the Y-axis corresponds to lateral distance.

The methodology for data processing ensured fidelity by aggregating sparse sensor readings to match GNSS fixes within a 250ms time window. Invalid data points, signifying detection unavailability, were systematically filtered out.

Charging Infrastructure

The assessment of charging infrastructure was grounded in the deployment targets established by the AFIR already mentioned in the RQs. For HDVs, the AFIR mandates the installation of charging stations with a minimum power output of 350 kW at intervals not exceeding 60 km along the TEN-T. However, a preliminary review of available datasets revealed significant heterogeneity in how charging station attributes are specified. To mitigate the risk of excluding viable infrastructure in the analysis due to data inconsistencies, the inclusion criteria were adjusted. Stations were selected for analysis if they met one of the following conditions:

- Explicit attribute designation as supporting heavy-duty trucks.
- A charging capacity of at least 250 kW.

Several data sources provide information on charging infrastructure in Europe. These include data published by national road authorities and other government agencies, large-scale datasets from the European Union, as well as databases maintained by private actors in the mobility sector.

Most of these datasets, however, do not account for the specific requirements needed to charge a heavy-duty truck – the type of vehicle addressed in the MODI project.

In an effort to identify the most accurate and up-to-date dataset suitable for truck charging along the MODI corridor, two candidate datasets were analysed and compared. The first is the EU's map of alternative fuels in the TEN-T network [4], which includes charging stations along the entire corridor. It provides details such as charging capacity, connector types, and public availability. This dataset offers consistent coverage across the full length of the MODI corridor, ensuring a uniform data structure. The second candidate is a composite dataset that must be assembled from various local sources. While potentially rich in detail, it requires significant effort to consolidate and harmonize the data to achieve full corridor coverage. A dataset from Open Charge Map (OCM) [5] was also considered, as it covers the entire corridor and includes capacity information that enables filtering. However, it was ultimately excluded due to significant discrepancies when compared with other reliable data sources, as well as concerns about the overall reliability of open-source datasets.

The composite dataset – henceforth referred to as MODI charging dataset – is compiled from four different sources: In Norway, the Norwegian Public Roads Administration provided information on both operational and planned en-route charging stations for heavy vehicles, sourced primarily from NOBIL and ENOVA and accessed via an ArcGIS REST API. For Sweden and Denmark, charging station data were retrieved from the NOBIL API and subsequently filtered to retain only stations with a charging capacity above 250 kW, as the dataset does not specifically distinguish truck-capable infrastructure. German data were collected from the Federal Network Agency's public register of charging stations and filtered using the same ≥ 249 kW threshold, because the dataset lacks explicit information on suitability for heavy-duty vehicles. For the Netherlands, data were taken from the National Charging Infrastructure Agenda (NAL) via two ArcGIS layers representing planned (Bouwvoertuigen) and operational (Vrachtvervoer) heavy vehicle charging stations. While the Dutch dataset identifies supported heavy-vehicle categories, it does not yet provide details on physical site requirements such as clearance, turning space, or pavement strength.

To achieve the fairest possible comparison between the two datasets, and to remove charging stations not suited for truck charging, the data were filtered using the same constraints. For both datasets, charging stations further away from the corridor than 50 km, as well as stations with a power capacity below 250 kW were removed. Note that this analysis used the official MODI corridor, while the Volvo truck drove a slightly different route through Denmark. The exceptions to the capacity constraints are the two dedicated truck charging datasets, who were only filtered by distance to the corridor. Lastly, only operational charging stations were compared, as TEN-T does not seem to have data on planned stations. This resulted in 1121 stations in the TEN-T dataset, and 724 stations in the MODI dataset.

The objective of the analysis is to assess dataset overlap, identify unique coverage, and validate data quality of the candidates. The overlap analysis uses a matching algorithm that both considers spatial proximity and attribute similarity.

- Confirmed match criteria:
    - Within 10 meters (GPS precision), OR
    - Within 100 meters AND name/address similarity >60%
- Possible match criteria:
    - Within 100 meters AND name/address similarity 30-60%

Manual inspection of the two datasets indicates that this approach is a reasonable method for programmatically identifying overlaps. Similarity assessment was performed using the Ratcliff/Obershelp pattern matching algorithm, implemented via Python's difflib. SequenceMatcher, applied to station names, addresses, cities, and operators [6].

In addition to the desktop study, data was collected from the four separate drives conducted along the Hamburg-to-Oslo corridor, covering approximately two-thirds of the MODI route. The data collection utilized two Volvo FM 42T electric heavy-duty trucks. Key specifications for the test vehicles included a battery capacity of 540 kWh.

To account for environmental conditions, the operational weight of the vehicles varied by route segment:

- Germany–Sweden: Adding a weight of 11 tons.
- Sweden–Norway: Adding a weight of 16 tons (reflecting added ballast for stability in winter conditions).

To assess charging infrastructure accessibility, a spatial analysis was performed on both the specific driven route and the full MODI corridor. The analysis calculated the distance from the route to the nearest truck-supporting charging station, allowing for a maximum detour radius of 10 km. These spatial calculations provided distributions for average, median, and maximum distances to infrastructure.

Energy consumption was simulated using a proprietary EnergyModule of Volvo, capable of calculating energy use and emissions based on vehicle parameters and route topology. The calculation parameters are shown in Table 9. The values are based on the FM42T truck complemented by FH Euro 6 trucks parameters where information of the electric truck was not available.

Table 9: The EnergyModule vehicle definition for the Volvo FM 42TE truck

Parameter	Value
name	Volvo FM 42T Electric
type	LargeGoodsVehicle
payloadWeightKg	100
frontArea	9.069216
formDragCoeff	0.8
rollResistanceCoeff	0.015
speedModel	HeavyVehicleModel
accessoryLoadW	2000
fuel	electrical battery
vehicleWeightKg	11000 / 16000
brakingPowerW	-490000
acceleratingPowerW	291000
powertrain	Electrical
maxMcUtil	0.85
gmEff	0.85
mcEff	0.35
meEff	0.90
gbEff	0.85
baEff	0.95
maxMeUtil	0.9
gbP1MaxOfMaxAP	0.5
preferredDeceleration	490000
maximumTotalWeightKg	26000
batteryCapacitykWh	540

The Volvo data was divided into drive segments, which corresponds to each of the six segments of decreasing state of charge. For each drive segment, the energy consumption was calculated using the EnergyModule API by giving the start and end coordinates (and an additional waypoint on two of the segments to ensure the energy calculations used the same route as the actual vehicle). The energy calculations are based on the vehicle defined in Table 9, a road network from OpenStreetMap, and elevation data from OpenTopoData / EU-DEM.

Q-Free Methodology

The campaign, executed between late March and early April 2024, involved traversing the entire MODI corridor in two directions:

1. Southbound Trip (Oslo to Rotterdam, March 27–30, 2024): Oslo, Gothenburg, Copenhagen, Hamburg, culminating in Rotterdam, with an explicit crossing of the border between Germany and the Netherlands.
2. Northbound Trip (Rotterdam to Oslo, April 4–7, 2024): Passage through Bremen, Hamburg, a detour via Flensburg, and Copenhagen before concluding in Oslo.

The test vehicle was equipped with a multimodal sensor configuration for logging positioning, communication, and visual perception parameters. The following three distinct GNSS units were utilized:

- Ublox, tracking L1 band satellites.
- SonyL1, tracking L1 band satellites.
- SonyL1L5, tracking L1 and L5 band satellites.
- Mobile Connectivity Systems: Three cellular phones were deployed to measure LTE / 5G performance across different networks: a Motorola G4 (Ice provider), a Samsung S21 (Telenor provider), and a Samsung S21 (Telia provider).
- Video Capture: A stand-alone Blackvue DR900X Plus dash camera continuously collected video footage of the windshield view. This camera was explicitly synchronized with the U-blox GNSS data for spatial-temporal correlation.

This paragraph focusses solely on the lane marking detection. The positional analysis can be found in Section 3.2.3. The lane marking detection analysis was performed using an automated, post-hoc process on the collected video data, focusing on obtaining a systematic assessment of lane line visibility and interpretability.

The steps for the data processing are as follows:

1. **Algorithm Selection and Calibration**: The core tool employed was LaneNet [7], an artificial intelligence (AI)-based algorithm leveraging an instance segmentation approach for lane detection. Since the sensor setup differed from the algorithm's training environment, specific parameters were calibrated empirically through grid search and visual verification.
2. **Video Pre-processing**: To mitigate optical interference from the vehicle's hood, which occupied the lower portion of the image due to camera placement, a pre-processing step involved masking this area by blacking it out.
3. **Defining Detection Zones**: Two reference trapezoids were empirically established on the image plane to delineate the expected areas for the left and right lane markings across varying road curvature and conditions.
4. **Data Processing and Classification**: Each video frame was spatially referenced by linearly interpolating the nearest GNSS coordinates. LaneNet detections were validated against the defined trapezoidal areas. Detection results were aggregated and filtered using two successive median filters to enhance temporal stability. The final output assigned a status to each route segment.
5. **Output Format**: The filtered and classified segments were subsequently stored as GeoJSON LineStrings, incorporating the detection status along with distance and duration measurements.

BASt Methodology

Data was collected in March 2024 along the German section of the MODI corridor, covering routes from the Dutch border to Puttgarden with additional segments near Osnabrück. Multiple runs ensured dataset diversity, and the vehicle was driven to mimic heavy truck behaviour for realistic traffic interactions. A more detailed description of this data collection drive is given in Section 3.3.

Since there is no official traffic sign database available like in Norway or the Netherlands, the video data from the dash cam has been evaluated by image classification. For this purpose, BASt has trained a convolutional neural network (CNN) based on the Synset Signset Germany dataset [8], which contain images of 211 different traffic signs. Sub-signs with additional information (e. g. ‘only valid from 22h to 6h’) are not included. The first classes are aligned with the former German Traffic Sign Recognition Benchmark (GTSRB) [9].

To ensure the best quality of the automated traffic sign recognition, a robust approach with three steps was chosen. The dash cam videos were recorded with 50 frames per second (fps) and a FullHD resolution of 1920 x 1080 pixels (width x height). In the first evaluation step, each video frame is analysed by a YOLO model (You Only Look Once) to specify traffic signs’ coordinates of any kind. YOLO is a single-stage object detection model based on a convolutional neural network (CNN) architecture. Unlike traditional object detection systems that use a two-stage approach, YOLO performs object localization and classification in one forward pass through the network. The pixel area (ROI – Region of Interest) with the highest confidence value from YOLO is then passed to the second step called classification. The CNN to complete this task is built upon a pre-trained ResNet50 architecture [10] with weights from the ImageNet dataset [11]. This architecture was trained for 450 more epochs on the Synset Signset Germany dataset which led to promising results as illustrated in Figure 7, showing the confusion matrix of the final model. The confusion matrix shows the model’s performance on a test dataset with the same 211 classes of traffic signs but different images. The optimal result would be a perfect diagonal from the upper left to the lower right corner. The generated CNN model shows only slight deviations from this diagonal due to false positives and false negatives.

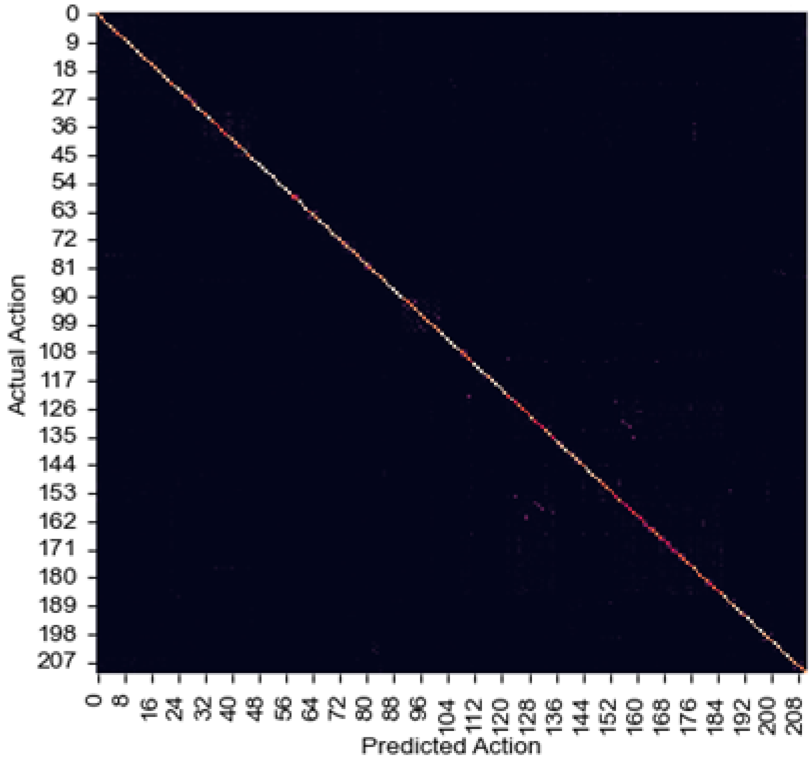


Figure 7: Confusion matrix of BASt's image classifier for traffic signs

To reduce these inevitable false classifications by the CNN, object tracking was implemented as a third step. The tracking is based on the DeepSORT algorithm [12] and compares both the classification and confidence of the last sequential video frames. For the assessment of the driven stretch, the last six frames had to be classified as the same traffic sign in an even region of the image. Furthermore, the minimum average confidence out of the last six frames was set to 82 percent.

HERE Methodology

The MODI project recognizes that HD maps play a key role in supporting L4 CCAM for heavy-duty logistics by complementing vehicle sensors to enable precise localization and safe navigation. Previous work, particularly deliverable D4.2 on optimal designs for physical and digital road infrastructure, identified key requirements for such maps: They must provide highly accurate and up-to-date representations of traffic regulations, lane-level road networks, and precise landmark positioning. Furthermore, standardized content and data formats across borders are essential for large-scale operations.

To examine how HD maps can help overcome barriers to achieving L4 automation, the project collaborated with HERE, a leading map provider, which granted access to its HD map data [12]. HERE's mapping services combine multiple layers of location and situational information and can integrate with vehicle sensors to enhance environmental awareness. Sensor data from vehicles also feeds back into the system to keep maps accurate and current.

The HD map is organized into tiles, which divide the globe into progressively smaller sections for efficient data access and spatial indexing. At the smallest level, each tile covers roughly 2.45 square kilometres, enabling quick retrieval and preloading of relevant data. Positions are stored using a proprietary coordinate system that compresses latitude and longitude into 64-bit integers, reducing storage size by encoding relative positions within tiles. Elevation data is stored separately in centimetres above the ellipsoid.

The dataset provided for this study includes 18 layers grouped into three main models. The Road Centreline Model contains routing network geometry and attributes such as speed limits and road curvature. The HD Lane Model offers detailed lane-level topology and geometry, including lane boundaries and attributes. The HD Localization Model provides precisely measured roadside objects – such as signs, guardrails, and markings – that vehicles can use for accurate positioning. Additional layers include administrative boundaries and internal state information.

The analysis focused on understanding how well the HD map covers the data types prioritized in MODI's infrastructure requirements, whether it can help address physical infrastructure challenges, and how it can support safe fallback manoeuvres for automated trucks along the MODI corridor.

3.1.3 Analysis Results

The analysis of the data collection with the focus on infrastructure are described in the following.

Quality Map Data Coverage

To evaluate how the HERE HD map supports the MODI project, prioritized data types were analysed. Deliverable D4.2 defined over 700 data types relevant to SAE L4 driving, each ranked by importance. For this study, only priority levels 1 and 2 were considered, covering both static data (such as road geometry and speed limits) and dynamic data (such as traffic and weather). Since the catalogue provided to us contains only static data, the analysis focused on comparable static datasets from the Norwegian Felles Kartdatabase (FKB) and NVDB. Data types outside the scope of HD maps, such as mobile communication points, were excluded, leaving 55 types grouped into three categories: digital infrastructure, physical infrastructure, and traffic regulation.

Data from HERE HD Lane Model layers was extracted for tiles covering the MODI corridor from Oslo to Rotterdam and compared against D4.2 descriptions. Among the highest-priority types, all were covered except roadblocks, though digital equivalents like conditional access restrictions may exist. Address data is also missing, as it resides in a separate HERE product. This resulted in 11 types with full coverage, 1 without, and 3 partially covered. For the second priority level, 23 types were covered, 12 were not, and 5 were partially covered. Missing or partial cases include features like parking areas, pedestrian streets, and underpasses, which are supported in the data model but not populated. Some gaps relate to niche elements such as cattle grates and culverts, while others, like speed bumps and ferry waiting areas, likely exist in other HERE services.

Road Sign Detection

The analysis of road sign detection performance focused on signs relevant for goods transport. Thereby, the focus was on signs indicating speeds limits for the Norwegian stretch while for the Netherlands stretch a broader set of signs was considered.

In the context of the Norwegian road network, a high rate of accurate detection for static speed limit signs was generally observed. Specifically, the detection system exhibited a success rate of 92% for normal speed limit signs. However, the system failed to detect approximately 8% of these static signs, despite their clear visibility in the recorded video footage.

A significant challenge was posed by electronic speed limit signs (variable speed limit signs), registering as the most problematic sign type for accurate detection. The detection rate for these dynamic signs was substantially lower at 62%, representing a critical discrepancy when compared to the performance for static signage. This outcome is hypothesized to stem from the interplay between the frequency of the signs' LEDs and the frequency of the onboard camera system. A potential remedy to this would be to have the dynamic speed data available in an HD-map. HERE has a variable sign id for all variable speed limit signs, that can be enriched with real time data. This data layer is not filled with data from all road authorities yet, but the digital infrastructure to do so in the future is ready.

In addition, Dutch road authorities provided an example of a narrow curve in the Valburg cloverleaf where the speed limit remains unchanged in the physical roadside signage, even though the curvature of the road calls for a slower speed. This is a good example of a situation where the HD-map can provide redundancy in several ways. As well as providing the curvature of the road through the ADAS attributes layer, the speed attributes layer in the HERE dataset sets a lower speed category on that part of the road link than the actual speed limit. As we can see in Figure 8, the speed limit is 130 km/h for the full length of the link, while only the bend has a speed category that is lowered from "101 – 130 km/h" to "51 – 70 km/h".

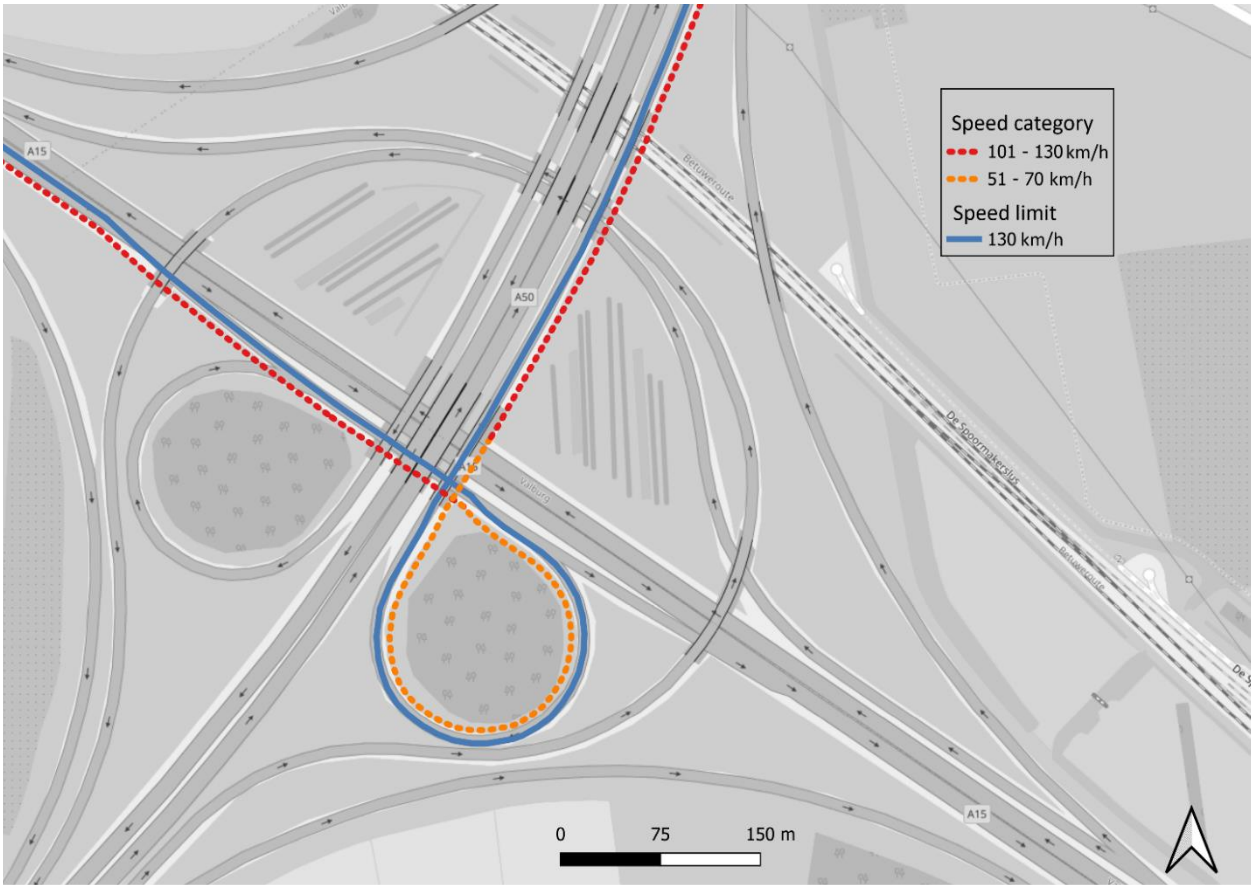


Figure 8: Speed category (dashed) vs. speed limit (solid) for the Valburg cloverleaf

Analysis of the comprehensive dataset collected in the Netherlands documented a total of 260 deviations between perceived and database-recorded signage. These deviations were systematically categorized in Table 10.

