MAGPIE

SMART GREEN PORTS

REPORT

E-SHUNTING LOCOMOTIVE

WP6: Demo 8

Port of Rotterdam
RAIL INNOVATORS GROUP
ProRail
TNO innovation for life

Funded by the European Union

E-SHUNTING LOCOMOTIVE D6.1

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AUTHOR	Maurits van Schuylenburg (Port of Rotterdam) M.schuylenburg@portofrotterdam.com

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1. Tabel of content

Executive Summary

While the main railway lines in the Rotterdam port area are all electrified, the final stretch that rinse into the different industrial areas and terminals is not. Therefore, these last miles of railway are serviced with diesel powered shunting locomotives. There are about 40 aged diesel shunting locomotives in the port of Rotterdam, in need of replacement in the coming years. That creates an opportunity for replacing the diesel locomotives with zero emission locomotives in line with the ambition of the port of Rotterdam and EU and national legislation (Annex 1). The two recently built zero emission locomotives, ordered by the Rail Innovators Group, are now in the process of authorization for The Netherlands, Germany and Austria.

During validation and authorization testing of the locomotives some significant deficiencies were identified. It was found that the design had to be adapted in several areas. This redesign, led -however- to a major delay in the authorization of the locomotive. The expectation is that no earlier than Q4 2027 or Q1 2028 the locomotives will have completed the testing and authorization phase. After which the locomotives are allowed to be used on the Dutch, German and Austrian tracks. That means that the Demo will unfortunately not be possible during the planned duration of the MAGPIE project. Nevertheless the testing of the locomotives will take place, but too late for the MAGPIE project.

The zero-emission locomotive project illustrates that rolling stock authorization remains a major risk factor in international railway projects. While European harmonization has improved the framework, national requirements, interpretational uncertainty, late feedback, and testing synchronization issues continue to pose significant challenges. Effective risk management therefore requires early engagement with authorities, careful planning of test programs, and sufficient schedule and budget contingencies.

As the locomotives are designed and built for The Netherlands, Germany and Austria, they are in most cases not equipped for use in other countries. As can be seen in chapter 6, the locomotives can be used in Rotterdam and Venlo. In other partner ports an upgrade is needed, e.g. extra battery capacity or authorization for another country. For Belgium another traction power system is required, which probably requires an adapted designed locomotive. Spain and Portugal have a wider gauge of 1668mm, which requires a total new design of the locomotive.

To stimulate the transition from diesel locomotives to zero-emission locomotives, the lengthy and labor-intense authorization process should be optimized. No longer should it be possible for member states to add national requirements on top of the EU legislation and the time needed for the process should be shorter and more transparent.

Next to that a subsidy programme for investing in zero emission locomotives, e.g. a new for old subsidy, could help to speed up the replacement of old diesel locomotives.

Although unfortunately not possible during the MAGPIE project, an intense monitoring period is advised to test the locomotive in different commercial use situations and weather conditions.

2. Introduction

The ambition of the port of Rotterdam is to be zero-emission by 2050. That ambition not only concerns the industry in the port, but also the shipping, the trucks and the trains.

In addition to the ambition of the port of Rotterdam, the EU TEN-T legal framework prescribes that in 2050 all rail transport should be electrified.. A deviation from this requirement can only be requested from the European Commission, if it can be substantiated that compliance is not feasible (see Annex 1).

Freight Transport by rail is already the most sustainable mode of transport. Long haul services use electrical locomotives (E-Locs), while diesel locomotives (D-Locs) are still used for shunting and short haul operations.

Last mile connections to terminals are in general not electrified., because of high costs of electrification, both construction and maintenance. Furthermore on the terminal premises also a catenary is not possible because of the loading and unloading processes. So on rail yards a switch from E-loc to D-loc vice and versa has to be made.

Zero-emission shunting locomotives make a complete zero-emission hinterland transport by rail possible. These locomotives are powered by an electric battery pack while operating in catenary-free areas and where an overhead line is available they operate on catenary power, As a result, the same locomotive can be used for both shunting and short haul, eliminating the need for locomotive exchange reducing costs and time.

In the port of Rotterdam some 40 old diesel locomotives are now in use, which can be in time(5-10 years) replaced by these zero-emissions locomotives.

In the MAGPIE project Demo 8 was included to test these new zero-emission shunting locomotives.

The partners in Demo 8 are:

- Rail Innovators Group (RIG): Owner and operator of the locomotives
- TNO: Measuring and analysing data during the pilot
- ProRail: Infrastructure manager: assists in the homologation and the operation during the pilot
- Port of Rotterdam: Demo lead

3. Background of demo 8: zero-emission shunting locomotive

While the main railway lines in the Rotterdam port area are all electrified, the final stretch that rinse into the different industrial areas and terminals is not. Therefore, these last miles of railway are serviced with diesel powered shunting locomotives. There are about 40 diesel shunting locomotives in Rotterdam port alone. These locomotives typically have a very long operational life and as such the majority is now more than thirty years old and in need of replacement in the coming years. Research by TNO[1] in 2017 showed that the shunting locomotives have relatively high emissions of CO_2 and NOx.

As part of MAGPIE Demo 8, an indicative estimate was prepared of the emission reduction potential that can be achieved by replacing a conventional diesel shunting locomotive (e.g. Vossloh G2000 class) with the zero emission battery-electric shunter.

A typical diesel shunting locomotive operating in port and last-mile freight services consumes approximately 180,000 liters of diesel per year, corresponding to around 56,000 km of operation and 4,445 engine hours annually.

Using standard European emission inventory factors for rail diesel traction (EMEP/EEA Guidebook) and national CO_2 reporting factors for diesel fuels (RVO/IPCC methodology), this level of fuel consumption is associated with the following indicative annual tailpipe emissions:

Pollutant	**Annual emissions**	**Per engine hour**	**Per km**
CO_2	≈ 478 tonnes/year	≈ 107.5 kg/hour	≈ 8.54 kg/km
NOx	≈ 8.15 tonnes/year	≈ 1.83 kg/hour	≈ 146 g/km
PM10	≈ 315 kg/year	≈ 70.8 g/hour	≈ 5.62 g/km
PM2.5	≈ 300 kg/year	≈ 67.4 g/hour	≈ 5.35 g/km
Black carbon (indicative)	≈ 195 kg/year	≈ 43.8 g/hour	≈ 3.48 g/km
CO	≈ 1.62 tonnes/year	≈ 0.364 kg/hour	≈ 28.9 g/km
NMVOC[2]	≈ 689 kg/year	≈ 0.155 kg/hour	≈ 12.3 g/km

Sources: EMEP/EEA Air Pollutant Emission Inventory Guidebook (Railways sector) and Dutch national fuel emission factors (RVO/IPCC methodology).

[1] **TNO 2017 R11414v2** Inzicht in het energieverbruik, de CO2-uitstoot en de NOx-uitstoot van het spoorgoederenvervoer

[2] Non-Methane Volatile Organic Compounds

Consequently, the deployment of a zero-emission shunting locomotive in port environments has the potential to deliver substantial reductions in greenhouse gas emissions as well as local air pollutants, contributing to improved air quality and supporting the decarbonization objectives of the EU Green Deal and Fit-for-55 framework.

This calculation represents an indicative order-of-magnitude estimate, intended to support the assessment of environmental benefits of zero-emission last-mile rail solutions within the MAGPIE demonstration programme.