Table 10: Distribution of deviations

False detection	Missing detection	False database record	Missing database record	Total
91	62	16	91	260

Of the 91 registered false detections, approximately two-thirds were attributed to the misinterpretation of small hectometre signs (31 instances) or erroneous classifications related to adjacent lanes (31 instances). Hectometre signs, which function as distance markers, are frequently detected but are typically excluded from official road sign databases, leading to inconsistency. Other false detection events included the misinterpretation of manually altered or inactive speed limit signs (e.g., misclassifying an erased limit as a 'no access for goods vehicles' prohibition).

The 62 missing detections included 16 instances where the sign type was not supported by the detection system (e.g., informational underpass height restrictions or recommended speed limits). Electronic speed limit signs accounted for 12 instances in the missing detection category. A further 13 misses were caused by double speed limit signs mounted one above the other, making accurate determination of the active limit challenging for the automated system. Furthermore, large informational signs (often containing text and exit distance details) were found to be routinely omitted from digital road sign databases (Figure 9).

Issues concerning database fidelity were quantified: out of the 91 missing database records, 24 related directly to temporary roadwork signage and corresponding altered driving patterns. An investigation into the 16 false database records revealed a notable spatial disparity, with 87.5% of these errors concentrated within second half of the analysed route segment.

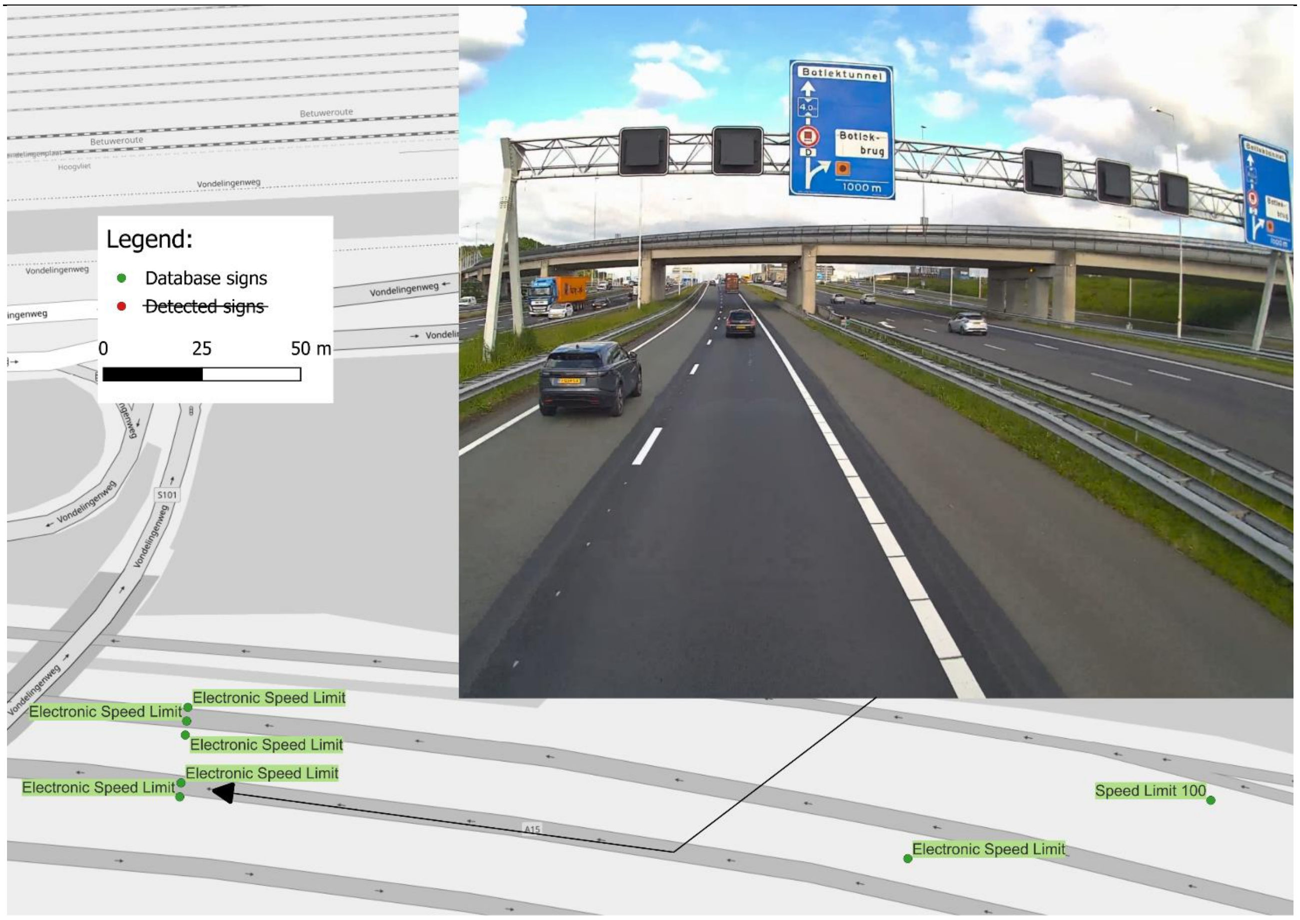


Figure 9: Missing detection example of complicated sign

As described in the methodology section 3.1.2, there is no official German database available for road signs. Thus, the German part of the MODI corridor was evaluated based on image classification. In the beginning of the data evaluation, all ROIs from YOLO were classified by the CNN. An example resulting image is shown in Figure 10. Both speed and accuracy of the classifier decreased noteworthy since tracking was too expensive in terms of computational resources. As stated above, the YOLO detection was reduced to its best result, eventually.

Figure 10: Traffic sign classification for all YOLO detections

In the postprocessing of the classified data, all available 211 signs were reduced to the following 11 classes:

- speed limit 50 km/h
- speed limit 60 km/h
- speed limit 70 km/h
- speed limit 80 km/h
- speed limit 120 km/h
- speed limit 130 km/h
- no overtaking
- no overtaking for vehicles > 3.5 tonnes
- caution
- bumpy road
- road works

In addition, data rows without any sign detected were ignored. In total, this led to 1,046 detected signs from the whole travel which included, besides the MODI route from Enschede to Puttgarden, additional kilometres for outward and return journeys to these spots. These residual entries from the raw data were validated by a human by reviewing the corresponding video frames and deleting only 55 false classifications. With the remainder of 794 actual traffic signs only between Enschede and Puttgarden, Figure 11 shows the detections plotted against the driven kilometres of the MODI corridor.

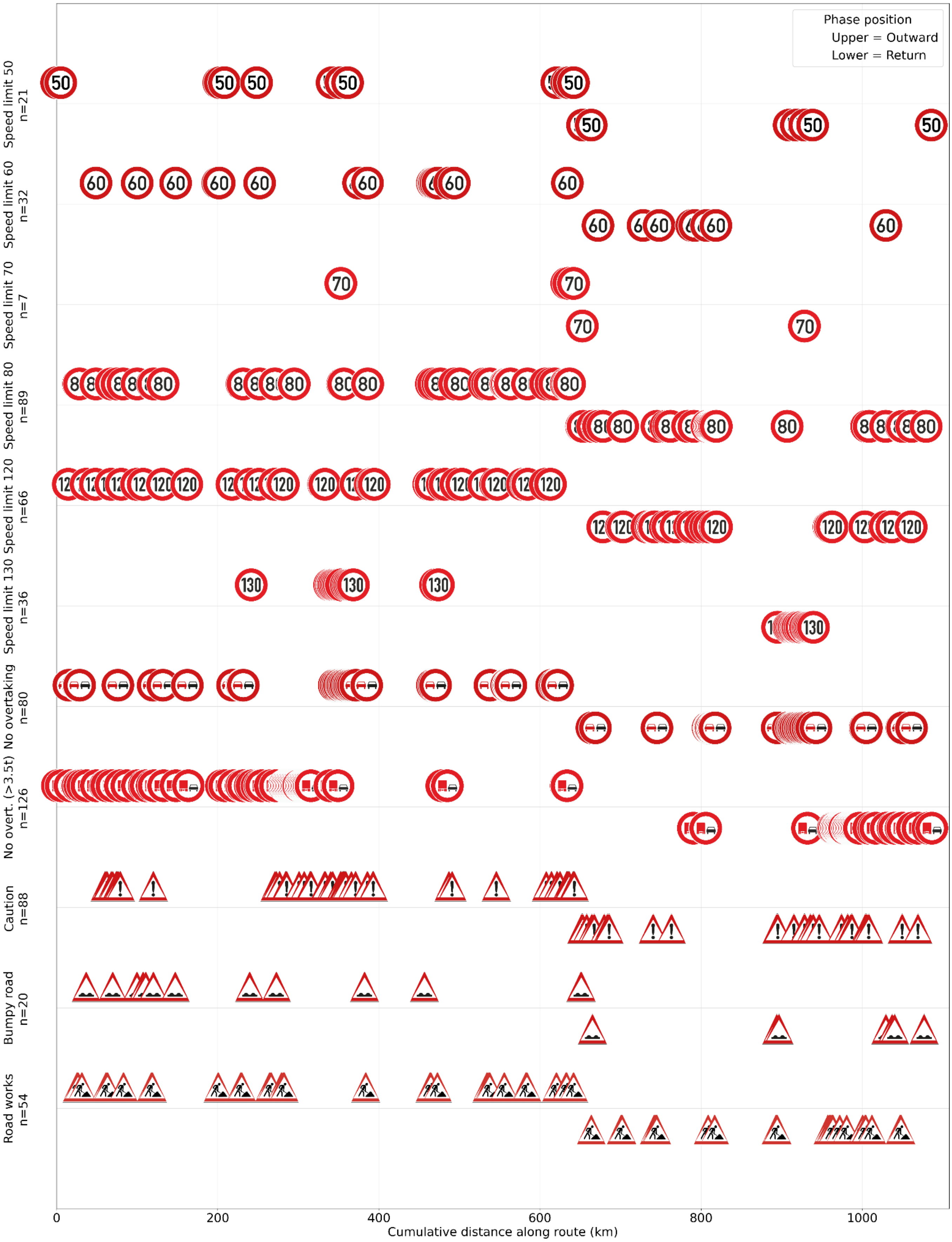


Figure 11: Traffic signs on the German part of the MODI corridor from Enschede to Puttgarden

The data collection drive was mainly conducted on the motorway (German Autobahn) with a very few kilometres on rural roads or urban areas. For this reason, the number of speed limit signs for 50 and 70 km/h is comparable small. Nevertheless, the speed limits from 50 km/h to 80 are relevant for heavy vehicles since 80 km/h is the maximum allowed speed. Due to construction work, speed limits of 60 or 80 km/h often apply on motorways. The evaluation of signs above 80 km/h is not relevant for trucks in the scope of MODI but interesting when it comes to the behaviour of other road users (see Section 3.3). Overtaking rules both for passenger cars and for heavy vehicles have the highest counts on the travelled stretch and are considered important for autonomous vehicles acting in mixed traffic situations. The caution and bumpy road signs were chosen from the whole class set as they are also considered important for autonomous driving software with regards to decision making, path planning and anticipating spontaneously occurring traffic situations. For localization of the traffic signs, moreover, maps were composed, containing the minimum number of signs for each class and the corresponding geolocations, marked as blue dots. As an example, the map in Figure 12 gives an idea of the density of construction sites. Since road works often come along with other restrictions such as narrowed lanes or poor road surfaces, this sign is also important for all kinds of vehicles.

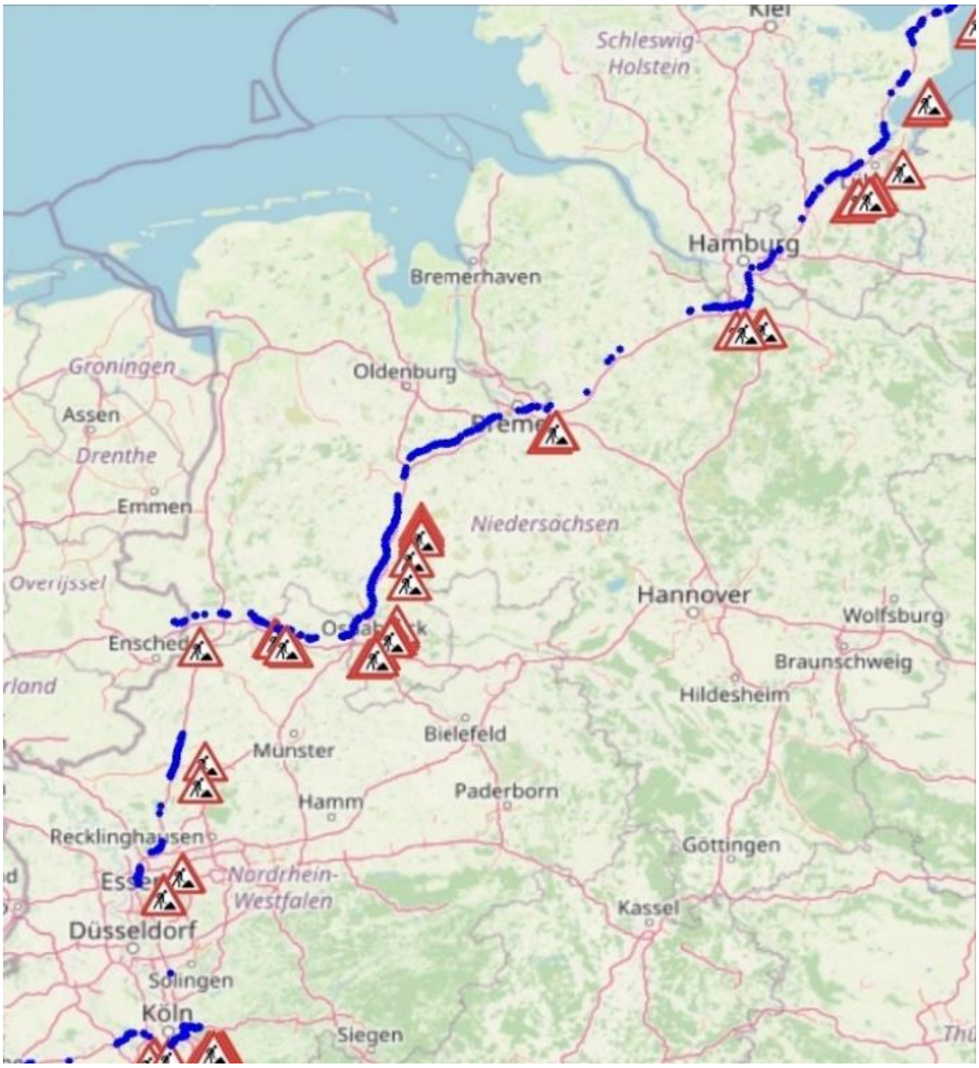


Figure 12: Minimum number and location of road works signs along the German route

Lane Marking Detection

Previous investigations of physical infrastructure in the individual MODI countries indicated that issues with lane markings may arise. Most road administrations reported that worn markings could pose challenges for automated vehicles relying on onboard sensors, underscoring the importance of redundancy in digital infrastructure. In addition, the Netherlands has some hard shoulders that are used as peak-hour lanes for most of the day. Navigating into these lanes – as heavy-duty trucks are expected to do – requires crossing several solid longitudinal lines, which is technically prohibited by local law and therefore poses a challenge.

The assessment of lane marking performance utilized data from multiple campaigns, integrating operational system status logs with vision-based algorithmic analysis and HD map data.

The evaluation incorporating data from the DAF system encompassed approximately 3014 kilometres of driven distance. Within this observed distance, the vehicle's lane departure warning system registered an ‘Unavailable’ status for approximately 407 kilometres. The ‘Unavailable’ state is empirically interpreted as the system’s inability to detect lane markings with sufficient reliability to ensure functional integrity.

A manual categorization of these 407 kilometres of unavailable segments yielded a detailed distribution of contributing factors:

1. Systemic Limitations and Infrastructure Quality: Approximately one-third of the distance driven in the 'Unavailable' state occurred on segments without identified shortcomings in lane marking condition.
2. Infrastructure Complexity: The predominant factors contributing to the unavailable status were related to complexity or ambiguity in the road markings. "Complex markings," typically observed in intricate urban areas or highway interchanges, constituted a substantial segment of the failures. "Confusing markings" frequently correlated with transient operational conditions, primarily originating from roadwork zones where overlapping permanent and temporary lane lines created visual contradictions.
3. Environmental and Kinematic Factors: Environmental conditions were identified as significant impediments to consistent lane marking detection. Lighting effects, specifically shadows cast by low-angle sunlight and reduced visibility during periods of darkness, were observed to compromise detection efficacy. Furthermore, wet road surfaces induced bright reflections, exacerbating the difficulty of visual detection. An analysis of the impact of surface moisture indicated a quantitative shift in detection performance based on marking wear.

The analysis drawing on the Volvo data utilized lateral distance measurements to quantify the integrity of the vehicle's perception of road lanes and edges. For the combined trips, the validity of the left road line measurement was found to be 95.1% of all datapoints, whereas the validity of the right road line measurement was marginally lower at 91.2%.

A trip-specific comparison of valid lane markings revealed systematic variations, notably for the right lane line as shown in Table 11.

Table 11: Valid lane markings

Trip	Valid left lane marking (%)	Valid right lane marking (%)
Norway → Sweden	96.1	92.9
Sweden → Norway	94.0	83.5
Germany → Denmark	96.4	93.2
Denmark → Sweden	94.2	94.0

Invalid data points lowering the score in the lane detection measurements were observed during several predictable operational and infrastructural conditions:

- Vehicle State: Invalid measurements frequently occurred when the vehicle stopped or during low-speed manoeuvres.
- Geometric Complexity: Failures were registered when navigating complex urban traffic patterns, entering confined areas, or encountering distinct structural changes in the road markings, such as those located directly prior to tolling stations.
- Environmental Factors: Snowy conditions, especially along the side roads, were documented as leading causes for missing or invalid right lane markings.

The analysis of the Q-Free data, utilizing the LaneNet algorithm applied to video data across the full corridor roundtrip, quantified the success rate of lane marking detection over a total analysed distance of 3558 kilometres (Figure 13).

Figure 13: Example detections from different datasets

This quantification categorized road segments based on whether zero, one, or two lane-markings were successfully identified. The aggregated results across the entire analysis yielded the following distribution:

- Two lane markings successfully detected: 1735 km
- Only one lane marking detected: 1096 km
- Zero lane marking detected: 548 km

A breakdown of these detection statuses by country demonstrates spatial variability in algorithmic detection performance as demonstrated in Table 12.

Table 12: Lane detections

Country	No lane markings detected [km]	Lane marking on one side detected [km]	Lane markings on both sides detected [km]
Norway	21.4 (8.7%)[2]	76.6 (31.1%)	148.5 (60.2%)
Sweden	167.5 (17.8%)	282.3 (30.0%)	491.3 (52.2%)
Denmark	85.5 (21.5%)	155.2 (39.1%)	156.6 (39.4%)
Germany	239.7 (17.6%)	421.2 (30.9%)	702.8 (51.5%)
Netherlands	33.8 (7.8%)	160.9 (37.4%)	235.9 (54.8%)
Total	**548 (16.2%)**	**1096 (32.4)**	**1735 (51.3%)**

---

[2] Percentages refer to the proportion of each lane-marking category relative to the total distance recorded per country. Minor deviations in the totals arise from rounding.

Most maps and road databases project the road as a single polyline at the centre of the drivable area. And while this is often sufficient for a human driver, who can interpret the road environment visually in real time and adapt to lane boundaries, widths, and topology without prior digital guidance, an automated vehicle needs up front information about where within the road surface it is safe and legal to drive. Reliable and accurate lane geometry also serves as a redundancy layer when onboard sensors and location services are degraded.

The Lane Polyline Geometry layer in HERE's HD map delivers accurate 3D geometry of all parts of a roadway by depicting the lane group centrelines, individual lane centrelines, and individual lane boundaries, as shown in Figure 14. It does not always include sidewalk and other roadway adjacent mobility features. This data layer can be coupled with e.g. the lane attributes layer to provide an even better digital awareness of the roadway environment.

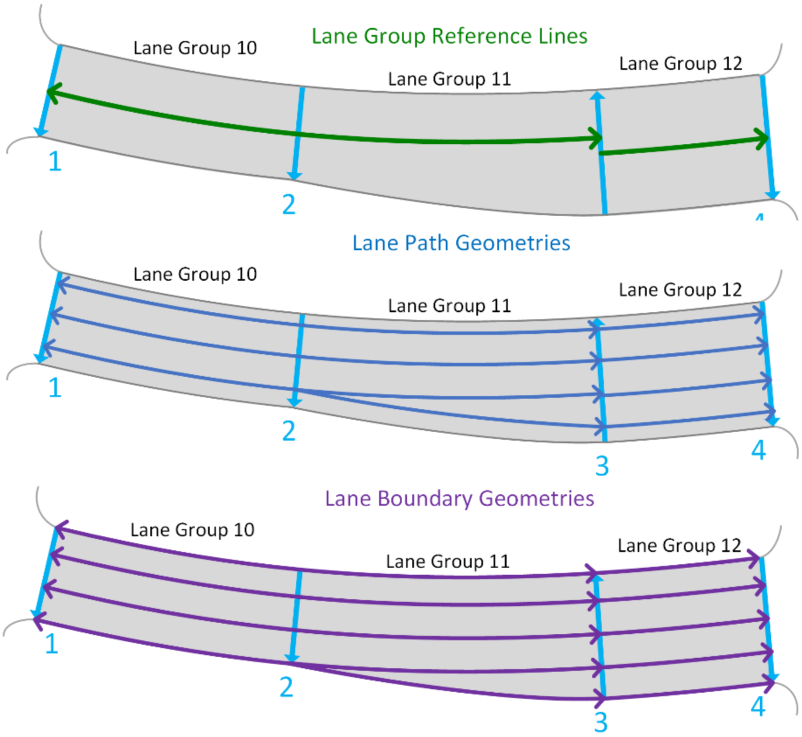


Figure 14: Lane geometry polyline concepts

Another possible challenge for automated vehicles when traversing the MODI route was reported to be linked to complex lane changes in certain areas. The lane topology layer of HERE HD map might assist in overcoming this obstacle, as it gives information on which lanes connect to each other.

As Figure 15 illustrates, each lane group has a start and end connector, along with details on how individual lanes link to adjacent lane groups. Having this information available before the vehicle relies on its onboard sensors allows for earlier planning and smoother preparation.

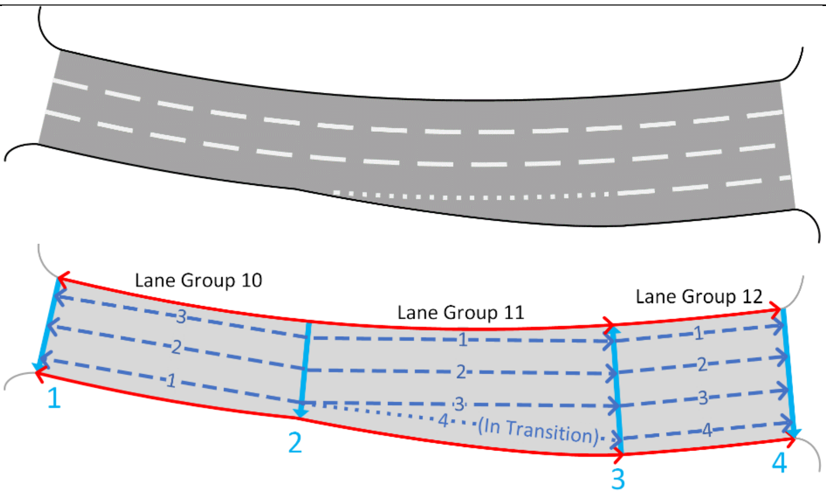


Figure 15: Lane topology concepts

An example of the HERE HD map visualized with an OpenDrive viewer is depicted in Figure 16. On the left, an overview of a route going through a roundabout and onto the highway is shown. The right image illustrates a zoomed and focused rightmost lane to enter the highway. In this visualization, it is possible to navigate the road network in 3D and inspect the detailed lane geometry.

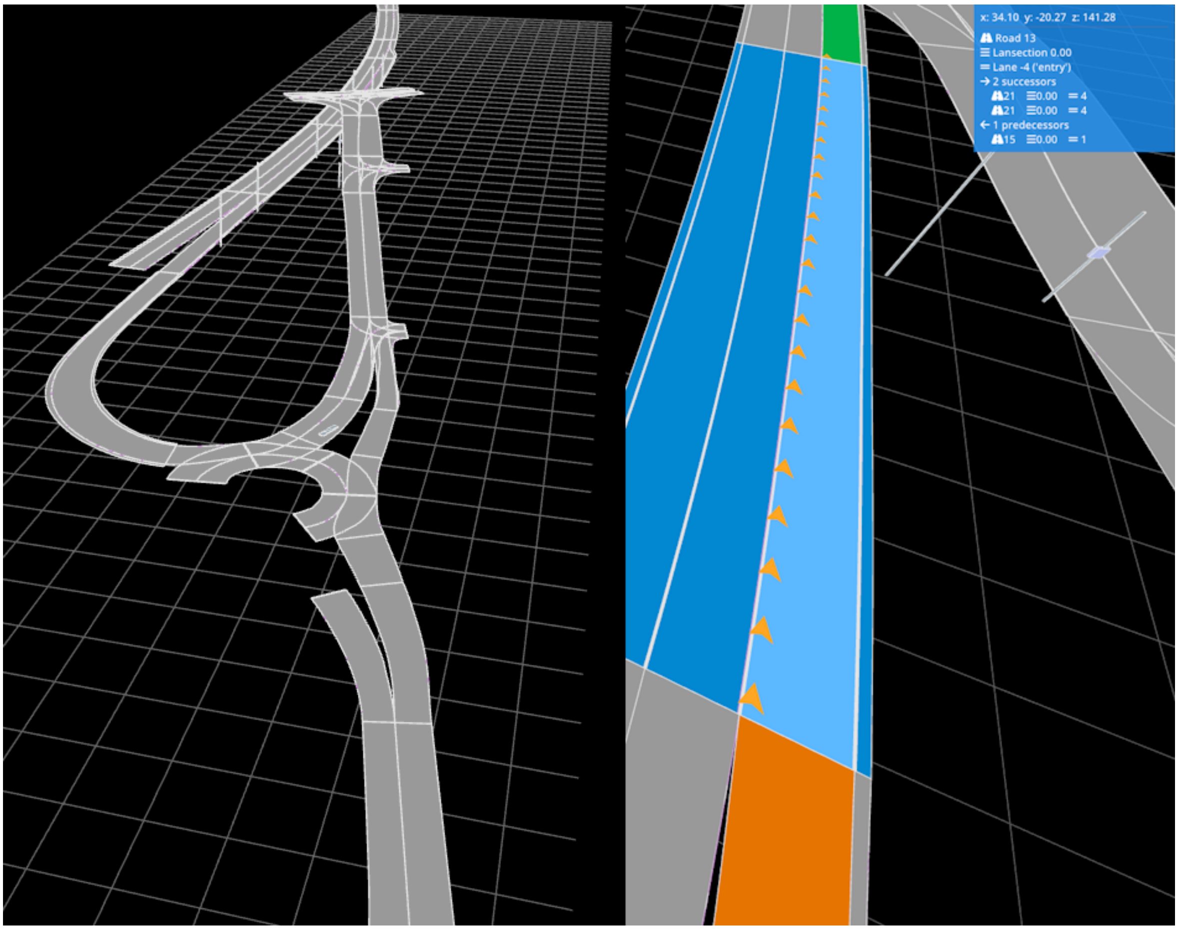


Figure 16: OpenDrive road network

The HERE HD map was used to evaluate the feasibility of Minimal Risk Manoeuvres (MRMs) for heavy-duty trucks along the MODI corridor, focusing on shoulder widths as the most accessible safe stopping area in case of system failure. An initial assessment based on maximum shoulder width values proved overly optimistic, so a more detailed method was applied using fixed-length segments and dense sampling. Compliance was defined as having a shoulder width of at least 2.5 meters on either side of the road. Out of 29,440 segments, 64% met this threshold, with a median width of 2.7 meters (see Figure 17).

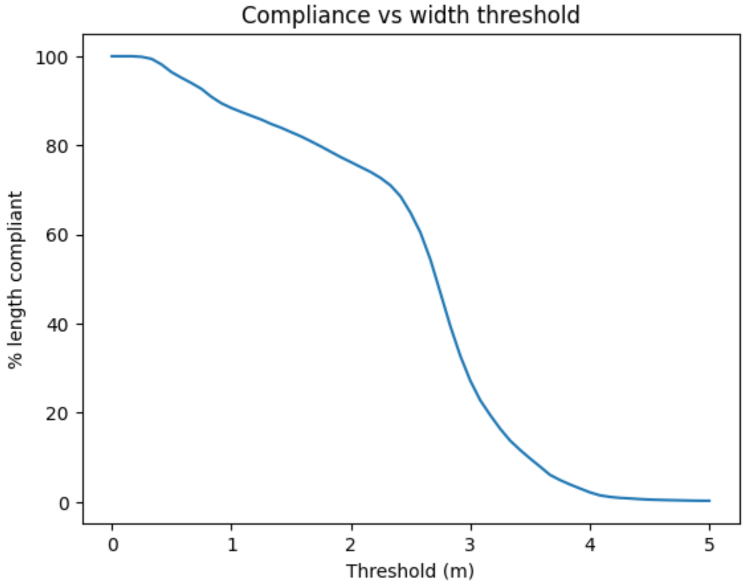


Figure 17: Compliance rate with varying thresholds

Across the full 2,848 km corridor, 1,842 km (65%) were compliant, with notable differences between countries: Norway, Sweden, and Denmark averaged around 2.2 meters, while Germany and the Netherlands had wider shoulders and higher compliance rates. Sweden showed the lowest compliance, with less than half of its corridor meeting the requirement (see Table 13).

Table 13: Summarized shoulder width statistics

Country	Total length [m]	Compliant length [m]	Compliant [%]	Length weighted mean width [m]
Total	**2,848,414.25**	**1,842,415.92**	**64.68**	**2.49**
Norway	234,971.08	140,927.65	59.98	2.17
Sweden	935,936.16	429,376.77	45.88	2.20
Denmark	349,166.87	214,529.97	61.44	2.22
Germany	846,718.70	646,386.65	76.34	2.63
Netherlands	481,621.43	411,194.88	85.38	3.18

These results indicate that while overall compliance is high, long stretches remain unsuitable for MRMs, underscoring the need for further evaluation of safe stopping options along the corridor. A spatial overview of compliant and non-compliant segments is provided in Figure 18, highlighting these geographic patterns and discrepancies in shoulder width compliance. Inset maps show the northern part of the Swedish corridor and the entire Dutch corridor. The former reveals a long stretch with virtually no compliant shoulders, while the latter illustrates that most of the Dutch corridor exceeds the 2.5-meter threshold.

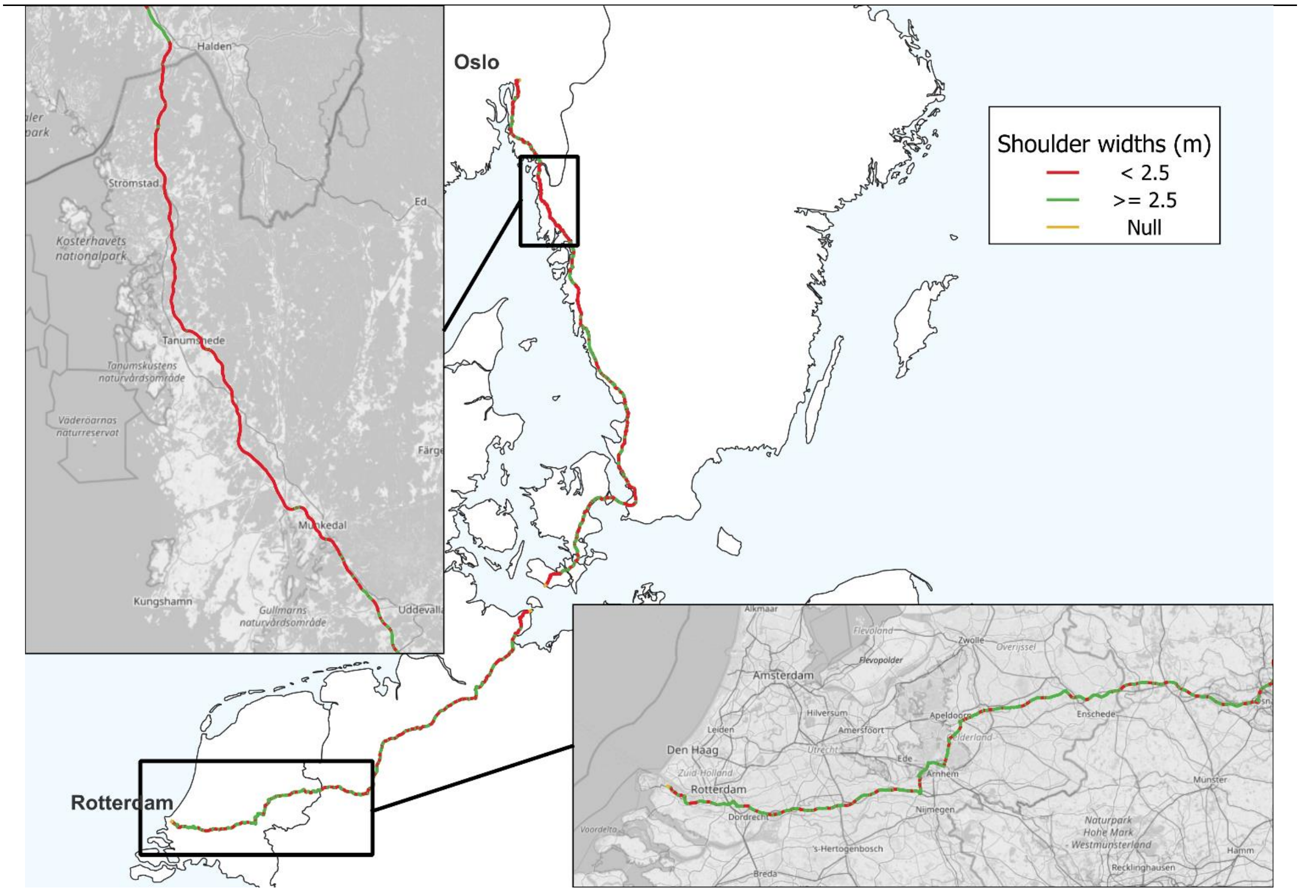


Figure 18: Compliant and non-compliant shoulders for the MODI corridor

Charging Infrastructure

The results of the analysis of the charging datasets as described in the method section 3.1.2 are as follows:

Figure 19 presents the results of the overlap analysis, showing a confirmed match rate of 30.6%, with 0 potential matches. Initially, three probable matches were identified, but manual review resolved these into two confirmed matches and one mismatch.

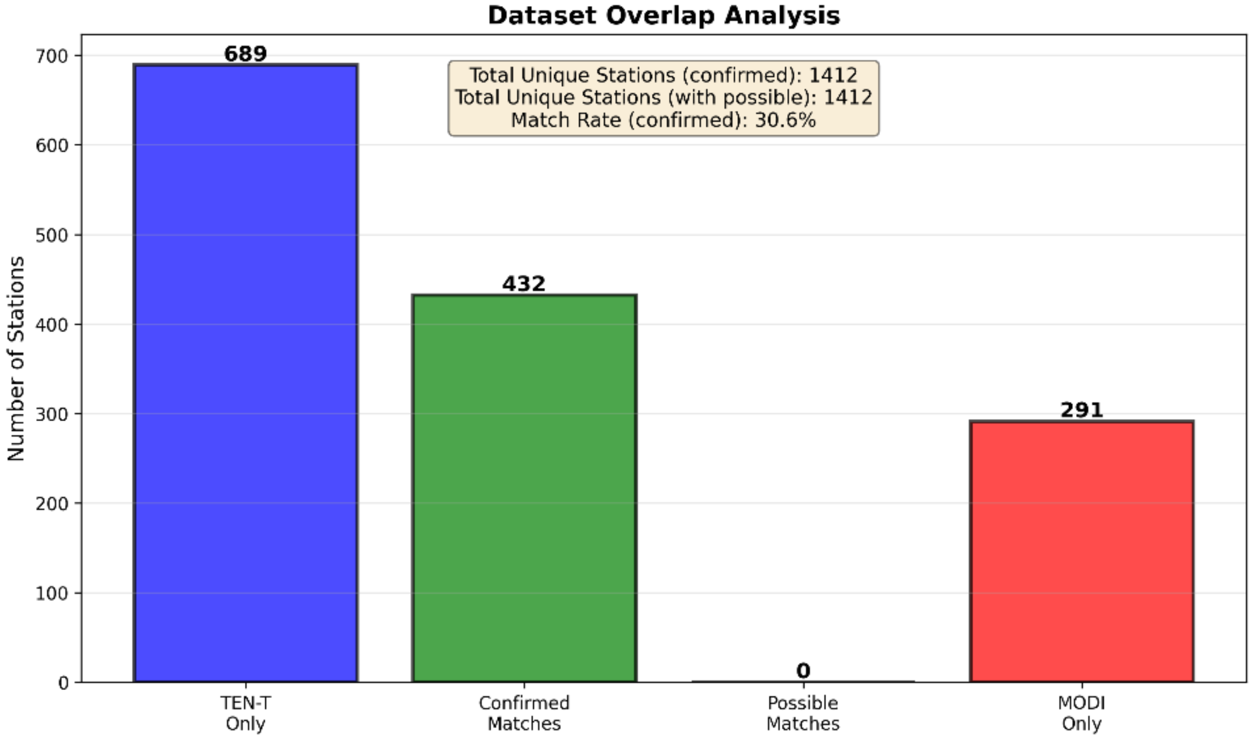


Figure 19: Bar chart that shows unique and overlapping stations in the two datasets

The map in Figure 20 illustrates the spatial distribution of matched stations, revealing that the highest match rates occur in Germany and Sweden. This is further supported by per-country statistics in Figure 21, which show that Norway, Denmark, and the Netherlands have significantly more stations listed in TEN-T, but a lower number of confirmed matches.