An important added benefit of the zero-emission hybrid shunting locomotives is, that they can not only be used for shunting in the port area, but also for short haul and mid haul operations. This is logistically a preferred option, as it avoids a costly and time-consuming handover between two locomotives (E vs D) at both the origin and the destination.

As many of the shunting locomotives in operations are currently at the end of their operational life, there is a window of opportunity for switching to a more sustainable alternative. A full electric version would be preferred and is in line with the ambition of the Port of Rotterdam to go for zero-emission transportation.

4. Objectives of the demo 8 pilot

As stated in the Grant Agreement, the main objective of Demo 8, is to prove the viability of a full electric shunting concept by executing a pilot with two prototype locomotives in real operational conditions. Data about the operations and technical information e.g. about loading and unloading cycles, speed, train load, used maximum power will all be monitored in real-time with the two e-shunting locomotives in real operational conditions.

The viability assessment contains technical, operational and economic performance aspects.

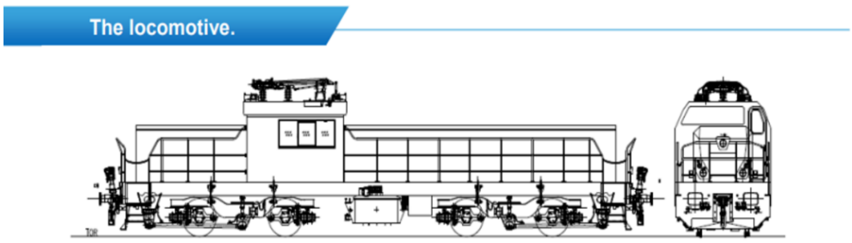
The technical performance assessment looks at the design specification and specifically focuses on the battery performance and the multi-mode operations.

The operational aspects consider the various operational modes / train loads and external circumstances (like ambient temperature, wind, wet conditions etc.).

The economic performance assessment considers the expected utilization of the locomotives, including the battery charging time as well as the potential benefits from not having to change locs for short haul and mid haul operations.

Description of the locomotive

The Rotterdam based Rail Innovation Group has ordered two full electric e-shunter locomotives by CRRC in China, with the above mentioned specifications. The locomotives provide a future-proof solution for freight transport by combining high performance under overhead electrification with emission-free battery operation on non-electrified sections. Thanks to its modular design and dual-mode capabilities, the locomotive is particularly well suited for projects where flexibility, sustainability, and operational continuity are key requirements.



Technical specifications:

- Power under catenary mode:
  AC15kV 16.67Hz (Germany) 2500kW
  AC25kV 50Hz (Port & Betuweline) 2500kW
  DC 1500V (Netherlands) 1200kW
- Signal system: ETCS 230d+ATB+PZB
- Country approval: NL/D/AT
- The locomotive is equipped with UIC power output

Capacity under battery mode:

- Battery power: 350kWh
- Operation distance in shunting mode:
  - 15km @ 2400t with 40km/h
  - 23km @ 1600t with 40km/h
- Charging time: from 10% > 90% in 60 minutes under catenary

Technical specifications of the locomotive

The locomotive is a hybrid locomotive, designed for freight operations on both electrified and non-electrified rail networks. The locomotive combines electric traction under overhead catenary with battery-electric propulsion for operation on routes without overhead line equipment. It has a standardized central cab and interchangeable energy and traction modules. This enables flexible deployment for mainline operations, shunting duties, and so-called last-mile applications. It is equipped with electric traction and two large battery modules, allowing locally emission-free operation on non-electrified sections of the network.

These locomotives are primarily intended for operation in the Port of Rotterdam and its hinterland, including the Ruhr area.

General vehicle characteristics

- Wheel arrangement: Bo'Bo'[3]
- Length over buffers: 18,700 mm
- Service weight: < 90 tonnes
- Minimum negotiable curve radius: 75 m
- Electric power: up to 2,500 kW
- Battery operation: approximately 500 kW
- The locomotive is designed for operation within temperature class T1 (–25 °C to +40 °C).

As the locomotive is primarily intended for use in The Netherlands and Germany, it is fitted with all the traction and signalling systems needed for these countries. This means that the locomotive can work under 15kV AC, 25kV AC and 1,5kV DC catenary power. Next to the national (class B) signalling systems for The Netherlands and Germany, it also has the European ERTMS signalling system on board. Austria was also added to the list of authorized countries. This is not because there is a clear plan to deploy the locomotives there, but because the extra effort is very limited if the locomotive is already suitable for Germany.

The locomotive is equipped with two battery units, each with a capacity of approximately 175 kWh, resulting in a total energy capacity of around 350 kWh. Lithium-Titanium-Oxide (LTO) battery technology is applied, offering high charge and discharge rates, long service life, and reliable performance at low temperatures. During operation under overhead line equipment, the batteries can be recharged, including through regenerative braking.

[3] A locomotive with two independent bogies, each equipped with two individually powered axles.

Specific scope elements of the pilot

It is envisaged that the pilot should include (but is not limited to) the following operational conditions:

- shunting in the port of Rotterdam in different areas such as Waal-Eemhaven, Botlek, Europoort and Maasvlakte
- short haul to terminals as Tilburg, Eindhoven and Venlo in The Netherlands
- mid haul to Duisburg in Germany
- potential for operations in other port areas will be included in the pilot

As indicated, during these various operational conditions, the external and load conditions will be varied to ensure that the full operating envelope is covered. Data about the operations and technical information e.g. about loading and unloading cycles, speed, train load, used maximum power will all be monitored in real-time. A fully comprehensive performance report, that includes the main raw data and the conclusions from the proof of concept will be made publicly available.

To assess the economic performance the utilization of the locomotives, including the battery charging time as well as the potential benefits from not having to change locs for short haul and mid haul operations, will be monitored.

However before the locomotives could be tested, the vehicle authorization process should be completed (Ch 5).

5. Vehicle authorization process explained

Introduction of the vehicle authorization process

Before a railway vehicle can be put into commercial operation, it must be authorized. Traditionally, this was a purely national authorization in which every country has its own technical rules and process. Over the past decades the authorization process largely shifted to the EU level, with the ultimate goal to eliminate all specific country requirements (SERA – single European railway area). However, this is currently by no means completed, meaning that in practice both the EU and the individual member states are involved in vehicle authorization. Compliance has to be demonstrated with both EU rules and the National Notified Technical Rules (NNTRs) in the intended countries.

The effect of this is that vehicle authorization for railway vehicles is generally perceived to be a very time consuming and high-risk aspect of every newbuilt (or modification) project. A very extensive test campaign is required and independent experts (NoBo, DeBo, AsBo[4]) have to be engaged to evaluate the outcomes before authorization can be requested.

The challenges and complexities related to the vehicle authorization are described in more detail in the final chapter of this report.

The locomotives will have to be authorized for use in The Netherlands and Germany. In practice, there is a lot of convergence between the technical rules for Germany and Austria. It was therefore decided to add Austria to the area of use, as a future proofing measure. The extra effort needed for the vehicle authorization is very limited.

Testing and certification form a critical phase in every new railway rolling stock development project. This phase is highly labor-intensive and involves significant financial and scheduling risks. These risks became particularly evident in the zero-emission locomotive project, which aims to develop a battery-powered shunting locomotive for cross-border operation in multiple countries, including The Netherlands and Germany.

The project clearly demonstrated that vehicle authorization is a complex regulatory process that requires extensive coordination between European and national authorities, not merely a technical exercise..

Vehicle Authorization Process – Basic Structure

The authorization process consists of three main steps.

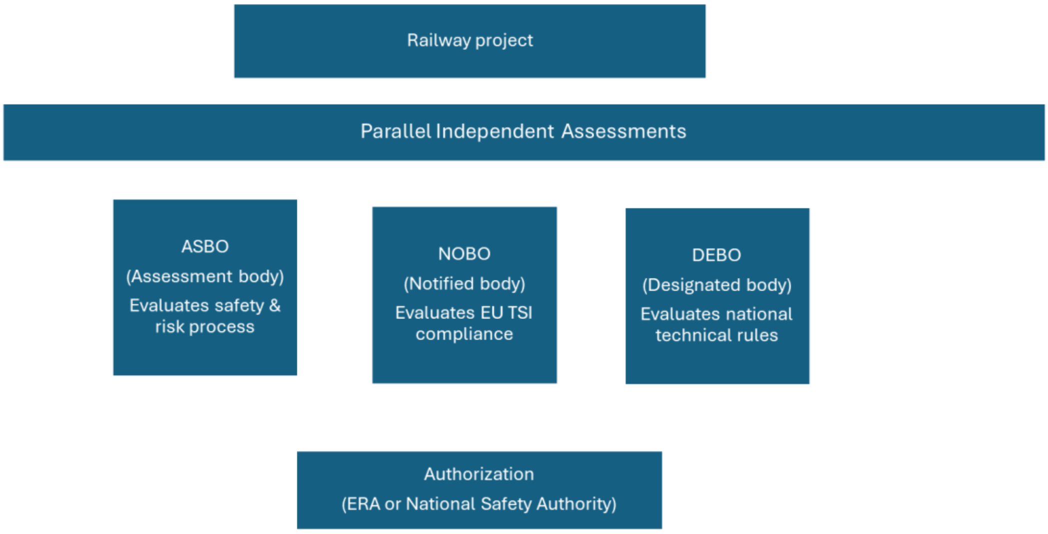
First, the vehicle must demonstrate compliance with the applicable European Technical Specifications for Interoperability (TSIs). Evidence must be collected to show that all relevant TSI requirements are met. This evidence can consist of technical documentation, analysis, or test results. Compliance is assessed by a Notified Body (NoBo), an independent, accredited technical specialist. A NoBo certificate is a prerequisite for any authorization application.

Second, the vehicle must comply with additional national technical rules (National Notified Technical Rules, NNTRs). These requirements are assessed by a Designated Body (DeBo) for each country of operation. In this project, this applied to The Netherlands, Germany, and Austria. A DeBo certificate from any country for which authorization is requested, is

[4] Notified Body, Designated Body, Assigned Body

required. Third, an independent Assessment Body (AsBo)evaluates the safety and the risk process.

Finally, an application for vehicle authorization is submitted to the European Union Agency for Railways (ERA), which issues the formal approval.



Schematic process of authorization

After initial authorization, it is possible to extend the authorization with further countries, provided the vehicle is technically compatible with the networks in these countries. In this process for Extension of Area of Use (EoA), the second step is repeated for one or more additional countries

Complications in the Authorization Process

Persistence of National Requirements

Despite European harmonization efforts, a significant number of national technical requirements still exist alongside EU-level requirements. As a result, alignment and approval are required both at EU level and at the level of individual Member States. Although the EU aims to gradually eliminate national requirements in favor of harmonized European rules, it is expected to take at least another decade before this goal is achieved.

Interpretation of Requirements

A considerable degree of interpretation remains, particularly with regard to national requirements. In practice, a clear understanding of detailed technical expectations and required evidence can only be achieved through intensive consultation with authorities or accredited experts. While progress has been made towards greater consistency, informal practices and unwritten rules may still apply, increasing uncertainty for project teams.

Late Certainty in the Process

Formal authorization is granted by ERA and can only be applied for once the technical file is fully completed. After submission, ERA has up to five months to respond. During this period, applicants have very limited insight into the status or progress of the assessment. Feedback is typically provided at a late stage, meaning that even relatively minor issues—such as missing results from specific sub-tests—can cause substantial delays if the test programme has already been concluded. Also, although the NoBo and DeBo's involved are tasked with the independent assessment of technical compliance, in practice the ERA specialists may decide to redo parts of technical assessment and may reach different conclusions.

Challenging Synchronizations of Testing Requirements

Both European and national requirements can generate testing needs. While tests are bundled as much as possible and country-specific tests are minimized, synchronization remains challenging. The time required to clarify and agree on test requirements varies significantly between countries, making it difficult to execute test programs quickly and efficiently.

This challenge is further exacerbated by the long preparation times often associated with testing, for example due to limited infrastructure availability or scarce capacity at specialized test institutes. As a result, delays in clarifying requirements can have a disproportionate impact on project schedules.

The high number of sometimes ambiguous requirements, extensive testing required to prove compliance and high number of parties involved (national and EU authorities, accredited engineering consultants, test organizations, engineering departments) typically result in long (1-3 years) and expensive (1-5 mio Euro) authorization processes, that -most importantly- have a very high risk of significant delays or further cost increase.

6. Status update of the demo 8 pilot

In the MAGPIE project, Demo 8 was intended to test the performance of two newly developed hybrid shunting locomotives, built in China by CRRC. CRRC is the world's biggest locomotive manufacturer. After taking over German based Vossloh a few years ago, the project was partly moved there in order to benefit from local knowledge and experience. While construction and testing was mainly moved to Germany, a substantial part of the development team remained in Zhuzhou, China. In Annex 2, the status per task, as defined in the Grant Agreement, is presented.

Status of design & construction

In the MAGPIE reporting period the technical design of the locomotives was completed in China and both units were manufactured. One locomotive is currently in EU (Germany) for authorization testing at Vossloh, a daughter company of CRRC. The second unit is also fully manufactured and was until recently used for validation testing in Zhuzhou. It will be shipped to Germany in Q1 2026. and will be used for further testing.

Second locomotive starting its journey to the EU

Interior of the locomotive

Status of the vehicle testing & authorization program

During the validation and authorization process, some significant deficiencies were identified. It was found that the design of the locomotives had to be adapted in several areas. Most changes were relatively easy to implement (e.g. parameter settings, software, minor mechanical adaptations), other required relative fundamental rework. For instance, the cooling concept for motors and power electronics had to be optimized. Also, the cabling lay-out and EMC (electromagnetic compatibility) behaviour had to be modified extensively.

Locomotive #1 undergoing braketesting in Minden,

Locomotive #2 undergoing 25kV traction testing in Zhuzhou, China

All redesign efforts are currently completed and implemented on both locomotives. This redesign did lead -however- to a major delay in the authorization of the locomotive. The expectation is that no earlier than Q4 2027 or Q1 2028 the locomotive will have completed the testing and authorization phase. After which the locomotive is allowed to be used on the European tracks. That means that the Demo will unfortunately not be possible during the planned duration of the MAGPIE project.