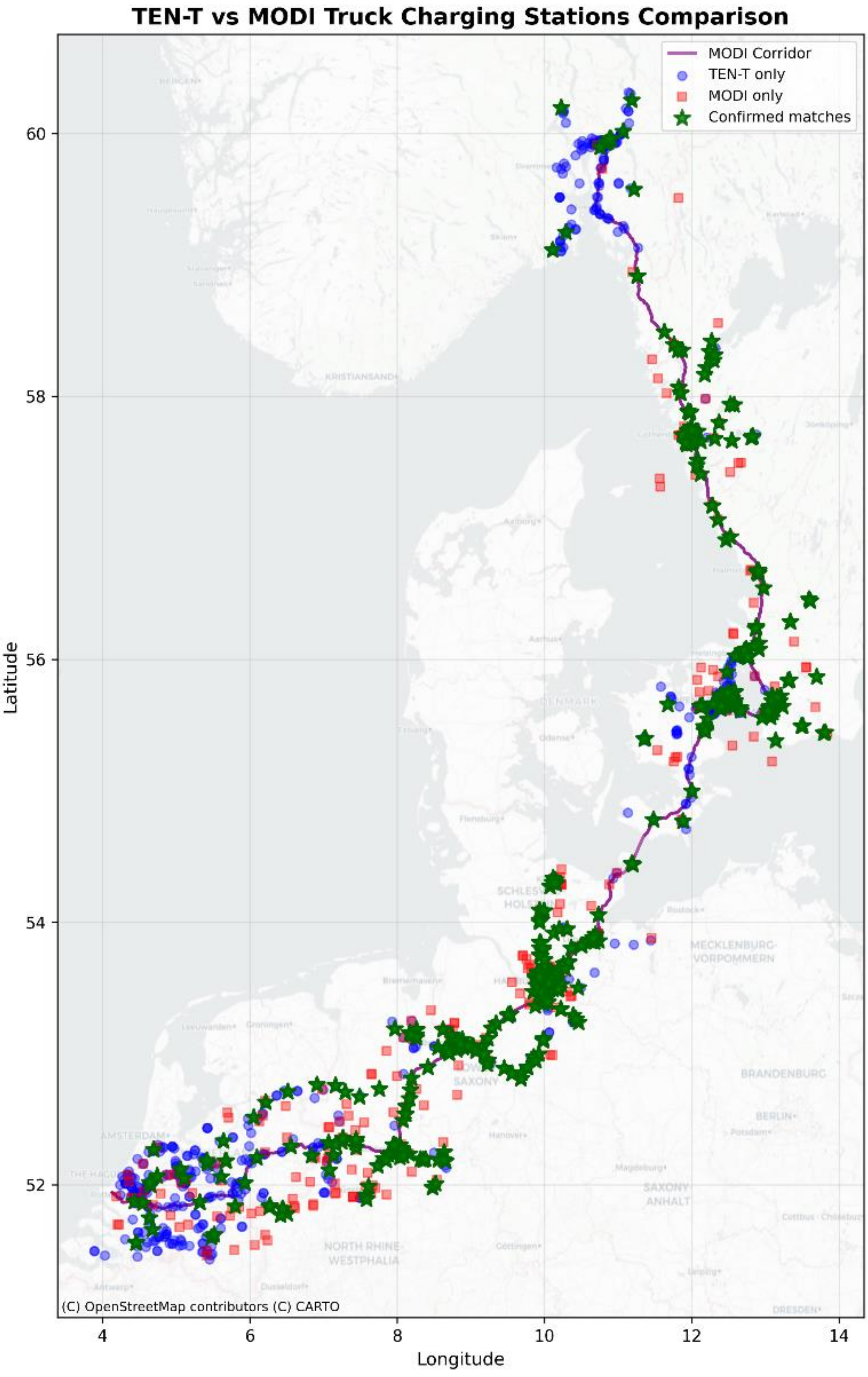


Figure 20: Map showing unique and overlapping stations along MODI corridor

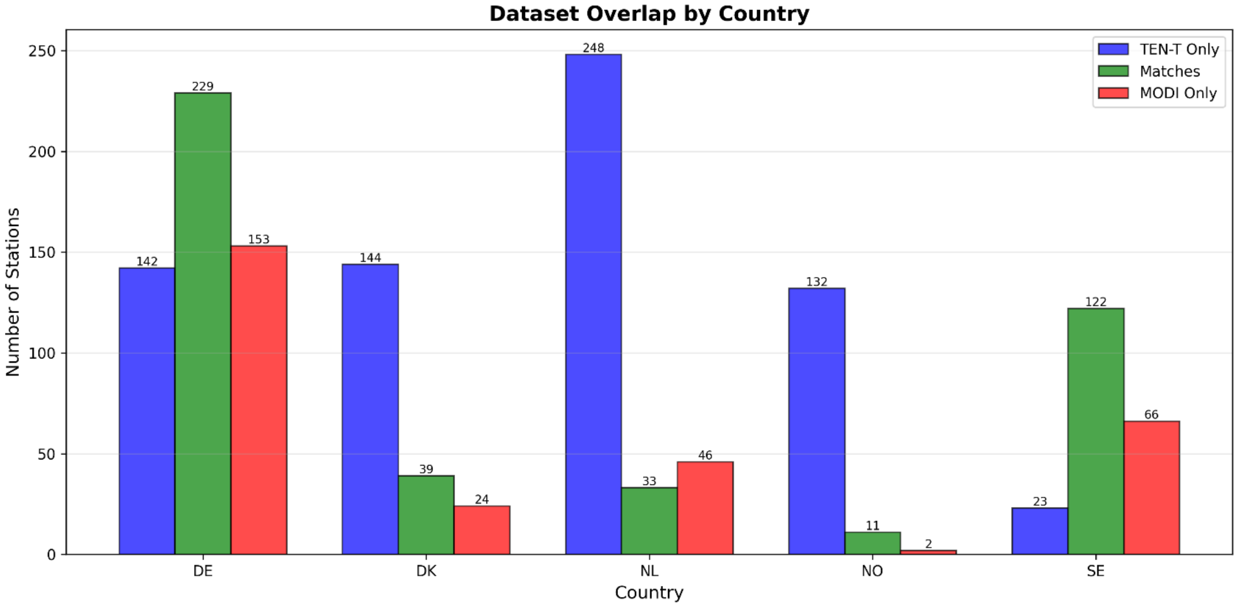


Figure 21: Unique and overlapping stations by MODI country

For Norway and the Netherlands, this is expected, as their data originate from truck-specific datasets. Denmark, however, shares the same original data source as Sweden, making its lower match rate irregular. To further evaluate data quality, a comparison of charging capacity was conducted. The metric used in the analysis was the maximum power of a single connector or charging point, rather than the total station power. As shown in Figure 22, the two datasets exhibit similar distributions for maximum charging capacity. However, the MODI dataset includes more extreme values, as evident in Figure 13. This can be partially attributed to the filtering of low-capacity stations from TEN-T, whereas the MODI dataset includes pre-filtered truck-specific stations without such exclusions.

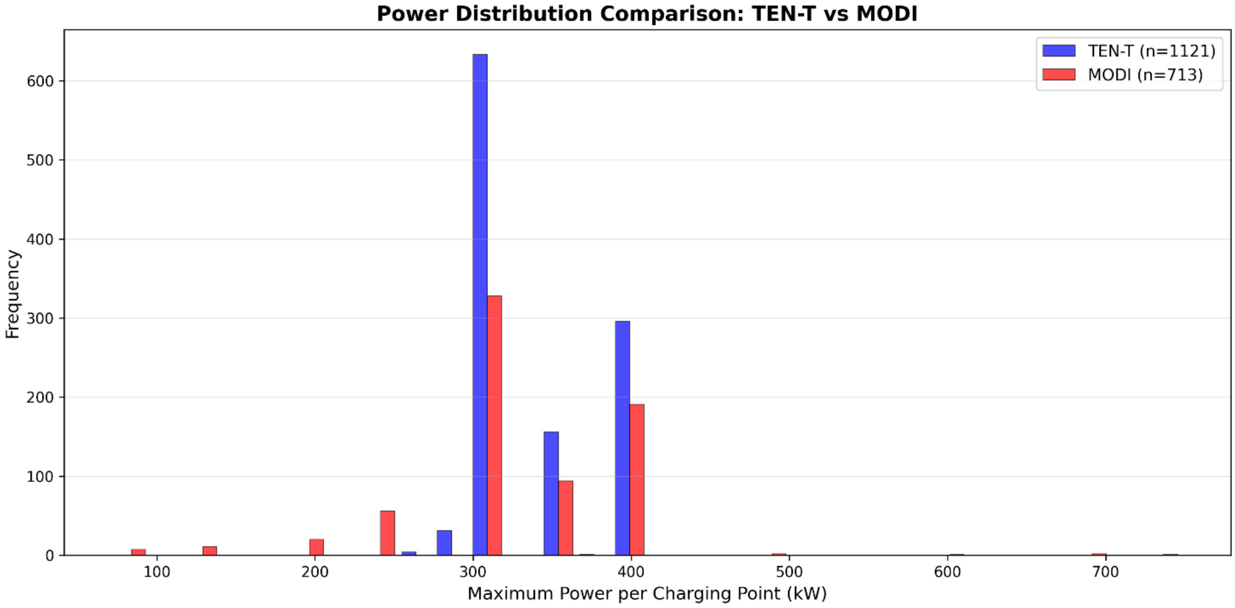


Figure 22: Distribution of max power per station in the two datasets

Based on the actual drives of the Volvo trucks and assuming that the truck can accept detours of up to 10 km in order to charge, the longest distance from any point along the route to the nearest charging station is approximately 26 km, and the average and median distances to the nearest charging station are 5.74 km and 4.19 km. The location with the longest distance is located in Sweden, just south of the Norway / Sweden border. Figure 23 shows the state of charge percentage along the route, as well as the locations where the vehicle was charged (red dots) and the truck-supporting charging stations within 10 km (orange dots) of the driven route.

Figure 23: Charging stations and driven route, colored by distance to nearest station

When applying the same charging station filter and distance analysis on the full MODI corridor, the results are quite similar: The longest distance from any point along the route to the nearest charging station is approximately 28 km, and the average and median distances to the nearest charging station are 6.35 km and 4.68 km. This is shown in Figure 24.

Figure 24: Charging stations and full MODI corridor, coloured by distance to nearest station

Current analyses suggest that charger coverage along the route appears relatively strong, as demonstrated by a Volvo truck completing a substantial portion of it. However, existing data does not confirm whether this infrastructure would remain adequate as the number of battery-electric trucks grows. In practice, charging operations can still face significant constraints – such as site layout and access, height and weight limits, bay length, queuing, payment and contract requirements, uptime, and security concerns. Furthermore, a nominal rating of 250 kW does not necessarily indicate truck compatibility in Europe. These gaps highlight the need for further assessment before assuming scalability.

The analysis of the consumption calculation shows that with the configuration as described in the method section, the estimated energy usage is slightly lower than the actual energy usage.

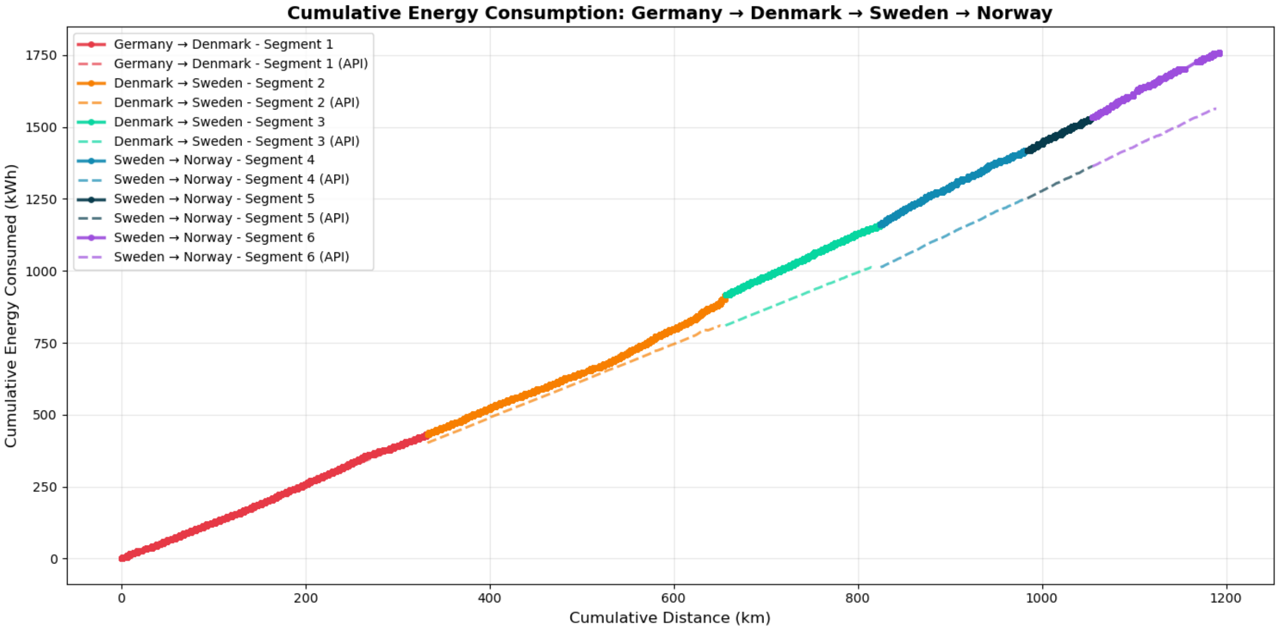


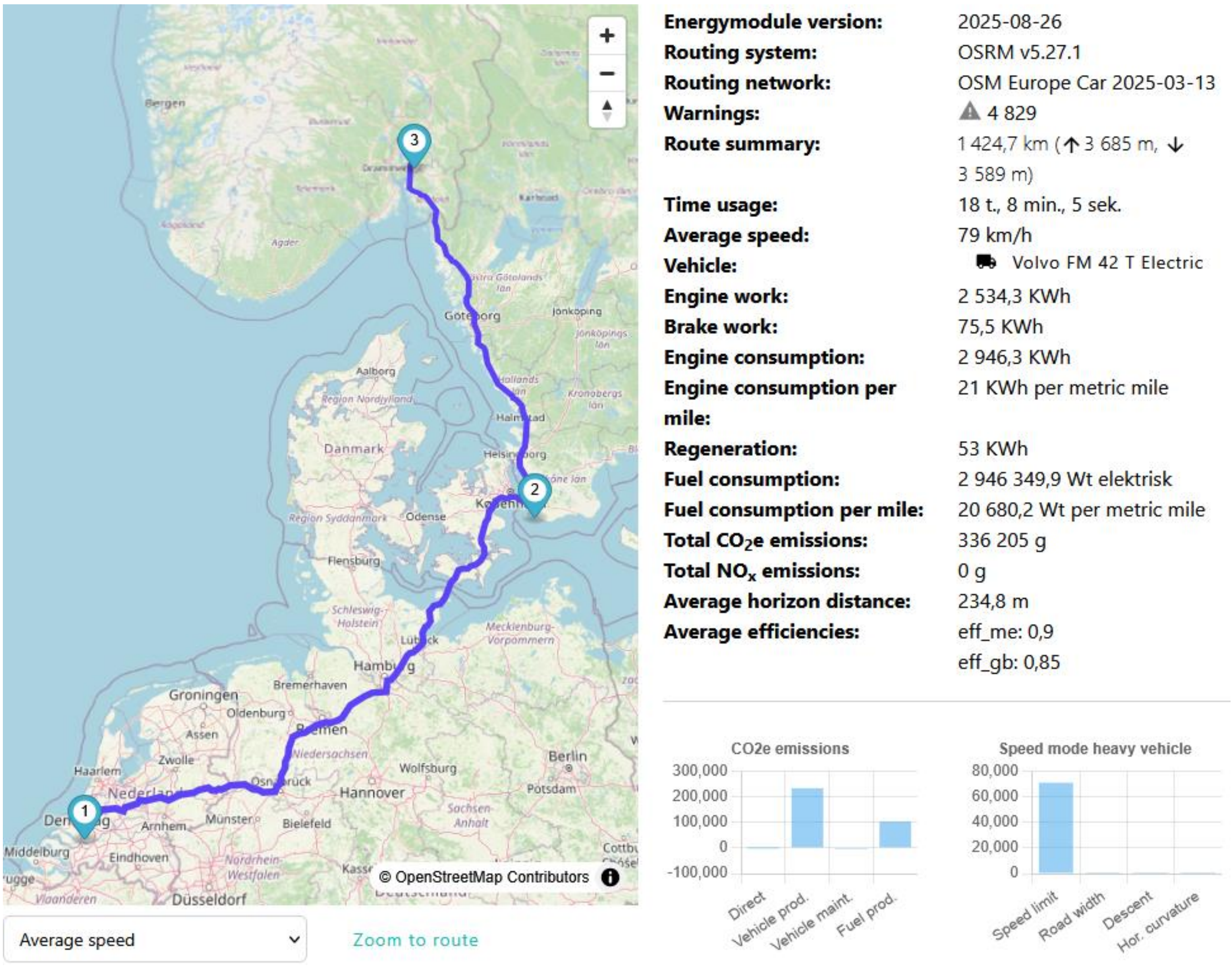
Figure 25: Segments with actual (thick lines) and estimated energy consumption (dotted lines)

The estimation is at around 95% for the stretches of the MODI corridor, that was driven by the trucks. This is depictured in Figure 25 and statistically summarised in Table 14.

Table 14: Summary of six drive segments

Route	SOC Start [%]	SOC End [%]	Route Length [km]	API Route Length [km]	Energy Consumption [kWh]	API Energy Consumption [kWh]
GE-DK	98.0	18.0	332.4	314.6	432.0	401.8
DE-SE	100.0	10.0	323.8	318.3	486.0	407.5
DE-SE	83.0	38.0	168.5	158.6	243.0	203.0
SE-NO	82.0	34.0	159.6	158.6	259.2	239.5
SE-NO	49.0	28.0	70.8	70.9	113.4	111.1
SE-NO	69.0	27.0	137.1	134.3	226.8	200.0
Total	–	–	1192.2	1155.3	1760.4	1562.9

The Volvo FM 42T E truck has a gross combination weight of 44 tons and a curb weight of 10 tons, which results in a total payload capacity of 34 tons. Given the assumption that a truck typically drives with a payload of 20 tons and calculating the energy consumption for the entire MODI corridor, the result is a total energy consumption of approximately 2946 kWh. Further, if the calculated 5% underestimation is considered as valid for the entire route, the adjusted energy consumption can be estimated to be 3100 kWh. With a battery capacity of 540 kWh, that means that such a truck would have to charge *at least* five times along the route (assuming that it started with a full battery and charged at almost empty every time). The findings of the calculation are summarized in Figure 26.



Energymodule version: 2025-08-26
Routing system: OSRM v5.27.1
Routing network: OSM Europe Car 2025-03-13
Warnings: ⚠ 4 829
Route summary: 1 424,7 km (↑ 3 685 m, ↓ 3 589 m)
Time usage: 18 t., 8 min., 5 sek.
Average speed: 79 km/h
Vehicle: Volvo FM 42 T Electric
Engine work: 2 534,3 KWh
Brake work: 75,5 KWh
Engine consumption: 2 946,3 KWh
Engine consumption per mile: 21 KWh per metric mile
Regeneration: 53 KWh
Fuel consumption: 2 946 349,9 Wt elektrisk
Fuel consumption per mile: 20 680,2 Wt per metric mile
Total CO_2e emissions: 336 205 g
Total NO_x emissions: 0 g
Average horizon distance: 234,8 m
Average efficiencies: eff_me: 0,9
eff_gb: 0,85

Figure 26: Energy calculation results for the entire MODI corridor

3.1.4 Conclusion

Taken together, the data collection campaigns show that the MODI corridor can support L4 freight automation in principle, but only within carefully constrained and explicitly defined stretches that act as individual ODDs. None of the investigated infrastructure dimensions – lane markings, signage, map data, or charging – is consistently robust enough to be treated as a single point of truth. Instead, safe L4 operation will depend on deliberate redundancy across sensors, HD maps, and infrastructure, as well as clear operational boundaries.

With respect to lane markings, the corridor cannot be regarded as uniformly “L4 ready.” While substantial portions are compatible with camera-based lane detection, performance collapses in predictable but frequent situations: complex or temporary layouts, adverse weather, and transitional areas such as interchanges, tunnels, and toll zones. For L4 use, lane markings should be seen as a *primary* but not *sufficient* information source. The ODD must either avoid the most challenging configurations and conditions or require complementary capabilities (e.g. map-based lane models, alternative localization, and robust fall-back strategies).

For road signage, the overall conclusion is similar: the combination of perception systems and existing databases can provide a reliable basis for regulatory compliance in many situations, but not in all. Dynamic signs, temporary roadworks, and non-standard or poorly catalogued signs remain problematic, and national databases are not yet of the quality required to serve as a dependable redundant channel across the whole corridor. From an L4 perspective, this implies that:

- ODD definitions must explicitly address how the system behaves when signage is ambiguous, missing, or conflicting between sensors and databases.
- Sustainable governance models for digital traffic sign data are needed if maps are to play a safety-relevant role.

The HD map analysis shows that nearly all of the highest-priority data types identified in D4.2 are available in the HERE HD map, with most priority level 2 types also covered. Missing elements were too specialized for HD maps. Overall, this indicates strong spatial and data-type coverage along the MODI corridor. Furthermore, the HD map can help address several key physical infrastructure challenges, such as lane geometry and signage, reinforcing its role as a redundancy layer and an essential component for L4 automated driving.