The locomotive #1 in Kiel, Germany

7. Transferability to other ports

a) In general:

The locomotive is mainly intended to be capable of any duty that may be needed in the transport of goods from the port of Rotterdam to the Ruhr area. This means that it is capable of:

1. shunting duty on catenary-free shunting yards
2. hauling medium-sized trains from the port to the electrified network. Here the aim was to be able to cross a 15 km catenary-free section with a 2400t train or 25km with a 1600t train.
3. hauling freight trains across the electrified networks of Germany and The Netherlands (including Betuweroute). They can therefore operate under any catenary power in those countries and have all signalling systems on board for those countries.
4. Charging of the batteries can be done both from any catenary system or (with lower charging speed) from dedicated charging infrastructure or depot power

As the locomotives will be authorized for The Netherlands, Germany and Austria, they can in principle also be used in all other ports in these countries. The main potential issue may be the battery capacity. As the network in the port of Rotterdam has a high rate of electrification, the battery capacity could be kept relatively low (at 350 kWh). It may be that other ports have longer catenary-free sections. In these ports, limits of use for the locomotive may exist, but it would still be possible to find usage. There is a very strong correlation between the battery-only range and the weight of a train. While a 2400t train may have a battery-only range of approximately 15 km, a solitary locomotive might have a range well over 100 km. Also, local limitations (e.g. maximum axle loads, curves, etc) may limit the useability on specific sites.

A minor upgrade of the battery capacity (from 350 kWh to 400 kWh) would be easy to implement in the current design. For larger upgrades the physical space may not be available.

It should be possible to add further countries to its area of use by adding further power- and signaling systems. Adding the 3kV DC catenary system would enable use in for instance Belgium and France, but it is not certain if it is possible to add a fourth power system to this locomotive. Adding further signalling systems however is relatively easy, as the locomotive already has ERTMS which is designed to work with all national systems, with Specific Transmission Modules (STM's).

b) MAGPIE and PIONEERS partner ports

The following partner ports within the MAGPIE and PIONEERS project are analyzed.

MAGPIE partner ports: ROTTERDAM, HAROPA (France), SINES (Portugal), DELTAPORT (Germany)

PIONEERS partner ports: ANTWERP-BRUGES (Belgium), BARCELONA (Spain), CONSTANTA (Romania), VENLO (Netherlands)

In the following table an overview is given about the transferability of the zero-emission locomotives in the other ports. Authorization is established for the locomotives for transport to and from the Port of Rotterdam (The Netherlands), Deltaport (Germany) and Venlo (The Netherlands). Other important criteria related to possible use of the loc, are the distance to be travelled without catenary system which becomes problematic for Deltaport with 25 kilometers, the traction power which does not fit for Antwerp-Bruges and Barcelona which is a strict excluding factor, the signalling system which is different for Haropa and Sines and the track gauge that differs for Sines and Barcelona which is also a strict excluding factor. In the Annex 2 information for each port is displayed.

Port	Type of port	Vehicle authorization in project scope	Distance not electrified	Traction power	Signalling system	Track gauge (mm)	Main operation
Port of Rotterdam	Large seaport	In scope	Up to 15 km	AC 25kV-50Hz	ETCS, ATB	1435	Shunting, direct last mile
Haropa - Le Havre Rouen Paris	Seaport, inland terminals	Not in scope	Up to 5 km	AC 25kV-50Hz	**KVB, crocodile**	1435	Shunting, direct last mile
Deltaport	Inland terminal	In scope	Up to 25 km	AC 15kV-16.7Hz	PZB	1435	Direct last mile
Sines	Seaport	Not in scope -	Up to 500 meter	AC 25kV-50Hz	Convel, ETCS	1668	Shunting, direct last mile
Antwerp, Bruges	Large seaports	Not in scope -	Up to 7 km	DC 3kV	ETCS	1435	Shunting, direct last mile
Barcelona	Seaport	Not in scope -	Up to 5 km	DC 3kV	ETCS, ASFA	1668 Spain 1435 to border France	Shunting, direct last mile
Venlo	Inland terminal	In scope	Up to 2 km	DC 1.5kV	ATB	1435	Direct last mile
Constanta	Seaport	Not in scope -	Up to 2 km	AC 25kV-50Hz	PZB	1435	Shunting, direct last mile

Green: the locomotives can be used as is. This is the case for the Port of Rotterdam and Venlo.

Yellow: the locomotives need some upgrades or adaptations (for instance signalling system, authorization or extra battery capacity) to enable use here. This is the case for Haropa, Deltaport and Constanta.

Red: the locomotives cannot be used as is, major changes in the design would be necessary. Due to different traction power and/or track gauge this is the case for Sines, Antwerp-Bruges and Barcelona.

8. Conclusions, findings and recommendations

Conclusions related to the zero emission locomotive

While the main railway lines in the Rotterdam port area are all electrified, the final stretch that rinse into the different industrial areas and terminals is not. Therefore, these last miles of railway are serviced with diesel powered shunting locomotives. There are about 40 diesel shunting locomotives in Rotterdam port alone. These locomotives typically have a very long operational life and as such the majority is now more than thirty years old and in need of replacement in the coming years. That creates an opportunity for replacing the diesel locomotives with zero emission locomotives in line with the ambition of the port of Rotterdam and EU and national legislation (Annex 1). The two recently built zero emission locomotives, ordered by the Rail Innovators Group, are now in the process of authorization for The Netherlands, Germany and Austria.

Conclusions related to the Demo pilot

During validation and authorization testing of the locomotives some significant deficiencies were identified. It was found that the design had to be adapted in several areas. All redesign efforts are currently completed and implemented on both locomotives. This redesign did lead -however- to a major delay in the authorization of the locomotive. The expectation is that no earlier than Q4 2027 or Q1 2028 the locomotive will have completed the testing and authorization phase. After which the locomotive is allowed to be used on the Dutch, German and Austrian tracks. That means that the Demo will unfortunately not be possible during the planned duration of the MAGPIE project. Nevertheless the testing of the locomotives will take place, but too late for the MAGPIE project.

Conclusions related to the authorization process

The high number of sometimes ambiguous requirements, extensive testing required to prove compliance and high number of parties involved (national and EU authorities, accredited engineering consultants, test organizations, engineering departments) typically result in long (1-3 years) and expensive (1-5 mio euro) authorization processes that -most importantly- have a very high risk of significant delays or further cost increase.

The Zero Emission locomotive project illustrates that rolling stock authorization remains a major risk factor in international railway projects. The factors mentioned above have all contributed to the current project delays.

While European harmonization has improved the framework, national requirements, interpretational uncertainty, late feedback, and testing synchronization issues continue to pose significant challenges. Effective risk management therefore requires early engagement with authorities, careful planning of test programs, and sufficient schedule and budget contingencies.

Conclusions Transferability

As the locomotives are designed and built for The Netherlands, Germany and Austria, they are in most cases not equipped for use in other countries. As can be seen in chapter 6, the locs can be used in Rotterdam and Venlo. In other partner ports an upgrade is needed for instance an extra signalling system unit (Haropa), or extra battery capacity (Deltaport), or authorization for another country (Constanta)

For Belgium another traction power system is needed, which is not easy. Of course dedicated locs can be built for Belgium by replacing the 1,5kV DC unit with a 3kV DC unit. Spain and Portugal have a wider gauge of 1668mm, which requires a total new design of the locomotive.

Recommendations

To stimulate the transition from diesel locomotives to zero-emission locomotives, the lengthy and labor intense authorization process should be optimized. No longer should it be possible for member states to add national requirements on top of the EU legislation and the time needed for the process should be made shorter and more transparent.

Next to that a subsidy programme for investing in zero emission locomotives could help to speed up the replacement of old diesel locomotives.