The assessment of MRM feasibility based on shoulder widths revealed that overall compliance is around two-thirds, but long individual stretches remain unsuitable for MRMs. This underlines the need for further evaluation of MRM capabilities along the MODI corridor. Such evaluation should ideally take place in dialogue with road authorities, as they hold responsibility for assessing situations and responding when a stopped vehicle is detected on a motorway. This is particularly critical if the vehicle is in a driving lane, but also when it has stopped on the hard shoulder during peak traffic periods, where moving it without assistance – or before rush hour ends – could pose significant safety risks.

For charging infrastructure, the analysis indicates that the corridor already supports end-to-end operation of an individual heavy-duty battery-electric truck without extraordinary planning effort. From an L4 demonstration point of view, this is a strong precondition: range limitations do not fundamentally preclude automated electric logistics on the MODI route. However, the findings are inconclusive regarding scalability. As the number of electric trucks increases, factors that were not assessed in depth – queuing, site layout, simultaneity of demand, and local grid constraints – may become binding. Thus, while charging does not currently constitute a hard barrier to L4 pilots, it could remain a potential bottleneck for mass deployment.

Overall, the research questions can be answered in a nuanced but consistent way:

- The MODI corridor is conditionally suitable for L4 freight automation from an infrastructure perspective, provided that the ODD is defined to exclude the most challenging infrastructure and environmental configurations, or that robust fall-back strategies are in place.
- Redundancy and fusion between perception, and digital infrastructure data are not merely desirable but essential; none of these layers alone is sufficiently reliable across all segments and conditions.
- Institutional coordination – on maintenance of markings, quality and governance of digital traffic and map data, and planning of truck-capable charging – is as important as vehicle technology for achieving corridor-wide L4 readiness.

In summary, the empirical evidence does not justify a blanket claim of “L4 readiness” for the MODI corridor from the infrastructure perspective. A realistic L4 scenario requires infrastructure improvements, digital harmonization, and precise ODD scoping. Incorporating temporal and seasonal limitations upfront will reduce reliance on real-time assessments and prevent unnecessary MRMs, supported by proactive engagement with road and emergency services.

3.2 Connectivity and Positioning

This section presents the evaluation of digital infrastructure performance – specifically positioning and mobile connectivity – along the MODI corridor to assess readiness for SAE L4 automated driving. Reliable high-accuracy GNSS positioning and robust LTE / 5G communication are essential elements of the ODD for highly automated freight vehicles.

The section quantitatively assesses Quality of Service (QoS) for positioning services and mobile networks based on measurement campaigns by Q-Free, NMA, Einride and Volvo using instrumented vehicles. Measurements covered cellular performance (signal strength, round-trip time (RTT), packet loss) and uplink throughput for functions such as remote operation (fallback or support function that enables a human operator to monitor or give instructions to an autonomous vehicle when it encounters conditions outside its ODD). Global navigation satellite system (GNSS) tests evaluate availability and horizontal position error for correction services including Network Real Time Kinematic (NRTK), Precise Point Positioning – Real-Time Kinematic (PPP-RTK), and Galileo High Accuracy Service (HAS).

3.2.1 Relevance of the Specific Research Question

The dependable provision of high-quality positioning and robust communication links is recognized as an important prerequisite for establishing the ODD of highly automated freight vehicles conforming to SAE L4. This chapter presents an empirical assessment of the MODI corridor's readiness. The evaluation is organized around six RQs, focusing on two key aspects: Connectivity and positioning.

RQs Concerning Connectivity

1. How is the mobile data (LTE / 5G) availability distributed along the route? **and**
2. What empirically determined circumstances have a negative impact on mobile service quality?

These RQs necessitate collecting empirical data to map the geographical variability and robustness of cellular service quality across the route. This quantitative mapping should be used for defining appropriate redundancy strategies for ADS and establishing the environmental and operational limitations of the ODD, particularly since poor mobile service quality could limit the accessibility to important notifications. Furthermore, supporting critical L4 functionalities, such as remote operation, requires sufficient uplink throughput for streaming control and video data. The investigation of network performance is consequently important to evaluate the necessary bandwidth integrity for such applications.

3. How is the mobile data (LTE / 5G) availability on border crossing along the route?

The MODI corridor crosses several national borders und thus ADS must work with different network providers. This could cause problems in cross-border interoperability and challenge for automated logistics. Dedicated measurements at national borders should be used to quantify the extent of observed service degradation.

4. How is the availability of CAM / DENM (ITS-G5) along the route distributed?

The availability of Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM) is an essential component of cooperative driving functions. Assessing the distribution of ITS-G5 availability should provide the basis for evaluating the extent to which short-range communication can support safety and efficiency improvements along the MODI corridor.

RQs Positioning / GNSS

5. How is the GNSS quality distributed along the corridor?

Empirical data collection is required to determine how GNSS availability varies along the route and to characterize the spatial distribution of coverage gaps or degradations. This quantitative assessment could provide input for defining system boundaries and planning redundancy strategies for interconnected ADS.

6. What empirically determined circumstances that have a negative impact on GNSS quality?

This RQ addresses the need to identify and map specific locations where infrastructure or natural elements – such as tunnels, bridges, urban canyons, or rock cuts – cause degraded GNSS signal quality, obstruction, or complete coverage gaps. Converged GNSS solutions, which combine multiple satellite constellations (e.g., GPS, Galileo, GLONASS, BeiDou) and correction services like RTK or PPP to improve accuracy, currently offer only partial availability for many correction services. Empirical identification of these persistent gaps is therefore essential to define development and deployment requirements for robust alternative positioning techniques that can ensure continuity in challenging environments.

3.2.2 Data Collection Methodology

The data collection methodology for positioning and GNSS was conducted similar to 3.1.2, i.e. the MODI corridor was driven through by vehicles equipped with different measurement units. In the case of Volvo, the data was collected within the same drives as outlined in 3.1.2.

Q-Free and NMA Methodology

Q-Free and NMA executed two extensive campaigns along the MODI corridor to evaluate connectivity and positioning performance for SAE L4 readiness. The first campaign, conducted in March–April 2024, focused on LTE / 5G connectivity and GNSS baseline quality using consumer-grade GNSS units and smartphones. Measurements included signal strength (RSRP), round-trip time (RTT), packet loss, and throughput. These metrics are critical for assessing whether cellular networks can accommodate supporting functions for automated driving such as remote operation and cooperative awareness.

The second campaign in June 2025 concentrated on high-accuracy GNSS positioning solutions. Eleven service-receiver combinations were tested, including NRTK, PPP-RTK, Galileo HAS, and the European geostationary navigation overlay service EGNOS. Vehicles were equipped with Ublox and Sony GNSS units and smartphones, logging data at 1–2 Hz. Data processing involved geospatial filtering and buffer zones around borders [12] to capture connectivity variations. Results from the campaign were compared with a static baseline campaign conducted by NMA at Hønefoss, Norway, in April 2025. This methodology ensures that both baseline and advanced positioning capabilities are evaluated under real-world conditions.

Volvo Methodology

Volvo conducted two electric truck drives along the MODI corridor in January and May 2025, covering Hamburg–Oslo and intermediate segments. The objective was to assess perception systems, energy consumption, and GNSS positioning under diverse conditions. Data collected included GNSS coordinates, lane and road edge detection, object detection, and vehicle dynamics such as speed and acceleration. Energy consumption and charging infrastructure were also mapped to evaluate operational feasibility for battery-electric trucks (see Section 3.1).

Positioning data cleaning involved removing invalid GNSS coordinates and aggregating sparse sensor readings into 250 ms windows. This approach ensures high-quality datasets for positioning analysis.

Einride Methodology

Einride performed two drives in April 2025, focusing on connectivity and uplink performance for remote operations – the critical connectivity aspect for SAE L4 functionality in logistics applications. The setup included two Sierra XR80 4G/5G modems and a Swift Duro GNSS receiver mounted on a vehicle. A large amount of connectivity data was collected using both standard tools like iPerf but also radio metrics directly from the modem. Similarly, various GNSS data points where captured and apart from just latitude and longitude also e.g. horizontal and vertical accuracy and satellite visibility was collected to measure the GNSS quality along the route. These measurements provide insights into network robustness and feasibility of remote assistance and supervision under real-world conditions.

3.2.3 Analysis Results

The analysis of the data collection with the focus on connectivity and positioning are described in the following.

Q-Free and NMA

The analysis revealed strong LTE / 5G coverage along the MODI corridor, with signal loss occurring in less than 2% of the route, mainly near borders and tunnels. Figure 27 shows a heatmap of cellular signal strengths throughout the whole MODI corridor measured in 2024. The heatmap visualizes poor cellular signal strenghts in the range of -110 to -120 dBm. Blue areas indicate a low number of measurements with poor signal strength, while yellow to red areas indicate locations where such poor signal conditions occurred more frequently.

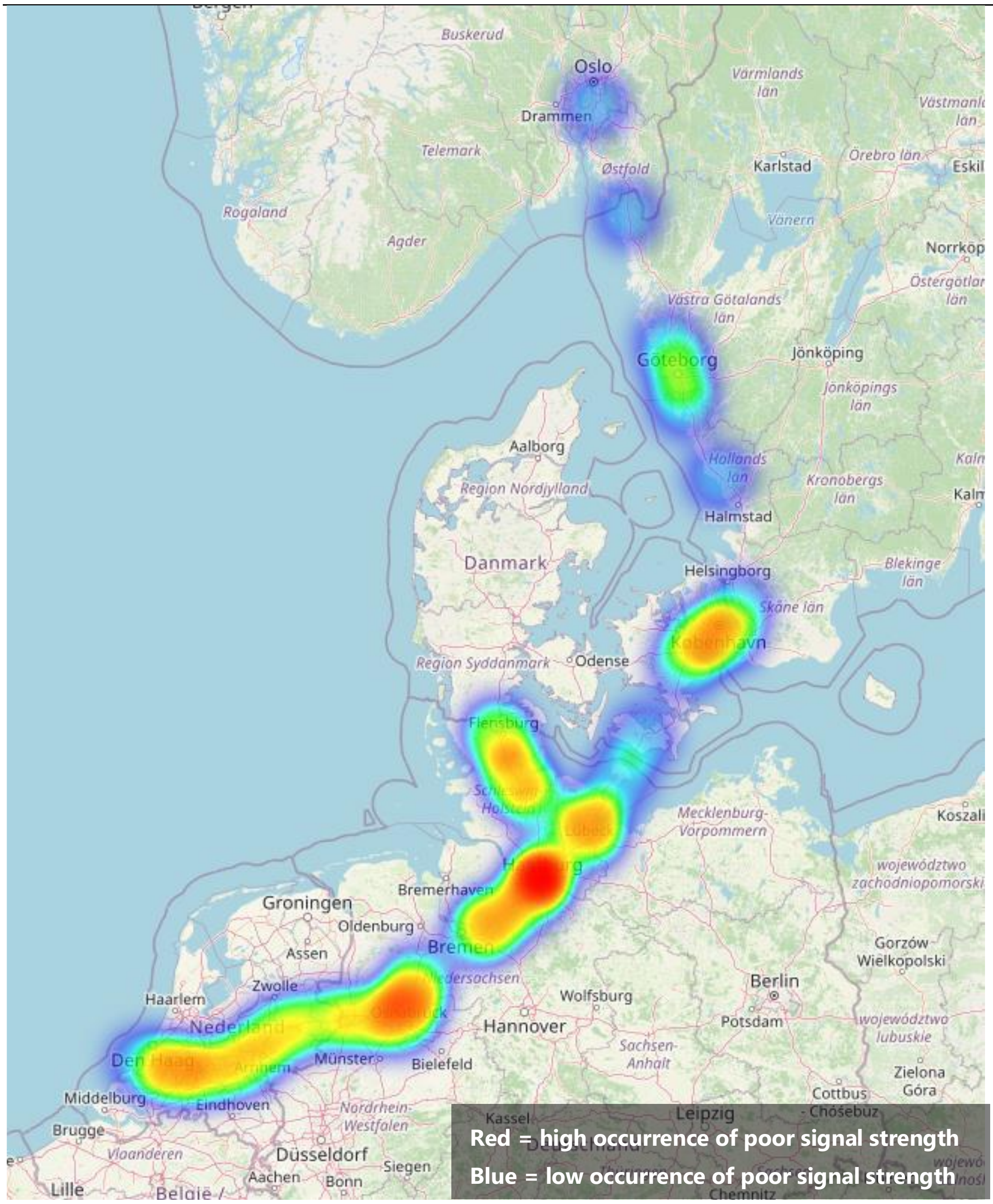


Figure 27: Heatmap of cellular signal strengths between -110 and -120 dBm

RTT improved between campaigns, and packet loss was negligible except for short spikes at border crossings. GNSS performance indicated NRTK achieved 92% availability with horizontal position errors around 4 cm, while PPP-RTK delivered slightly lower accuracy. A service loss was defined as a lack of downlink data for more than 2 seconds. Figure 28 shows the signal loss for the 2025 data collection on the map.

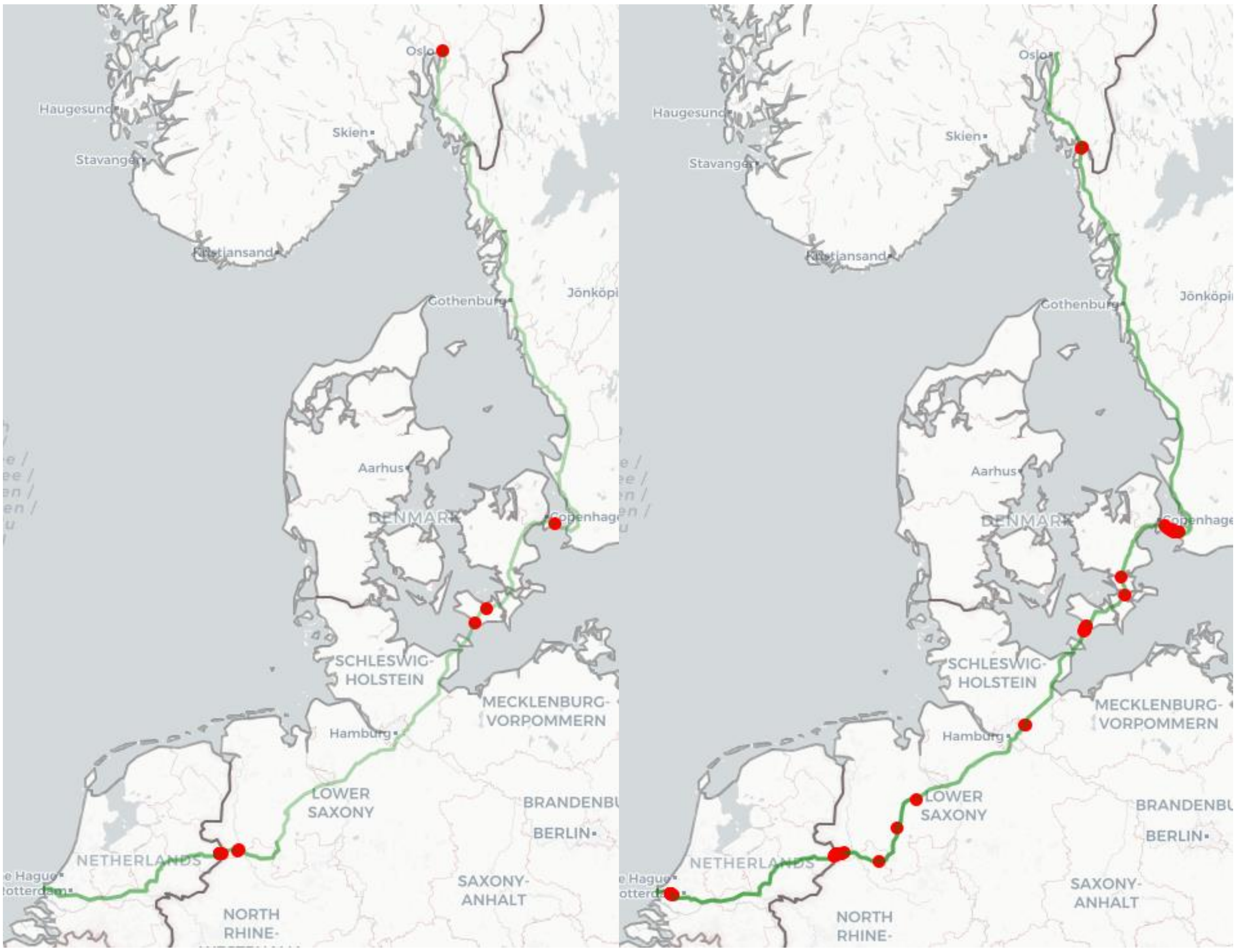


Figure 28: Sections with service loss in the southbound (left) and northbound direction (right)

The eleven different receivers with seven different correction services were tested and analysed with respect to various key performance indicators relevant for automated vehicles. For kinematic data capture on the route from Oslo to Rotterdam, the well proven NRTK services based on OSR shows availability of precise positions of 92% of the captured data, with HPE95 (the 95th percentile of ∆Horizontal,) of 4 cm. For Commercial PPP-RTK service availabilities are 91% and 57% with HPE95 of 12 cm and 10 cm. National PPP-RTK service have availability of 83% and HPE95 of 13 cm. Galileo High Accuracy Service (HAS) has varying results based on which receiver in use with availability of 2%, 76% and 12% and HPE95 of 0.7 m, 1.1 m, 3.6 m. These results are in stark contrast to results from the static campaign, where Galileo HAS performed comparably to PPP-RTK services. Thus, Galileo HAS exhibited poor kinematic performance, whereas EGNOS improved standalone accuracy to approximately 1.8 m.

Coverage gaps were primarily caused by tunnels and urban canyons, with reconvergence times typically under 10 seconds for high-accuracy services.

A detailed analysis of both data collections conducted by Q-Free and NMA is documented in [15], [16] and [17].

Volvo

Volvo's analysis indicated GNSS validity around 80%, with gaps explained in most cases by tunnels and charging stops. Signal losses during charging breaks can be attributed to vehicle cold starts, as these periods typically occur when the vehicle has just resumed driving after a break and the GNSS system has not yet fully re-initialized [18]. The dataset includes coordinates, which is either a valid coordinate pair or an invalid fixed number. Figure 29 shows that the coordinates follow the driven route. The orange parts are the spots where there are at least 20 invalid coordinates in a row. A closer look at the areas show that they can mostly be explained by tunnels or stops along the way.

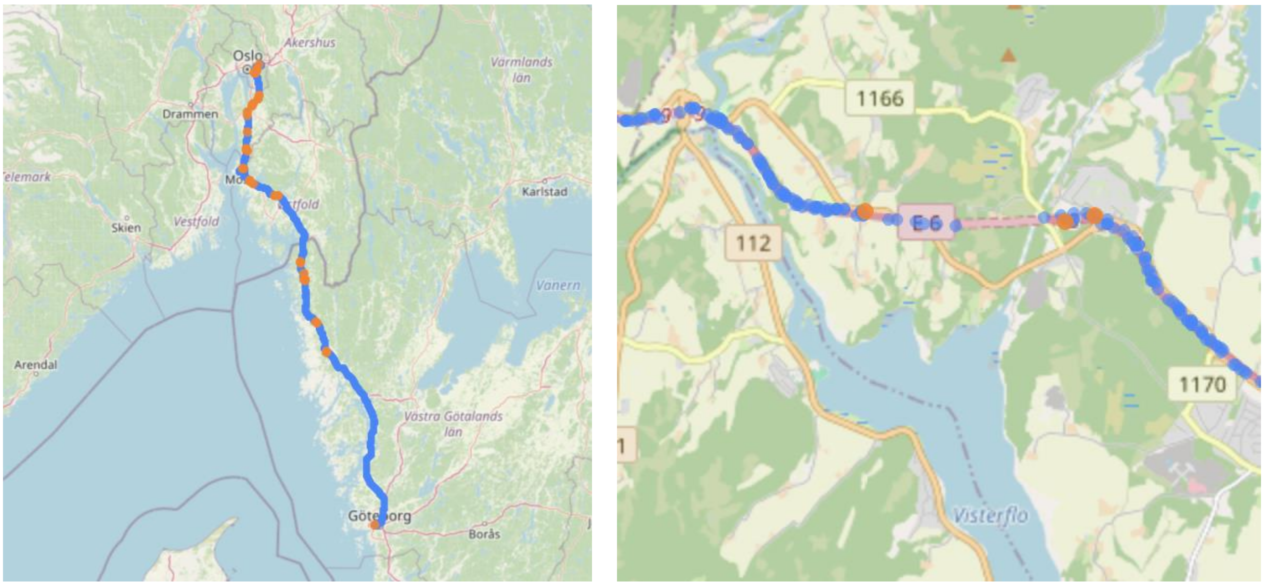


Figure 29: Overview of GNSS connectivity on the left, and detailed view on the right

While Section 3.1 assessed infrastructure aspects like lane markings and charging coverage, the focus here is on evaluating connectivity and positioning performance, which remain critical for automated operations and require further improvement in adverse conditions and areas with limited signal availability. Connectivity and positioning systems generally performed reliably under most conditions, with accurate object detection and stable lane recognition in the majority of cases. Environmental factors such as snow and confined areas, however, continue to pose challenges for perception and GNSS-based positioning.