Although not possible any more during the MAGPIE project, an intense monitoring period is advised to test the locomotive in different commercial use situations and weather conditions

Annex 1: Legal framework

- **Zero-Emission Rail Transport Has a Legal Framework**
- In 2013, the EU adopted the TEN-T Regulation, which was revised in 2024. This regulation aims to strengthen the *Trans-European Transport Network*—including rail—partly by making it more sustainable and harmonizing technical standards. Some railway lines are part of the "comprehensive" network, for which full electrification by 2050 is required. Only when it can be substantiated that this is not feasible, a deviation from this requirement can be requested from the European Commission, following the conditions described in the regulation.
- In 2019, the European Climate Law was adopted as part of the Green Deal. It stipulates that Europe—across all sectors, including mobility—must be climate-neutral by 2050, with interim targets of a 55% emission reduction by 2030 compared to 1990, and a 90% emission reduction by 2040 compared to 1990.
- In 2023, the Dutch government also adopted a Climate Act, embedding the same end goals.
- In 2023, the EU adopted the Regulation on Alternative Fuel Infrastructure (AFIR). For the rail sector, this means that Member States are required to assess which infrastructure is needed for alternative fuels on railway lines that cannot be fully electrified. They must also report on this every two years.
- For rail operators, from financial year 2024 onward (depending on company size), the EU Corporate Sustainability Reporting Directive (CSRD) applies. Companies must report annually on sustainability policies, performance, and objectives. This requires them to be transparent about their environmental performance and makes the greening of their rolling stock a strategic priority, as the reporting may influence investment opportunities.
- In 2024, the Dutch government decided to include the rail sector in the EU Emissions Trading System 2 (ETS2). This means that fuel suppliers in The Netherlands will pass on the costs of emitted CO_2 to rail operators via fuel prices starting in 2027. These prices will increase annually because the number of certificates available in the market will decrease each year. Although no end date is set for the emission trading system, projections by Enerdata show that with an end year of 2050, the CO_2 price may rise from €70 per ton in 2030 to €130 in 2040 and €500 from 2042 onward—significantly affecting the operation of (a concession including) diesel trains.

Annex 2: Status Demo 8 per task

In the Grant Agreement different tasks for Demo 8 have been described.

Per task the status is presented:

Task 1.0: Preparation and pilot development / scoping activities

Basic outlines of the monitoring program were set. An initial list of the relevant parameters was developed. Preparation of the pilot was halted, when it became clear first that the pilot was delayed beyond the time frame of the MAGPIE project.

Task 1.1: Design -and construction prototyping support

This task is fully executed. During the Covid-years, the support and supervision could not be done on-site in China and was done remotely instead. Although this reduced the level of involvement, it resulted in a cost reduction for the program. The test- and certification program is now mainly executed from Kiel, Germany (Vossloh site).

Task 1.2: Support for prototype acceptance / homologation process

Supervision and support of the homologation process is ongoing. As the program progresses, focus shifts from the EU-level regulation to the additional national rules. It is expected that engagement with national authorities will ramp up in the coming months.

The tasks:

Task 2.0: Proof of Concept

Task 2.1: Hardware performance testing of the e-shunting locs

Task 2.2: Extended operational Pilot period

could not be executed, because the Demo requires fully certified locomotives. The authorization process was not ready yet and thus the locomotives were not allowed on the European railway network

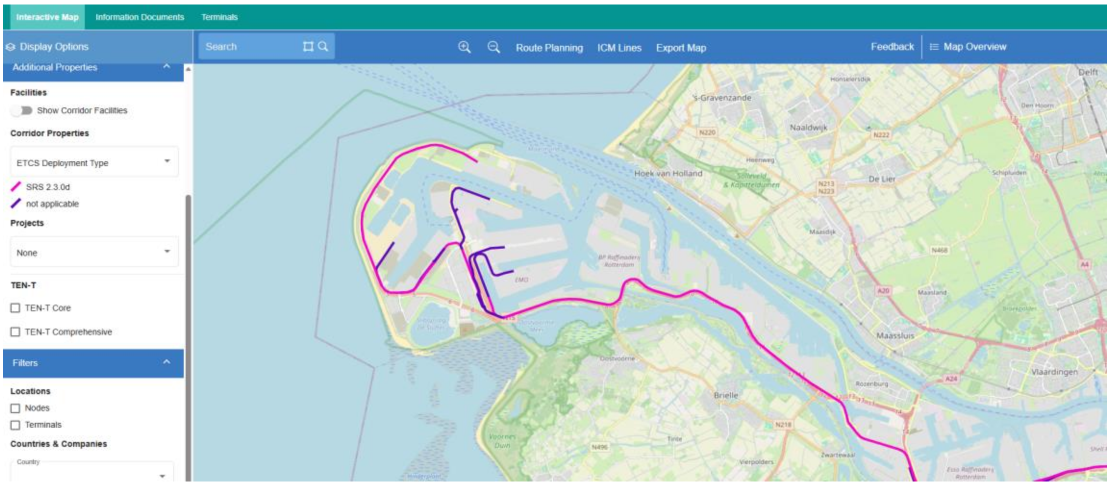
Task 3.0: Desk study learnings of the pilot for the possibility of zero-emission locs in HaRoPa and Sines ports

In chapter 7 of this report the transferability of the locomotive to other ports, is described, based on the theoretical specs of the locomotives. Not only the MAGPIE ports (HaRoPA, Deltaport and Sines), but also the ports in the PIONEERS project (Barcelona, Antwerp-Bruges, Constanta, Venlo) have been taken into account.

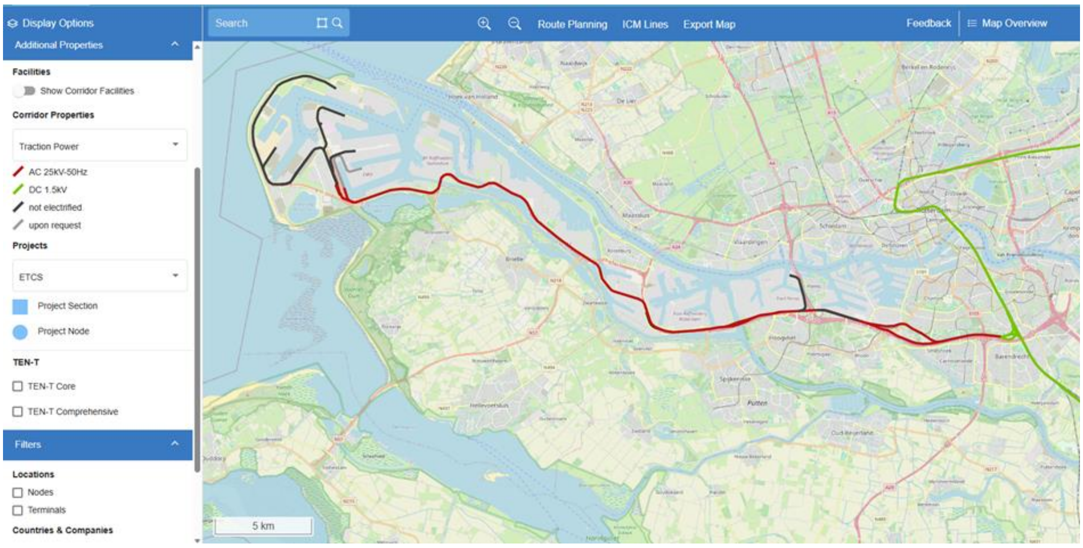
Annex 3: Specifications of rail infrastructure in the ports

In the following maps, derived from the CIP platform of Rail Net Europe, per port can be seen which traction power system and signalling is available.