Einride

Einride's measurements confirmed generally good signal strength, with occasional drops near border crossings. Average uplink throughput ranged between 28 and 33 Mbps, sufficient for remote operation video streaming. GNSS data showed horizontal accuracy near 0.9 m and vertical accuracy around 1.7 m, with consistent visibility of approximately 15 satellites. These results demonstrate that connectivity and positioning performance meet the requirements for remote operation, though border transitions remain critical points for improvement.

The underlying report about the Einride data collection and analysis is written in a separate document [19].

Figure 30 shows three different measures for the quality of the cellular signal. Since RSRP, RSRQ and SNR values can be recorded even when no GNSS fix is available, these measurements are also included in the statistical plots.

Reference Signal Received Power (RSRP): Measures the average power received from a single Reference Signal (RS) resource element in dBm (decibel-milliwatts).

Reference Signal Received Quality (RSRQ): Measures signal quality in dB (decibels) and considers both the received signal strength (RSRP) and the amount of interference and noise present.

Signal-to-Noise Ratio (SNR): Measures the ratio of the desired signal power to the combined power of noise and interference in dB (decibels).

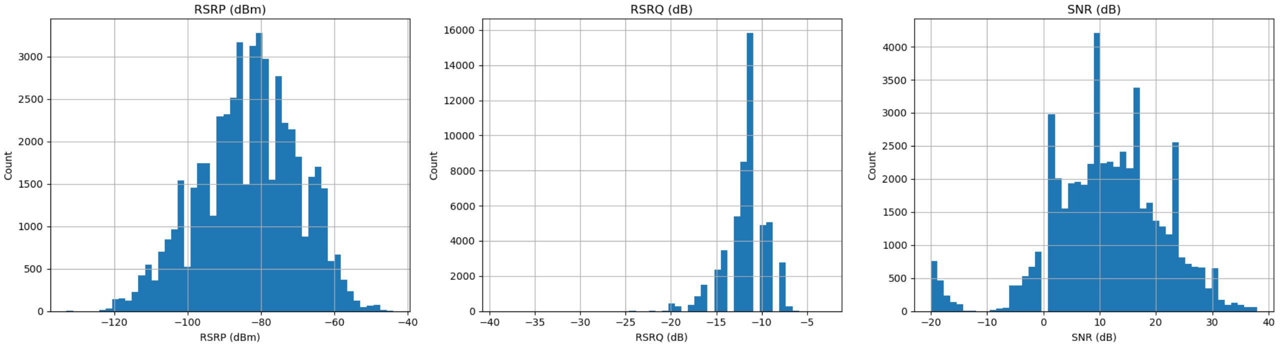


Figure 30: RSRP, RSRQ and SRP measures for cellular quality

The graphs show good to strong signal strength (RSRP) for most measurements, excellent signal quality (RSRQ), and variable, but often good to excellent SNR, implying that while many areas have very high-quality connections, there are also areas with more challenging signal environments.

3.2.4 Conclusions

High-accuracy GNSS, often augmented by correction services, is a key enabler for automated driving but remains vulnerable to obstructions and environmental conditions. Analysis of realistic data shows that service availability – the share of epochs with a converged, accurate solution – typically reaches 80–90%, leaving notable gaps. Service interruptions frequently stem from tunnels, bridges, and gas stations. When errors occur, most position-error anomalies last five seconds or less, though longer events do happen. Error estimates provided by receivers have potential for quality monitoring, but their usefulness is limited by heavy-tailed error distributions and inconsistent implementations across devices. After GNSS disruption, reconvergence times for both NRTK and PPP-RTK are generally short, with median values around 10 seconds, much faster than full initial convergence. Among correction methods, NRTK (OSR-based) services are the most accurate, outperforming PPP-RTK (SSR-based) solutions. However, cross-border operation is complicated by differences in national ETRS89 realizations, highlighting the need for better standardization of geodetic reference frames and EPSG codes. Tests using Galileo OSNMA with authenticated-only satellites yielded ~88% availability.

The combined results from Q-Free and NMA, Volvo, and Einride indicate that the corridor provides a promising baseline for SAE L4 trials, provided that ODDs are scoped and operational constraints (e.g., cross-border continuity, tunnels, and fallback procedures) are addressed. D5.5 includes positive findings, one of the many aspects in bringing CCAM vehicles on the road. LTE / 5G connectivity is generally available, though tunnels and border crossings require redundancy strategies. The capacity is mostly sufficient for downlink traffic, but insufficient over 15% of the time in the uplink direction. Perception systems perform reliably under normal conditions, and charging infrastructure suffices for single-vehicle use, with scalability still to be assessed. Overall, stable, accurate GNSS positioning is achievable but not yet fully dependable across long, cross-border routes. Complementary positioning methods and harmonized standards are essential for robust CCAM operations and effective ODD definition.

3.3 Traffic Events

Automated vehicles are operating in a dynamic environment with interaction with other traffic participants. This could cause situations that might be difficult to handle for L4 vehicles, e.g. due to unexpected behaviour of human drivers, rare events such as traffic accidents or unprecedented situations.

3.3.1 Relevance of the Specific Research Question

In total three RQs are formulated with regards to traffic events.

1. What kind of unplanned events occur during driving the route?

This question is intended to catalogue a set of real-world anomalies an ADS must be prepared to handle safely and effectively. The relevance extends beyond common, predictable scenarios to encompass the identification of rare but critical "edge cases" that could challenge the ADS system's resilience.

2. What is the occurrence frequency of unplanned events?

Risk is often defined as the product of impact and likelihood. While the impact of an unplanned event can be categorized by answering the first question, this question targets the estimation of the likelihood, and therefore the frequency, of unplanned events that can occur along a lengthy tour such as driving through the MODI corridor.

3. How do other traffic participants behave around an (automated) ego vehicle?

This question aims to identify situations in which other traffic participants behave around the ego vehicle in unexpected ways, for example, by not complying with the speed limit or by performing dangerous manoeuvres such as short-distance cut-ins.

3.3.2 Data Collection Methodology

The data collection methodology for traffic events was, in general, conducted by driving parts of or MODI corridor by vehicles equipped with different measurement units. In the case of Volvo, the data was collected in Norway, Sweden, Denmark, and Germany with the truck described in Section 3.1.2. BASt drove the German part of the corridor with a passenger car, behaving similar to standard truck.

Volvo Methodology

With the goal to analyse sudden speed change events, eight data recordings were consolidated into two datasets representing specific routes and dates: Sweden to Norway (January 12, 2025), Norway to Sweden (January 15, 2025), Germany to Denmark (May 22, 2025), and Denmark to Sweden (May 22, 2025).

To ensure relevance for speed change analysis, all non-essential columns were removed, retaining only position, navigation, and pedal-related variables: Time, Longitude, Latitude, Velocity, Bearing, AccPedalPos, and BrakePedalPos. Rows lacking values in any of these columns, except for Time, were excluded to maintain data integrity.

Sensor readings were aggregated to GNSS fixes using a 250 ms time window, resulting in each row representing a single GNSS fix accompanied by all sensor values recorded within 250 ms after that fix. Subsequently, speed differences between consecutive observations were computed, and an acceleration metric was derived based on changes in speed and time. To reduce noise and improve reliability, acceleration values were smoothed using a rolling median with a window size of three.

BASt Methodology

The data collection activity was designed to investigate how surrounding traffic participants move in relation to an automated ego vehicle. This research question is of particular importance within the MODI project, as it directly supports the identification of challenging behaviours of other road users as well as the detection of latent traffic aspects such as flow characteristics and speeding patterns. To address this question, the activity followed a structured four-step approach: sensor instrumentation of the ego vehicle, systematic data collection along the German section of the MODI corridor, processing of the recorded signals into a trajectory dataset, and preparation of the data for subsequent analysis.

In the first step, the ego vehicle was instrumented with a heterogeneous sensor setup to capture both, its own motion, and the behaviour of surrounding participants. The configuration comprised a Velodyne HDL-32E LiDAR sensor providing 3D point clouds, a Continental ARS 408-21 radar delivering object lists, and a Genesys ADMA-G DGPS-IMU system supplying accurate ego-vehicle position and dynamic properties. Additionally, a front-facing GoPro Hero 8 camera recorded video data to provide visual context of the driving environment. This multimodal setup ensured complementary perspectives on the observed traffic scenarios. The vehicle and the setup are depicted in Figure 31.

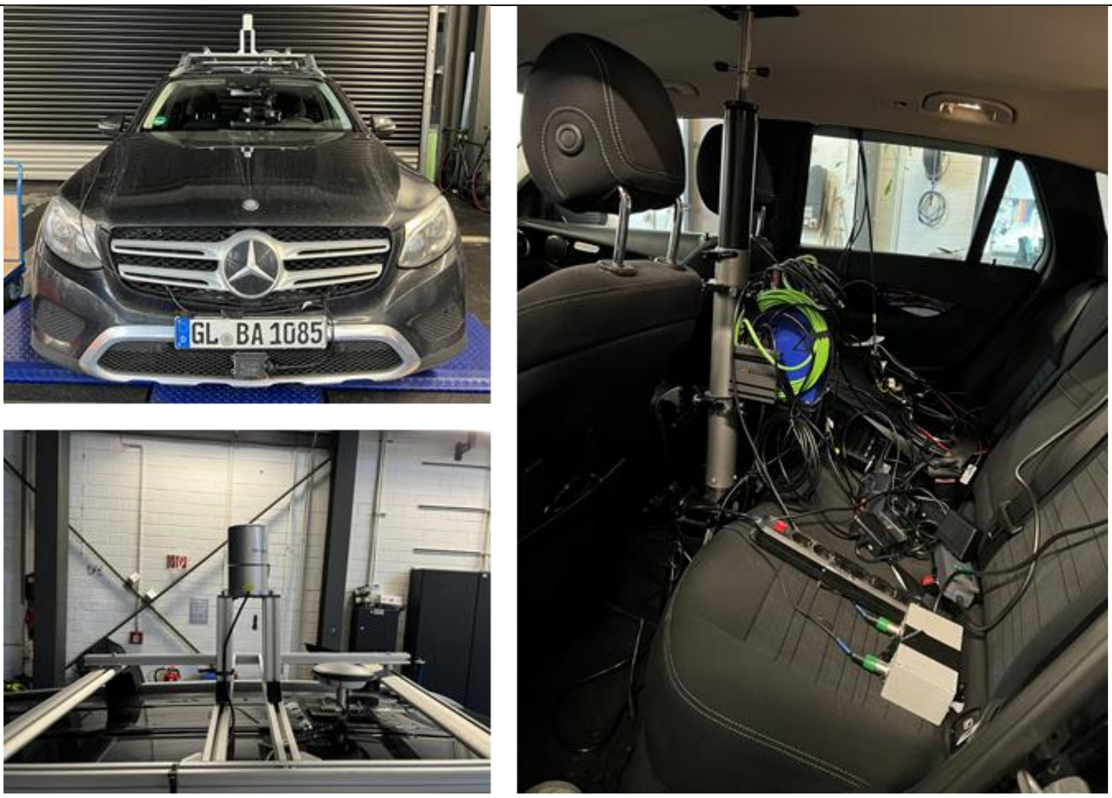


Figure 31: BASt passenger car equipped with LiDAR, Radar, IMU and dash cam

The recorded raw data underwent a structured processing pipeline to produce a usable trajectory dataset. LiDAR point clouds were processed using a PV-RCNN architecture [20] implemented with the OpenPCDet framework [21], yielding 3D bounding boxes of detected vehicles and motorcycles, while trucks could not be consistently identified with the chosen configuration. Detected objects were subsequently tracked using an UKF-IMM-JPDA tracker [22], with a similar approach applied to radar detections, resulting in continuous trajectories stored within a dedicated database. To ensure data protection compliance, recorded video material was anonymised through the automated blurring of faces and license plates. Post-processing was performed to increase consistency and improve the overall quality of the trajectory dataset.

The data collection campaign was conducted from 19 to 21 March 2024 along the German part of the MODI corridor as depictured in Figure 32. The route extended from the Netherlands–Germany border crossing near De Lutte/Bad Bentheim via motorway A30 and A1 to the Fehmarn–Puttgarden ferry terminal, continuing along the E47, with additional segments driven between the border and Osnabrück. Multiple traversals were performed to achieve a dataset with more variations. During these drives, the ego vehicle was operated in a manner resembling heavy truck traffic, maintaining comparable speeds wherever feasible to elicit realistic interactions with other participants. This led to an average driving speed (considering the times when the vehicle was actually moving (speed > 1 km/h)) of 79 km/h, as displayed in Table 15.

Table 15: Aggregated driving statistics

Day	Distance Driven [km]	Average Driving Speed [km/h]
2024/03/19	235	83
2024/03/20	460	77
2024/03/21	459	78
Total	**1154**	**79**

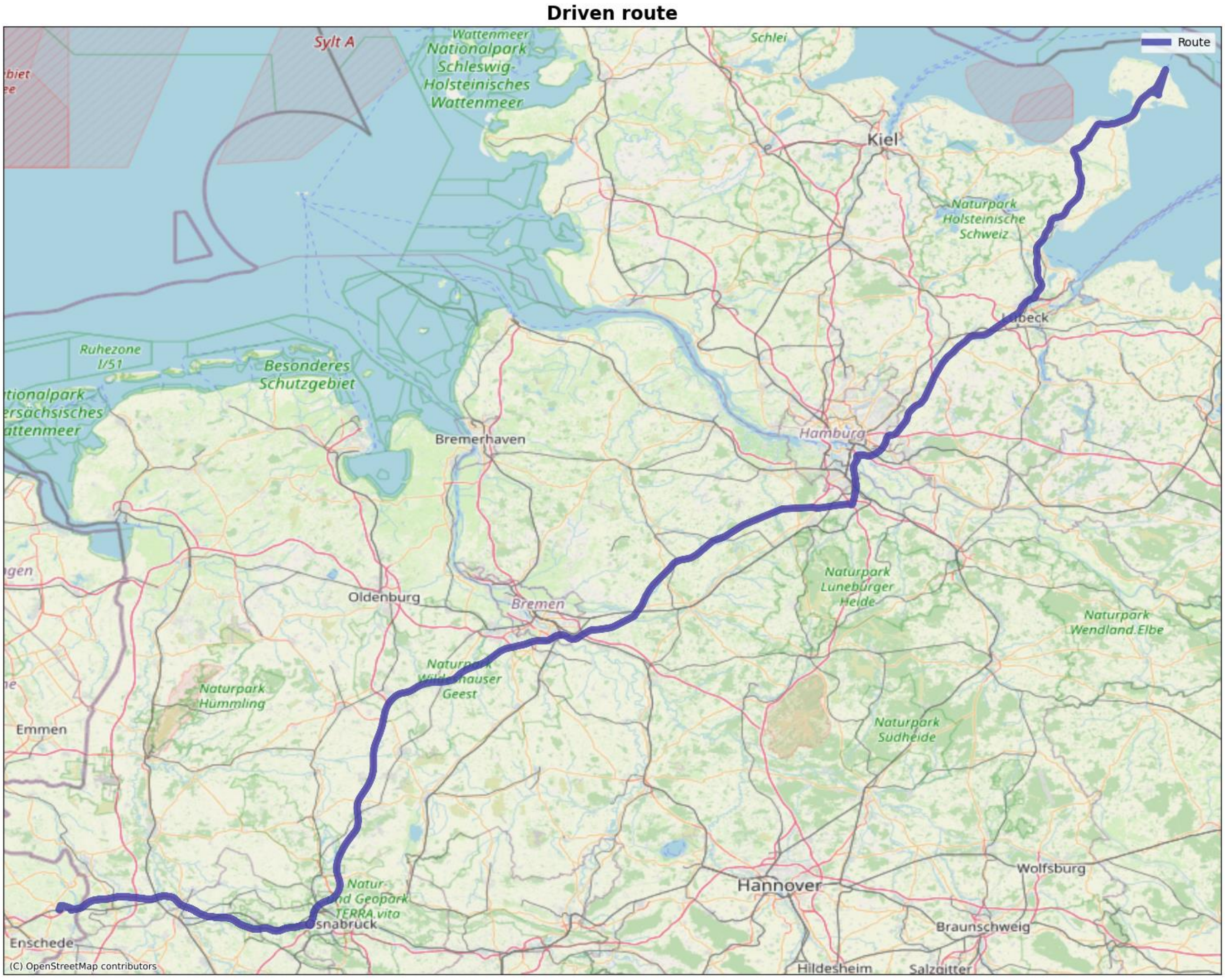

Driven route

Figure 32: Driven route for the data collection related to traffic events

3.3.3 Analysis Results

This section presents the results both from the Volvo data collection about sudden speed changes and the analyses by BASt regarding surrounding traffic participants.

Sudden Speed Change Events

For this evaluation, a sudden speed change event is defined as any time interval during which the acceleration exceeds ±3.0 m/s². Events occurring within 2 seconds of each other (±1.0 s window) are grouped together as a single event.

During the trips between Norway and Sweden, no such events were recorded. On the return trip from Sweden to Norway, one event was detected; however, due to missing video footage from this trip, further investigation was not possible. Figure 33 illustrates the event, showing speed in the top row, acceleration in the second row, pedal position in the third row, and altitude difference in the last row.

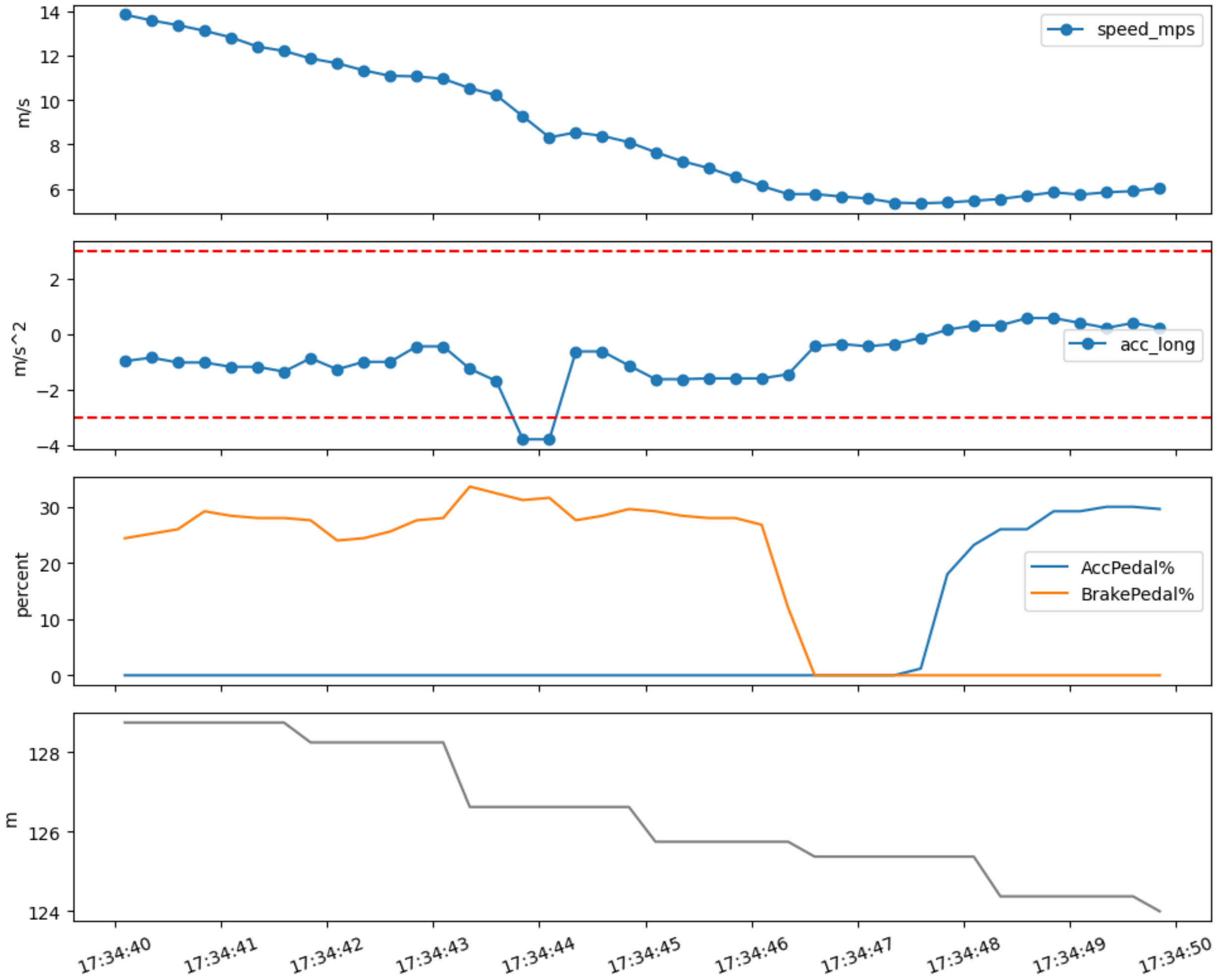


Figure 33: Sudden speed change event

On the trip from Germany to Denmark, one instance of rapid deceleration was also observed. This abrupt braking was caused by a traffic light that was partially obscured by a tree and switched to red immediately after other trucks had passed. Figure 34 shows the hidden traffic light.

Figure 34: Traffic light hidden by branch

Movement of surrounding traffic

Unless otherwise stated, the speed limit for heavy trucks on German motorways is 80 km/h. During the data collection campaign, it was observed that this limit (according to the speedometer) was exceeded quite frequently. This observation is confirmed by Figure 35, which shows the speed distributions of objects identified as trucks by the radar sensor. The distribution indicates that a significant share of the recorded truck speeds exceeds the permitted speed limit.

Although the distribution may be slightly biased toward higher speeds (since no clear distinction can be made between different classes of trucks) the figure demonstrates that human drivers did not follow the speed restriction during the data collection period. In contrast, automated vehicles are required to strictly adhere to speed limits and therefore cannot exceed a speed of 80 km/h. Consequently, the deployment of automated freight transport could lead to an increase in overtaking manoeuvres by human drivers and, as a result, to a higher potential for critical traffic situations.

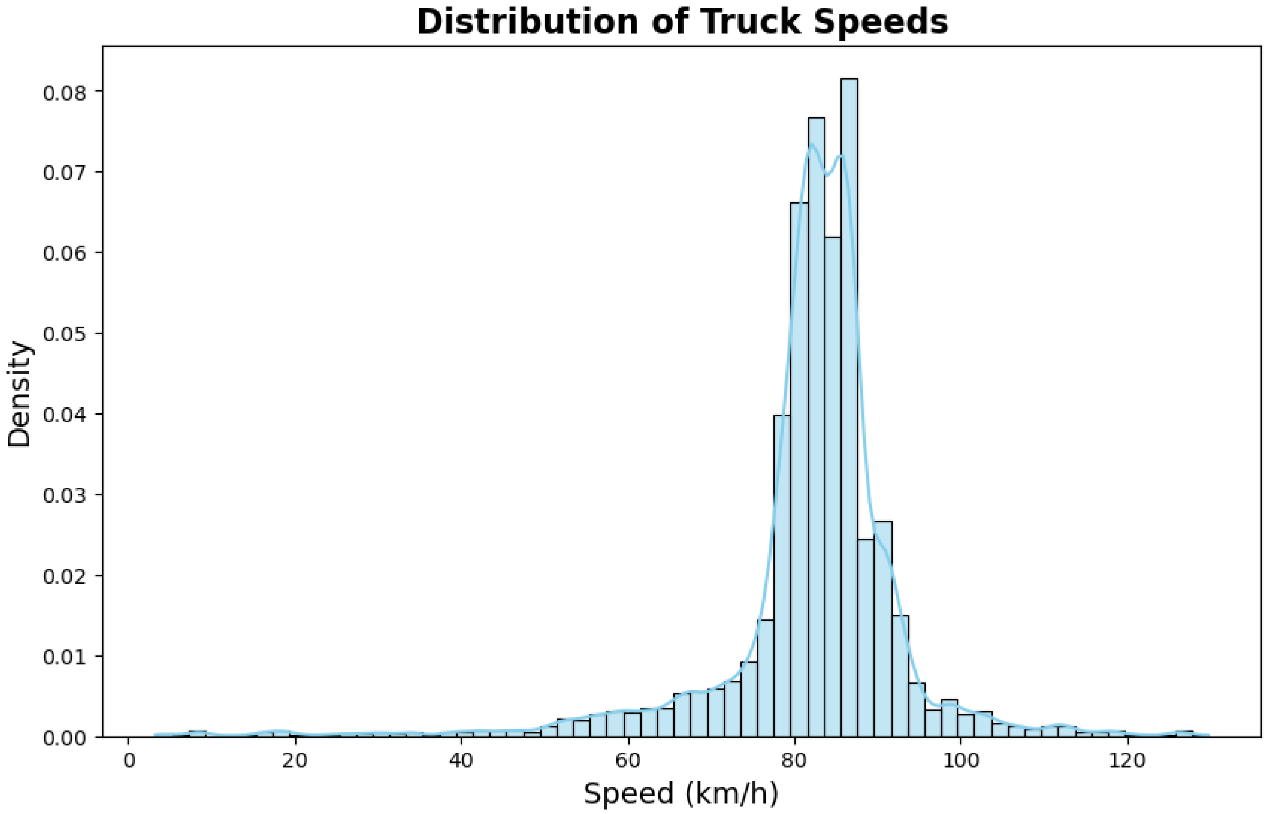


Figure 35: Speed distribution of traffic participants that have been identified as trucks

Figure 36 shows the distribution for the three surrogate safety measures (SSM) Distance Headway (DHW), Time Headway (THW), and the Time-To-Collision (TTC) (note: THW values above 5 s and TTC values above 10 s are neglected due to very low criticality).

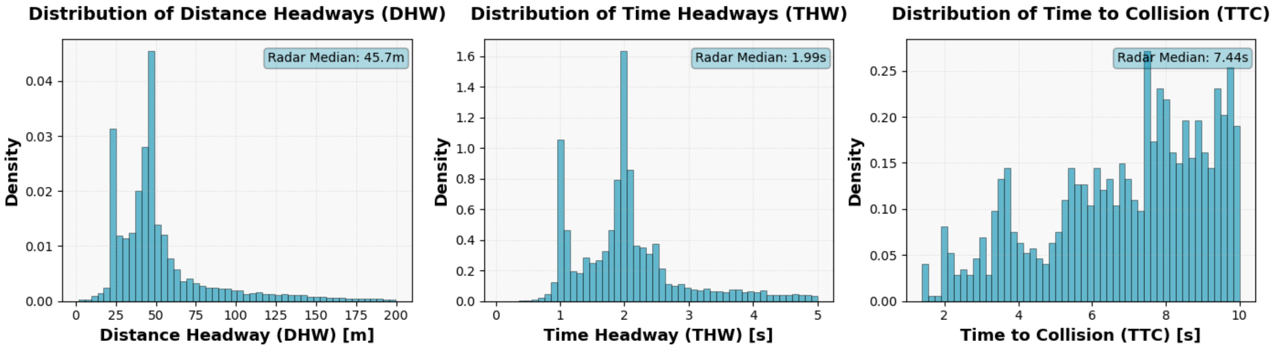


Figure 36: Distribution of different SSM from the measurement vehicle perspective

The DHW distribution exhibits a pronounced mode in the 40–50 m range (Median: 45.7 m). This correlates strongly with the German Road Traffic Regulations (StVO) requirement for trucks on highways to maintain a minimum distance of 50 m [23]. The Time Headway (THW) median of almost 2 s aligns coherently with the DHW median of 45.7 m and the median driven speed of 83 km/h. While the dominant THW mode centres on the 2-second mark, the distribution shows a left-skew with a secondary cluster of data points around the 1-second mark. These instances quantify the "perturbation phase" that could be caused by cut-in manoeuvres, where another traffic participant temporarily violates the ego-vehicle's safety gap before the controller can restore the target distance. This behaviour can be seen in Figure 37, which shows the distributions of the SSMs for the situations where another vehicle cuts-in in front of the measurement vehicle. Here, the dominant DHW mode is around 25 m while also the THW centres closer to the 1-second mark.

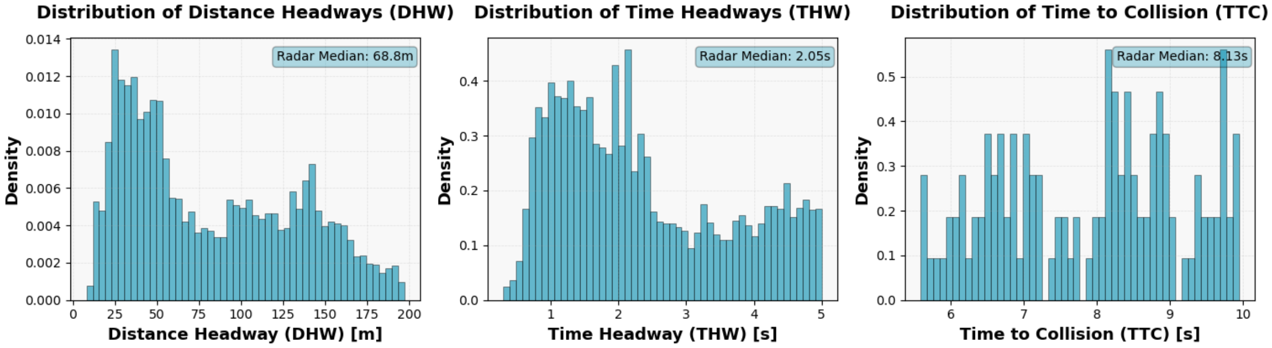


Figure 37: Distribution of SSMs during cut-In events in front of the ego vehicle

The TTC distribution in Figure 36 is heavily skewed towards the uncritical range, with only a marginal fraction of events falling below the critical 3.0 s threshold. This indicates that during the data collection only a few events with a higher criticality have occurred.

However, this lack of criticality must be interpreted with caution. It is likely attributable to the specific boundary conditions of the data acquisition, which consisted of a single traversal of the test corridor. Consequently, the dataset represents a snapshot of 'nominal' traffic conditions. The probability of encountering rare, stochastic 'long-tail' events, such as aggressive cut-ins with hard braking or emergency manoeuvres, is statistically minimised in such a limited observation window.

3.3.4 Conclusion

Although sudden speed change occurrences are rare, safety-critical situations like obscured traffic lights can lead to sudden and severe decelerations, posing significant risks to both drivers and surrounding traffic. These scenarios highlight the importance of implementing geofenced pre-warning systems that alert drivers before entering high-risk areas. In addition, robust detection algorithms are essential to identify potential hazards in real time, even under challenging visibility conditions. Finally, well-defined degraded operational modes must be in place to ensure the vehicle can respond safely when full functionality is compromised.

With regards to the RQs, the following can be concluded:

RQ1 (Type of Unplanned Events) and RQ2 (Frequency of Unplanned Events): Due to the limited sample size of the single corridor traversal, these questions cannot be conclusively answered at this stage. The quantitative analysis of safety metrics (TTC, THW) did not identify any critical anomalies or severe "edge cases" during this specific run. However, the absence of recorded incidents does not imply the absence of risk. Unplanned events and critical scenarios are, by definition, stochastic, and often rare ("long-tail events"). Consequently, a single pass represents a "nominal" traffic snapshot that is statistically insufficient to extrapolate the true frequency or variety of potential hazards along the route. To robustly catalogue these anomalies and estimate their likelihood, significantly longer-term data collection would be required.

RQ3 (Behaviour of Other Traffic Participants): In contrast to the first two questions, the data allows for more concrete derivations regarding the behaviour of surrounding traffic. A key observation was that other heavy goods vehicles frequently exceeded the posted speed limits. This behaviour highlights a critical integration challenge for ADS deployment: A strict adherence to speed limits by the automated ego-vehicle could create a persistent speed differential relative to the surrounding human-driven truck traffic. This discrepancy may force the ADS into the role of a "moving bottleneck," provoking frequent overtaking manoeuvres and close-range cut-ins by other vehicles.

4 Recommendations and L4 Readiness

The analyses in Chapter 3 demonstrate that L4 operation along the Rotterdam–Oslo corridor is feasible in principle when segment-level ODDs are defined, and multi-layer redundancies are implemented. No single source – vision-based perception, HD maps, digital traffic sign data, or GNSS – provides sufficient reliability across all segments and conditions. This chapter consolidates recommendations for PDI, vehicle capabilities and fall backs, and regulatory and organizational enablers, and outlines what L4 readiness entails for the corridor.

4.1 Corridor Issues Informing Recommendations

The evidence points to the following constraints that shape readiness actions:

- Dynamic signage and variable speed limits are difficult for camera systems and lack uniform digital feeds.
- Complex and temporary markings, including rush-hour lanes and roadworks, frequently trigger perception unavailability and conflicts.
- GNSS suffers predictable outages in tunnels and urban canyons and exhibits reconvergence delays.
- National databases are heterogeneous and miss important attributes such as marking quality and temporary traffic management.
- Digital traffic sign governance is immature, with gaps and inconsistencies across countries, and border crossings introduce short cellular service losses and geodetic reference differences.
- Night, wet roads, snow and wind degrade perception and increase operational risk.
- Corridor-level ODDs must be refined to section-level and condition-based definitions.
- Charging coverage is adequate for single vehicles but scalability is unquantified.
- Rare, safety-critical events – such as traffic lights near tunnel entrances or barriers on construction sites – necessitate detection and fall-back strategies.

4.2 Technical Recommendations

PDI: Standardized marking layouts across countries and assurance of suffient visibility, would facilitate deployment of autonomous driving at L4. Lane changes and complex geometries near interchanges, tunnels, tolling and ferry terminals should include clear lane guidance and predictable lane-change corridors. The assessment of MRM feasibility based on shoulder widths showed that long stretches remain unsuitable, highlighting the need for further evaluation along the MODI corridor.

Based on the results of the analysis and the subsequent learnings, a set of recommendations regarding road sign- and lane marking infrastructure are presented in Table 16.

Table 16: Recommendations on road sign- and lane marking infrastructure.

Infrastructure	Topic	Comment
Road sign	Redundancy	Since many of the deviations between actual signage state and detected signage state are not due to issues with physical infrastructure, redundancy through digital infrastructure should always be in place.
Road sign	Standardization	Road sign detection will benefit from standardized signage across countries.
Road sign	Machine-readable	Road signs should belong to a predefined list of symbols that can be detected and should require as little interpretation as possible.
Road sign	Unambiguous	Ideally, each sign should be as focused as possible and only give one piece of information each.
Road sign	Placement	When multiple lanes are present and traffic signs apply only to specific lanes, instead of relying on a map or graphic to show which rule applies where, L4 driving would benefit from placing signs directly above the relevant lane.
Lane marking	Redundancy	As most of the reasons for lane detection failure have nothing to do with physical infrastructure, digital infrastructure will be pivotal to create redundancy here as well.
Lane marking	Maintenance	To facilitate L4 deployment, attention is needed to maintain markings according to the agreed standard.
Lane marking	Standardization	Standardized lane marking across countries would limit the amount of marking patterns the detection software will have to be trained on and thus make detection less complicated.

Digital infrastructure and data governance:

- Establish real-time APIs for variable message signs and digital traffic signs using harmonized data models based on METR standards (identifiers, geometry, time validity, lane applicability, etc.) and implement quality assurance.
- Standardize HD map schemas and include marking type and quality, dynamic signage references, and geometry polygons for tunnels and bridges.
- Harmonize cross-border geodetic realizations and EPSG codes for GNSS correction services and define handover profiles for border areas.
- Expand C-ITS coverage at problem locations (roadworks, tunnels, borders) using suitable communication technologies (ITS-G5, IP-based) and define a broker layer to fuse cooperative messages with VMS feeds.

Vehicle capabilities and fall-back:

- Make sensor-map fusion the default, combining lane detection with HD map lane models and resilient localization
    - GNSS with NRTK / PPP-RTK
    - Inertial Navigation Systems (INS)
    - Lane-edge from camera / LiDAR / RADAR
- Define degraded ODD modes with restricted speeds and manoeuvres when perception confidence drops and enable remote intervention only where uplink throughput and latency meet policy thresholds.
- Reliable lane perception for robust distinction of temporary and fixed markings.
- Implement geofenced pre-warning logic for hidden signals and dynamic signage and formalize handover strategies and reconvergence bounds for border crossings and tunnels.

4.3 Regulatory and Organizational Enablers

Treat digital traffic signs and VMS data as regulated infrastructure components with service-level agreements for accuracy and availability, standardized machine-readable formats (METR, DATEX II), and clear responsibilities among road operators and tunnel/bridge entities. Require digital publication of temporary traffic management – such as road works or lane closures – as covered in the Commission Delegated Regulation (EU) 2022/670. Harmonize cross-border rules for GNSS reference frames, roaming and use of CCAM-critical data feeds, and define policies for remote operation (uplink requirements, privacy, and data security). Establish co-investment models among OEMs, road operators, and technology providers, supported by standard cost–benefit assessment templates balancing vehicle and infrastructure measures.

4.4 ODD Definition and Operational Strategies

To ensure safe and predictable automated freight operations, ODDs should be defined with clear constraints and fallback strategies. They must remain flexible enough to handle real-world variability and operational gaps. The following considerations are recommended:

- Close cooperation between road authorities and vehicle manufacturers is essential, as manufacturers define the vehicles' ODD while authorities determine where and under which conditions automated driving is permitted; optimal solutions require joint planning and alignment.
- Define ODDs only for validated route sections where physical and digital infrastructure meet agreed thresholds. These segments should be regularly assessed to maintain compliance.
- Apply condition-based constraints for night, wet, and winter operation unless robust degraded-mode strategies are active. Clear criteria for activating and lifting these restrictions are essential.
- At complex nodes such as interchanges, tunnels, tolling points, and terminals, either close the ODD or reduce functionality with explicit fallback processes. These processes should be documented and tested.
- Continuously monitor live quality indicators, including GNSS availability and uncertainty, VMS feed status, and cellular signal strength. ODD activation and deactivation should be tied to these metrics to avoid unsafe conditions.
- Specify where ODD transitions between automated and manual operation are expected and define how they are managed to ensure continuity of service.

- Outline procedures for cross-border handover, emphasizing the human driver's role in maintaining safety and compliance during these transitions, particularly when temporary loss of GNSS and cellular signals requires the driver to safely control the vehicle until systems are fully re-initialized.
- Clarify under what conditions remote operation or supervision is permitted and define escalation protocols for triggering remote intervention.
- Establish handling strategies for exceptional scenarios such as roadworks, GNSS loss, and severe weather, including fallback modes and communication requirements.

While these measures provide a base for a structured approach, significant gaps remain in validated infrastructure coverage, degraded-mode strategies, and real-time monitoring reliability. Further development and testing are essential before assuming scalability or seamless end-to-end service.

4.5 Scaling and Business Readiness

To move from single-vehicle demonstrations toward scalable operations, several actions are required to ensure infrastructure readiness and operational efficiency:

- Near-term capability: Individual heavy-duty battery-electric trucks can already traverse substantial portions of the corridor with only modest detours for charging.
- Site audits: Assess charging locations for manoeuvring space, ingress/egress, queuing capacity, load management, and grid connection capability.
- Capacity planning: Develop corridor-level models for capacity and queuing to manage simultaneous demand effectively.
- Incentives: Promote truck-capable charging sites along TEN-T segments to support long-haul operations.
- Operational integration: Incorporate state-of-charge forecasting and real-time charging availability into planning systems to optimize routing and reduce downtime.

5 Data Collection Conclusions

This chapter synthesizes how the data collections contribute to MODI's objectives. Rather than repeating analyses, it distils the main findings, their implications for L4 readiness, and how they inform the Book of Recommendations (D1.5), Impact Assessment (D2.4) and Gap Analysis (D2.5).