Rotterdam

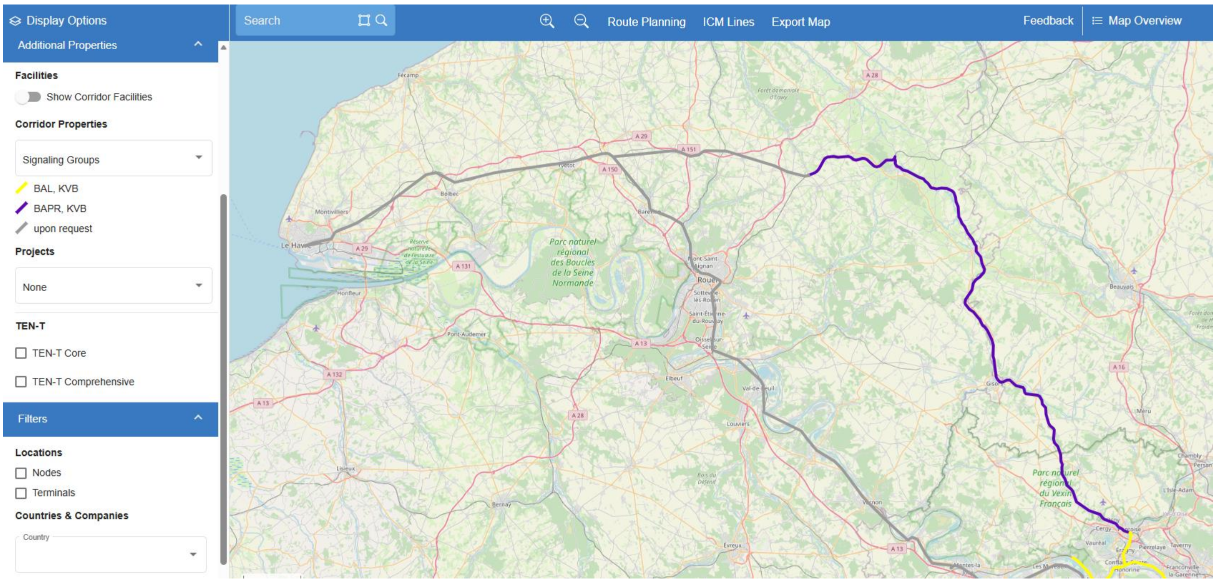


Signalling system: ETCS 2.3.0d

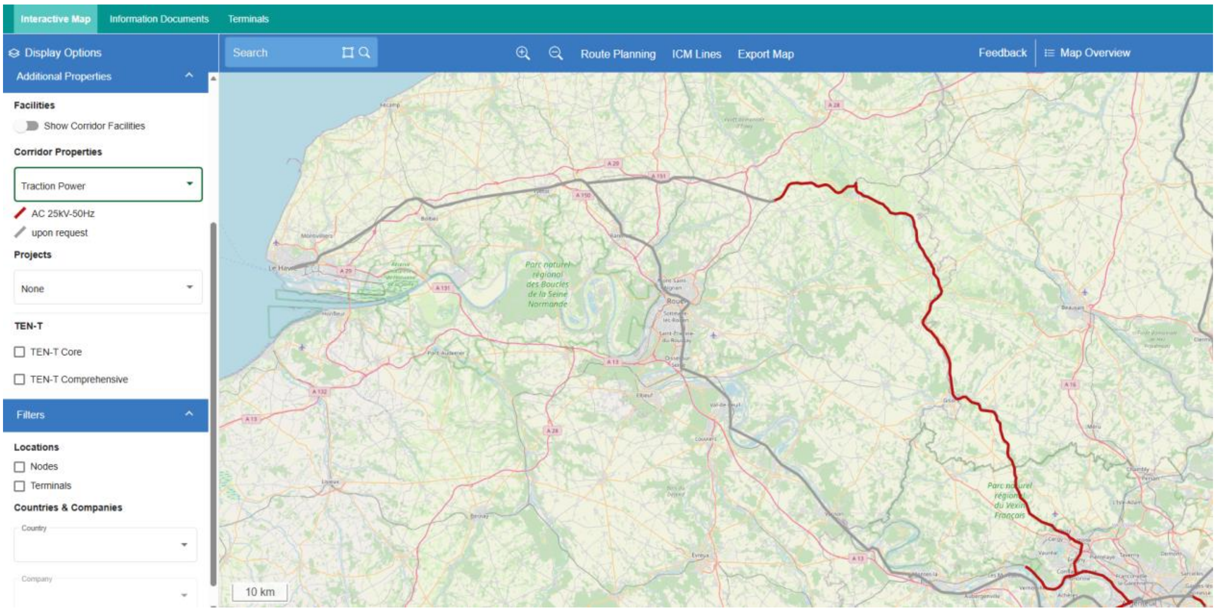


Traction Power: 25kV AC 50Hz

HAROPA

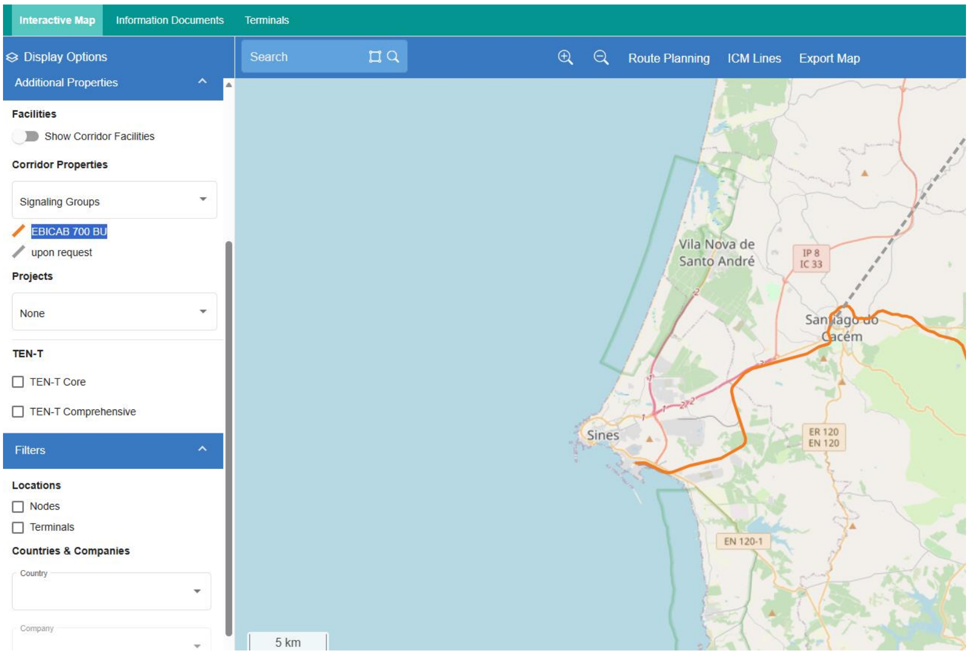


Signalling system: KVB