5.1 Key Findings

PDI: Lane and sign perception is reliable on simple motorway segments but degrades with complex or temporary markings and dynamic signage, especially under night, wet and winter conditions. Only about two-thirds of the route provides enough shoulder width for MRMs, and long sections – especially those without a hard shoulder – remain unsuitable. This shows the need for further assessment of MRM capability along the MODI corridor in cooperation with road authorities.

Digital traffic sign databases vary in coverage and quality; temporary measures are underrepresented. Creating an HD map is feasible but depends on harmonized attributes and reliable links to dynamic content. Overall, the results highlight the critical role of HD maps in automated driving. Mapping data providers offer high-quality solutions with much of the required data already in place, a proven data pipeline for vehicle integration, and the infrastructure to support future data-sharing needs. The analysis also shows how a detailed HD map can provide valuable insights into physical infrastructure.

Connectivity and positioning: LTE / 5G connectivity along the corridor is generally strong, with short losses concentrated at borders and tunnels. High-accuracy GNSS delivers precise positioning for large parts of the route but has predictable outages and reconvergence delays; cross-border geodetic differences complicate seamless operation.

Charging: With a 10 km detour radius, the nearest truck-capable charging station is typically within a few kilometres, and the longest observed gap is below 30 km. This supports single-vehicle operation today, while scalability under higher concurrent demand remains a risk requiring further study.

Traffic events: Though rare, safety-critical events such as hidden traffic lights can induce abrupt decelerations. These require geofenced pre-warnings, robust detection strategies, and defined degraded modes. Further, the strict adherence of the ADS to speed limits could create a persistent speed differential with frequently speeding human-driven heavy goods vehicles, effectively turning the automated vehicle into a "moving bottleneck". This effect may be compounded by difficulties in performing lane changes strictly according to traffic rules in very heavy traffic or congestion. This discrepancy may provoke frequent overtaking manoeuvres and close-range cut-ins, demonstrating that regulatory compliance can paradoxically introduce "dynamic friction" and elevated interaction risks within a non-compliant human traffic flow.

5.2 Contribution to MODI Objectives

The findings concretize recommendations (D1.5) for PDI, digitalization and governance of dynamic signage and traffic sign data, GNSS harmonization and fall-backs, ODD engineering and remote intervention policies, and scalable charging infrastructure planning. They provide evidence for the Impact Assessment (D2.4) on safety and efficiency potential under constrained ODDs and identify clear gaps for the Gap Analysis (D2.5), prioritizing dynamic digital feeds, temporary marking precedence, GNSS cross-border consistency, and charging scalability.

5.3 Lessons Learned and Best Practices

Data fusion outperforms single-source reliance; robust L4 operation depends on combining perception, maps, digital feeds, and positioning with explicit conflict resolution. ArcGIS-supported preselection of segments coupling databases with visual inspection is effective. Operations must be conditioned for night, wet and winter variability, with enable / disable logic tied to live quality indicators.

5.4 Roadmap for Further Work

To enable safe and efficient automated driving along the corridor, the following technical priorities are essential. It is important to note that lane marking upgrades, sensor development for detecting these markings, and HD map evolution are closely interconnected.

- Corridor-wide real-time VMS and digital traffic sign APIs with Service Level Agreements (SLAs).
- PDI standardization (e.g., signage, localization) demands intensified collaboration among all stakeholders.
- GNSS cross-border harmonization and INS/lane-edge fallbacks with defined reconvergence metrics.
- ODD engineering for section- and condition-based profiles and degraded modes.
- Charging scalability studies and site audits.
- Scenario libraries and simulations for safety-critical edge cases with field validation.

5.5 Conclusion

A blanket L4 claim for the entire corridor is not supported by the evidence, yet a pathway is emerging, provided that the remaining infrastructure, digital service continuity, and operational governance gaps are addressed. Targeted PDI improvements, harmonized digital data and APIs, resilient vehicle fall-backs, and carefully scoped ODDs can together transform the corridor into a realistic and scalable environment for L4 automated freight transport. Given budget constraints, it would be helpful to have a prioritized list of no-regret measures for PDI – starting with those offering high impact and low investment risk. An estimate of short-, medium-, and long-term costs would be valuable.

The integration of L4 automation along the Rotterdam–Oslo corridor could potentially offer operational and strategic benefits for logistics stakeholders. In addition to possibly reducing driver dependency – which might help address the chronic driver shortage – automation could enable more predictable transit times and reduce variability caused by human factors. This predictability might support advanced fleet planning and dynamic scheduling, aligning with MODI's objectives for efficiency and reliability. Real-time data exchange between vehicles and infrastructure, combined with harmonized APIs for digital traffic signs and VMS, could pave the way for logistics operators to optimize routing and reduce idle times. Sensor–map fusion and degraded ODD modes might help maintain continuity under adverse conditions, thereby reducing disruption risks. Furthermore, scalable charging infrastructure and corridor-level capacity planning could contribute to decarbonization goals, supporting ESG commitments and compliance with EU Green Deal targets. Taken together, these measures might enhance asset utilization, lower operational costs, and create a competitive advantage for early adopters of automated freight transport.

Deployment of L4 automated freight transport must be synchronized with European and national regulatory frameworks to ensure interoperability and legal certainty. MODI's findings underscore the need for harmonized governance of digital traffic signs, GNSS reference frames, and cross-border data exchange. EU directives on ITS [25] and TEN-T [26] infrastructure as well as the strategy on CCAM [27] provide the legislative backbone and strategy for corridor-level investments, while national laws must address liability allocation, remote operation policies, and cybersecurity. Service-level agreements for digital infrastructure, standardized machine-readable formats, and regulated publication of temporary traffic management data are essential to guarantee reliability and safety. Additionally, cross-border harmonization of geodetic reference frames and roaming policies for CCAM-critical data feeds will prevent operational discontinuities. These actions directly support MODI's objectives for safe, scalable, and interoperable L4 operations across member states.

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Annex I: Challenges and Pain Points

Table 17: Complete list of assumed pain points

Pain points – road elements – What is difficult?	Why is it difficult?	Suggestions for how to fix what is difficult - optional	Pain level – light, medium, hard
Tunnels/overhangs/no clear sky view	Loss of GNSS	Augmented GNSS signals ITS-G5, sensor in vehicle for navigation (e.g. LiDAR), Ultra-wide band radio Beacons	Hard
Urban road	Mixed traffic, high density of VRUs and other traffic		Hard
Snow	Sensor covered	Sensor cleaning solution	Hard
Snow covered ground	Vehicle unable to read road markings etc.	Redundant localization	Hard
Heavy rain	Sensor covered	Add sensor cleaning solution and perception filtering	Hard
Wet ground	Mirroring effects on ground makes it hard to read road markings, false positive object detections etc.	Perception filtering and redundant localization	Hard
Emergency vehicle	identify vehicle type and understand intention	C-ITS service	Medium
Vulnerable Road Users	Irrational ways of moving/acting. Hard to predict behaviour	Object classification, movement prediction	Hard
Other, manually driven vehicles	Predict behaviour of other road users.		Medium/Hard
Merging lanes (e.g. onramp to highway) with traffic	Requires "silent" negotiation with other road users		Hard
Variable Message Signs (especially placed above road)	Requires vehicle to identify and understand messages through camera.	Information sharing in real time though.	Hard
Unplanned events (roadworks, debris, lost goods, accidents etc.)	Requires vehicle to act on changing environment that it is not programmed for or does not have trained algorithms for.	To some degree through real time updates from e.g. Here or other databases, connected TMA-vehicles.	Hard

Pain points – road elements – What is difficult?	Why is it difficult?	Suggestions for how to fix what is difficult - optional	Pain level – light, medium, hard
Police man's signals	Extremely hard to interpret e.g. hand signals	Information beforehand to the Remote Intervention Operator who could plan for action.	Hard
Complex traffic environments	Combination of complex infrastructure and other traffic can be hard for a human driver, but extremely hard for an autonomous vehicle.		Hard
Movement/path prediction	Having a vehicle understanding other road users' movement and intentions. E.g. when a person is first noticed by the autonomous vehicle, then obstructed by something, and then again appears. This is extremely hard for an autonomous vehicle to predict.		Hard
Heavy traffic / high traffic density	Risk of standstill AV blocking other traffic because of hesitation		Hard
Vague/old/unclear road markings	Vehicle unable to read road markings	Redundant localization	Hard
Railroad crossings	Risk of AV stopping on railroad		
Road without divider (such as rural road)	Higher risk of collision with oncoming vehicles, animals etc. in high speed		Hard
Country legislations in EU not harmonized	Different regulations between countries when passing borders	Harmonization within EU (Schengen)	Hard
Volvo will NOT provide L4, BUT crossing borders on a prioritized lane (for pre-declared goods) would be of great interest	Within EU easier, but also to incl. EES to make transportation in Europe smoother.	Again, Harmonization	Hard
Consideration to traffic congestion (also on TEN-T network)	Driving time cycles (4,5 hrs. *2 driver times) etc.	Better traffic- and transportation planning tools etc.	(very) Hard
Traffic situations reg. EMS2 (or longer and heavier) (FIN/SWE 34,5/25,25 m., 76/74T)	Different rules reg. no. of axles and weight and dimensions over Europe.	Again, harmonization	Hard (and time consuming)

Pain points – road elements – What is difficult?	**Why is it difficult?**	**Suggestions for how to fix what is difficult - optional**	**Pain level – light, medium, hard**
Tunnels	Sometimes narrow shoulder		
Tunnels	Accidents have a higher consequence (fire/smoke).		
Tunnels	Reduced guidance from LiDAR. If tunnel walls are smooth (concrete shells), there is few details in the HD-map.	Ultra-wide band radio Beacons	
Underpass (short tunnel)	Loss of phase lock for navigation system	INS navigation	
Roundabouts	Difficult to assess when it is the right time for the L4 vehicle to enter if the roundabout is busy.	Traffic lights	

Annex II: MODI Corridor by Country

The Netherlands

In the Netherlands, the following route was selected (red arrows in Figure 38):

Rotterdam – motorway A15 direction Nijmegen (core TEN-T and important freight route) – A50 Arnhem – Apeldoorn (comprehensive TEN-T) – A1 Enschede (core TEN-T) – border crossing.

An alternative route is (pink arrows): Rotterdam – A15-A16-A20-A12 – Utrecht – A27 – Amersfoort – A1 Enschede – border crossing.

Figure 38: MODI-route in the Netherlands

Germany

In Germany, the following route was selected (see Figure 39):

1. A1 – A30 NL-D border crossing in Enschede
2. A30 - A1 Osnabrück
3. A7 passing Hamburg through Elbe bridge
4. A1 – E47 Heiligenhafen
5. E47 to ferry terminal Fehmarn-Puttgarden

All these roads are part of the TEN-T core network.

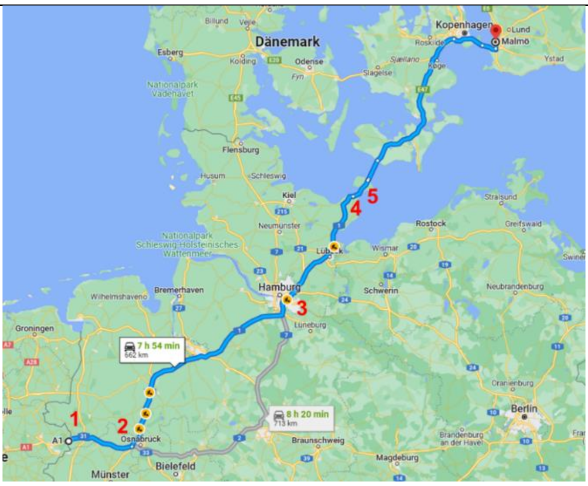

Figure 39: MODI-route in Germany

When selecting this route through Germany, also the following longer and more complex route was considered (see Figure 40):

1. A1 – A30 NL-D border crossing in Enschede
2. A30 – A2 Bad Oeynhausen
3. 3a A2 – A352 Hannover
4. 4a. A352 – A7 Mellendorf
5. 3b A2 - A7 Hannover / Langenhagen
6. A7 passing Hamburg through Elbtunnel
7. A7 – E45 D – DK border crossing in Ellund

The A30, A2 and A7 are part of the TEN-T core network, the A352 (feeder road) is not.

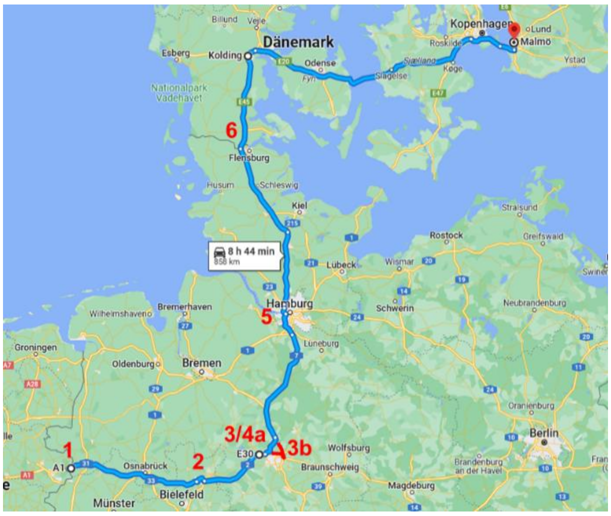

Figure 40: Alternative route in Germany

Denmark

In Denmark, the route Rødby – Øresundsbroen was selected (see Figure 41). In Denmark are several alternatives:

1. Rødby – Helsingør
2. Frøslev – Øresundsbroen
3. Frøslev – Helsingør

However, in the context of the MODI-project, the route Rødby – Øresundsbroen, with a variety of road characteristics, was considered the most interesting.

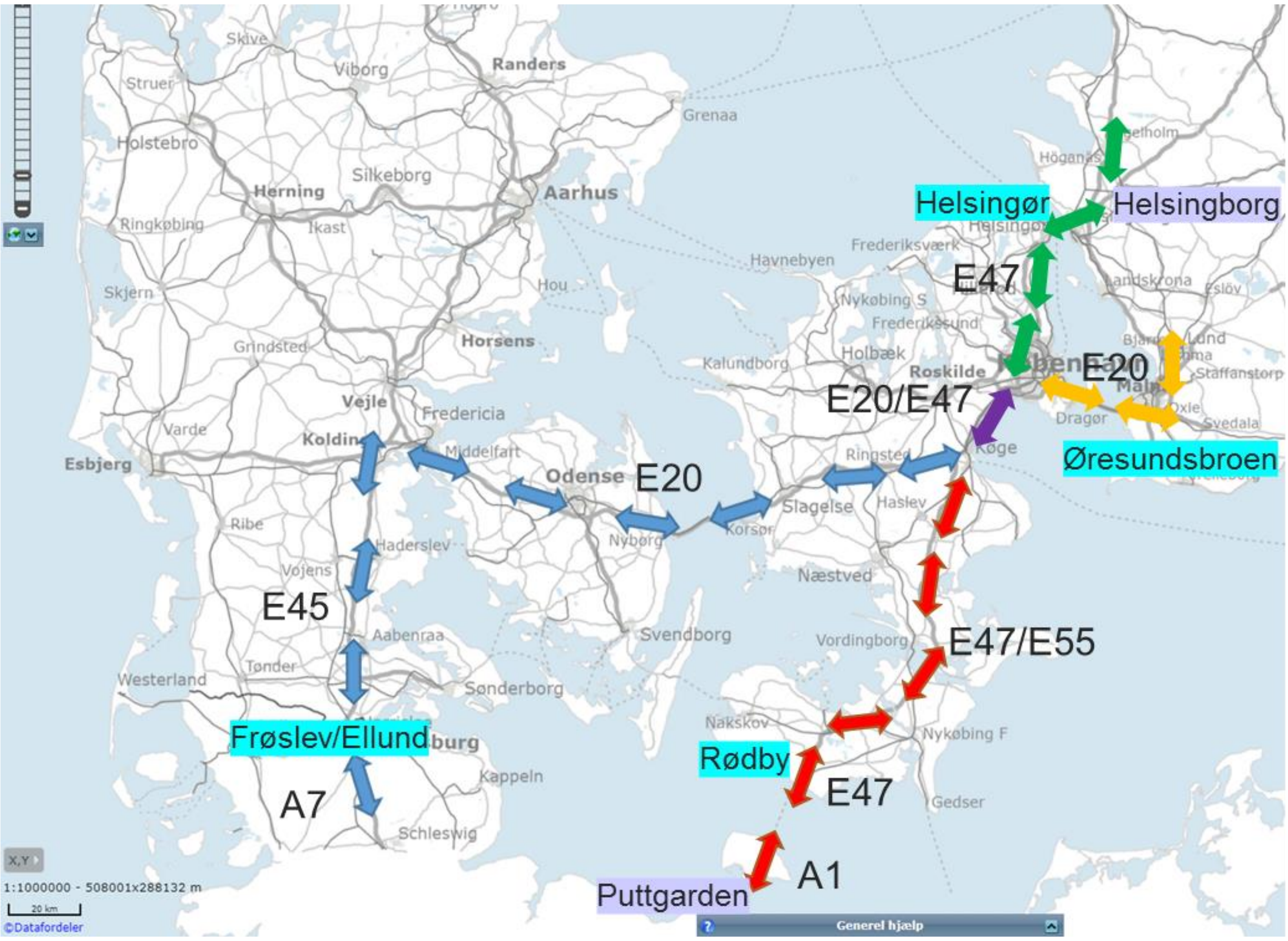

Figure 41: Routes in Denmark

Sweden and Norway

In both Sweden and Norway there is only one realistic route in this context (see Figure 42):

- Sweden: from the Øresund-bridge to the border at Svinesund (NO).
- Norway: from the border at Svinesund to Oslo.

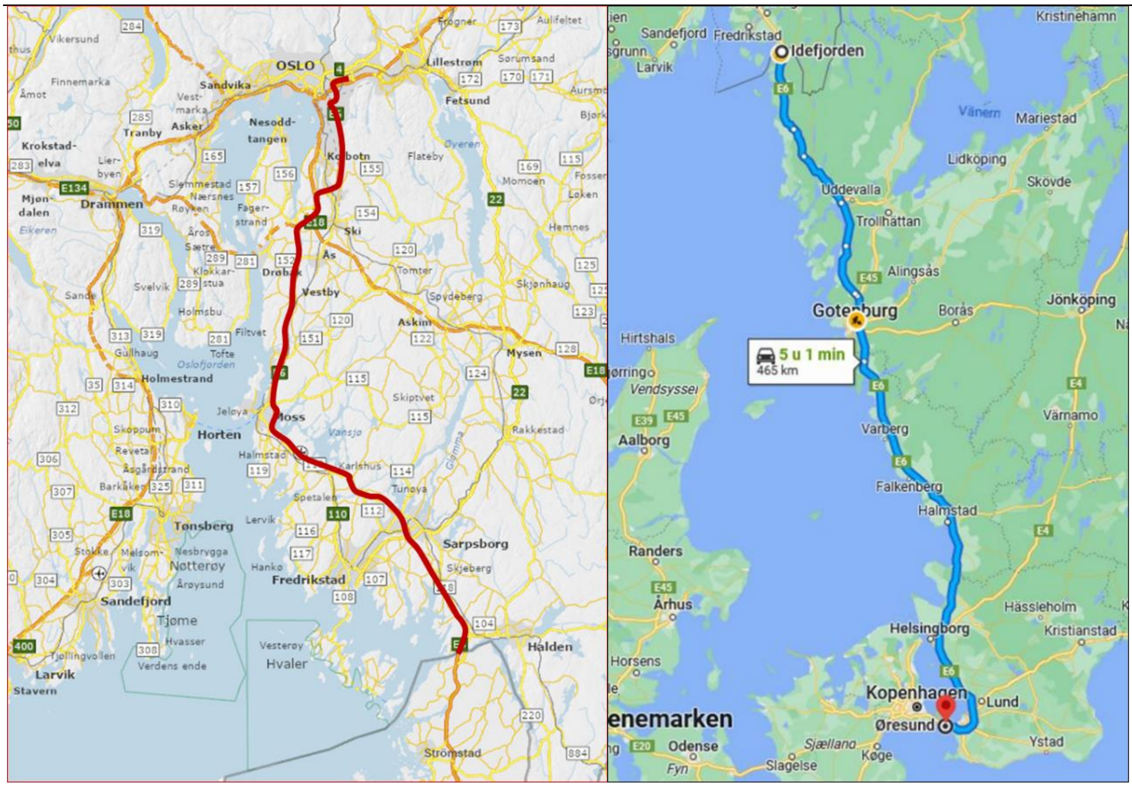

Figure 42: MODI-routes in Sweden and Norway