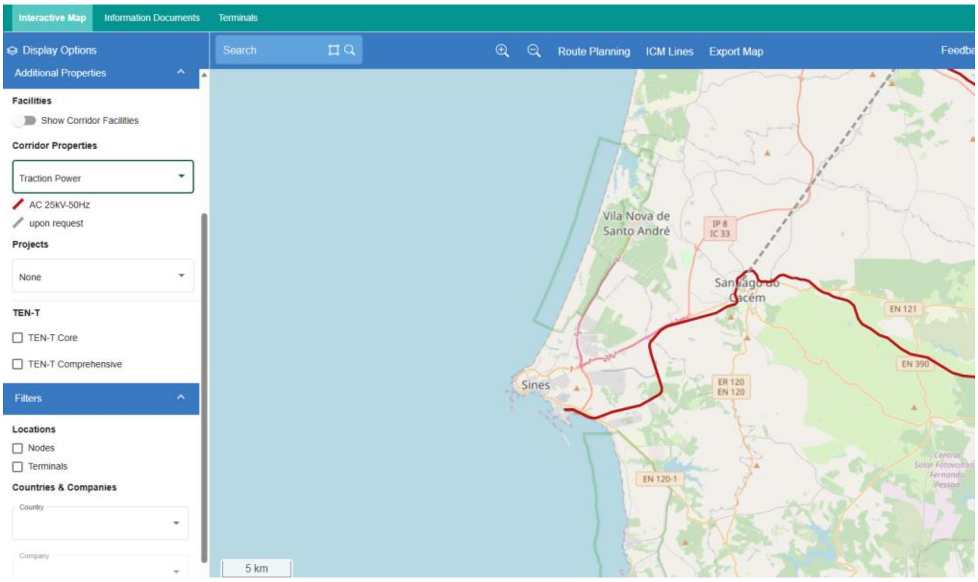


Traction Power: 25kV AC 50Hz

SINES:



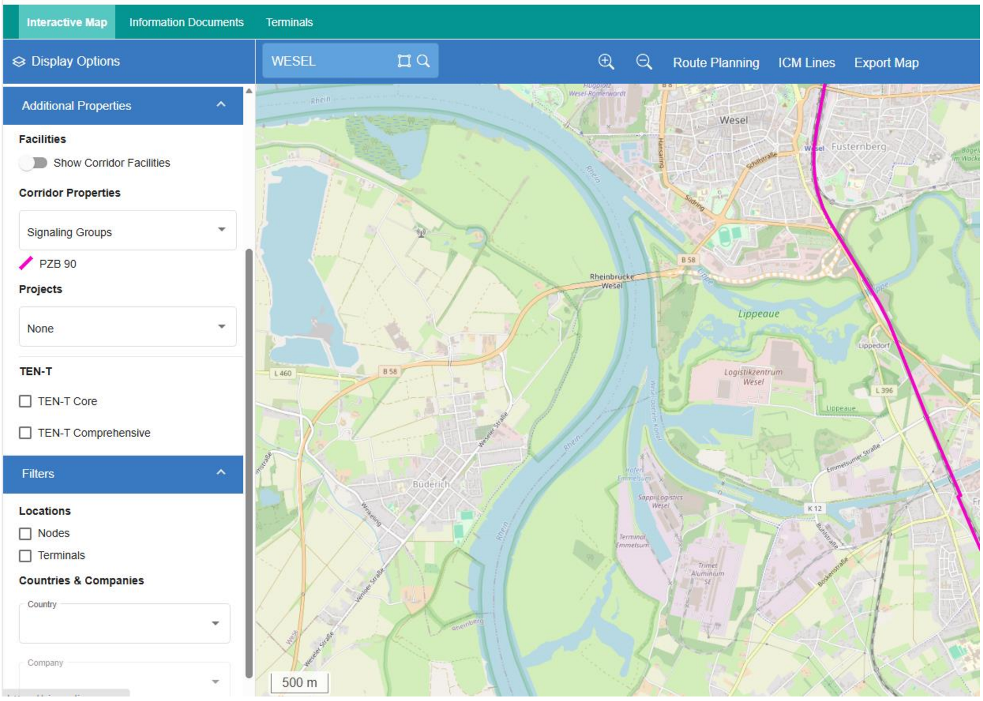
Signalling system: EBICAB/ECTS



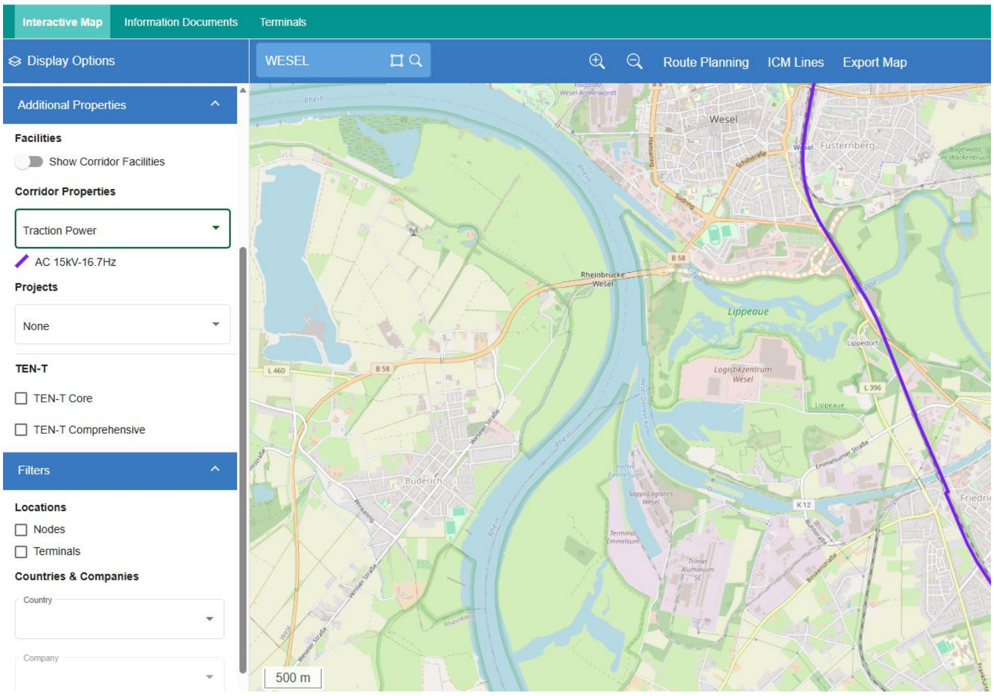
Traction Power: 25kV AC 50Hz

Track gauge: 1668mm

DELTAPORT:

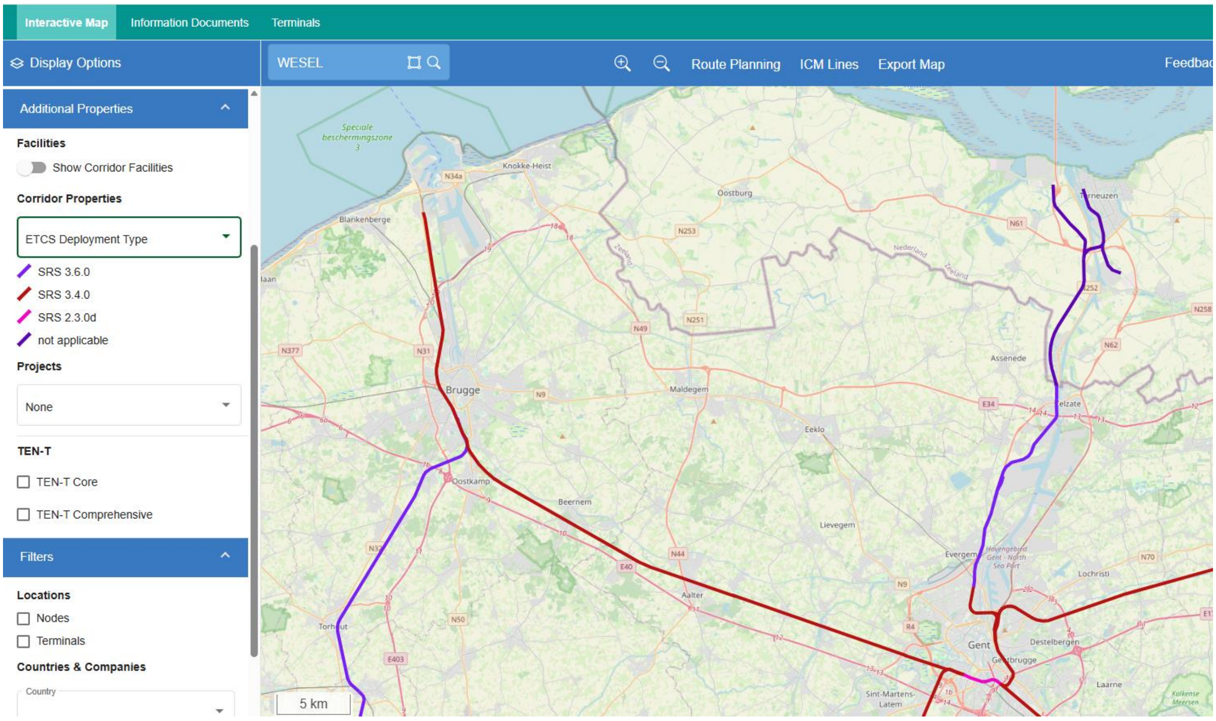


Signalling system: PZB

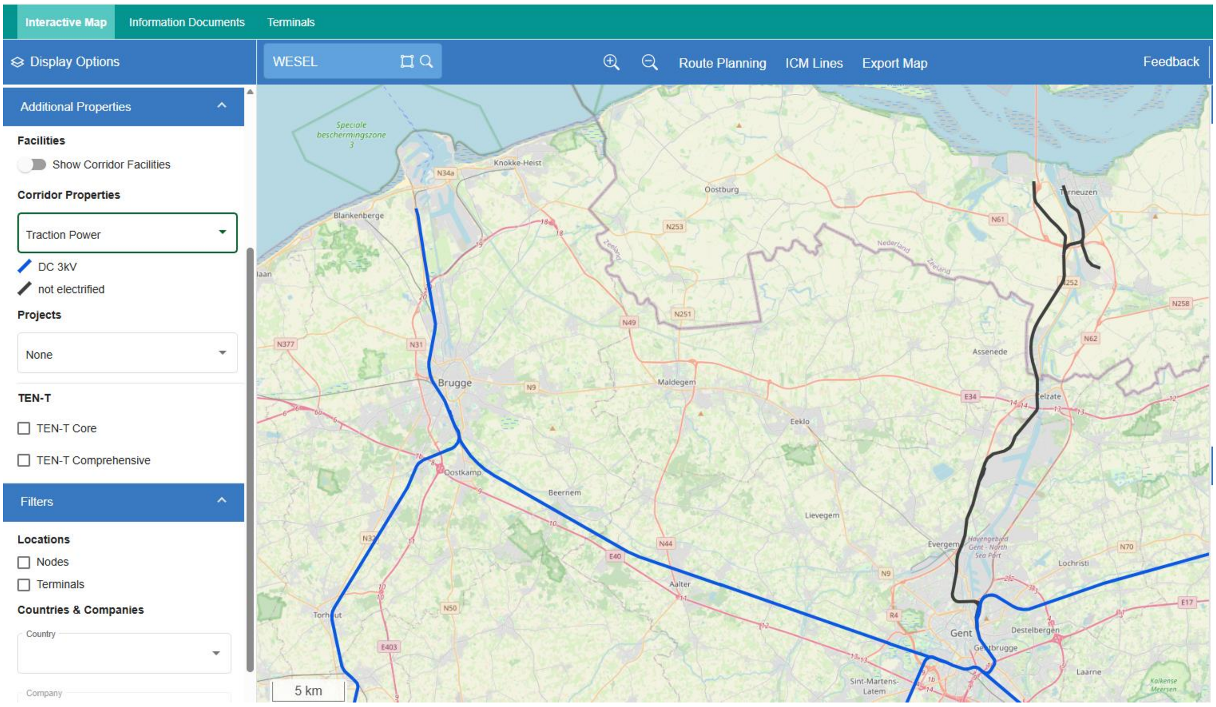


Traction Power: 15kV AC 16 2/3Hz, but 25km without catenary

ANTWERP-BRUGES

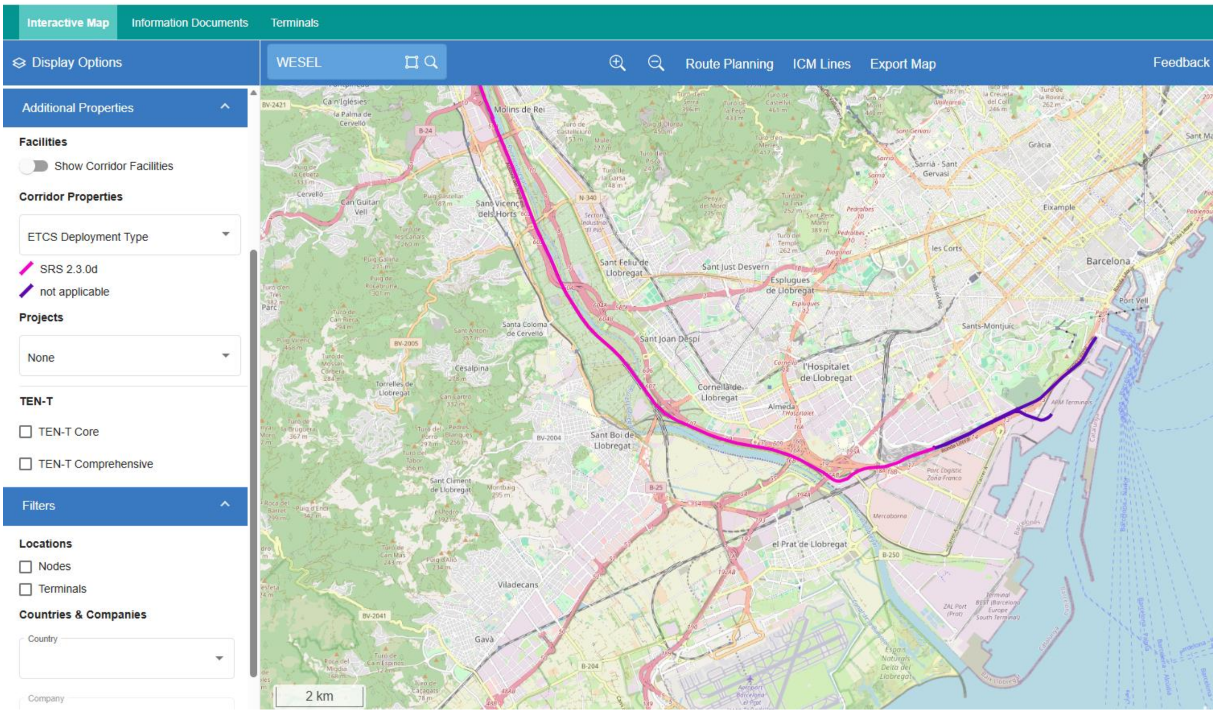


Signalling system: ECTS 3.4.0

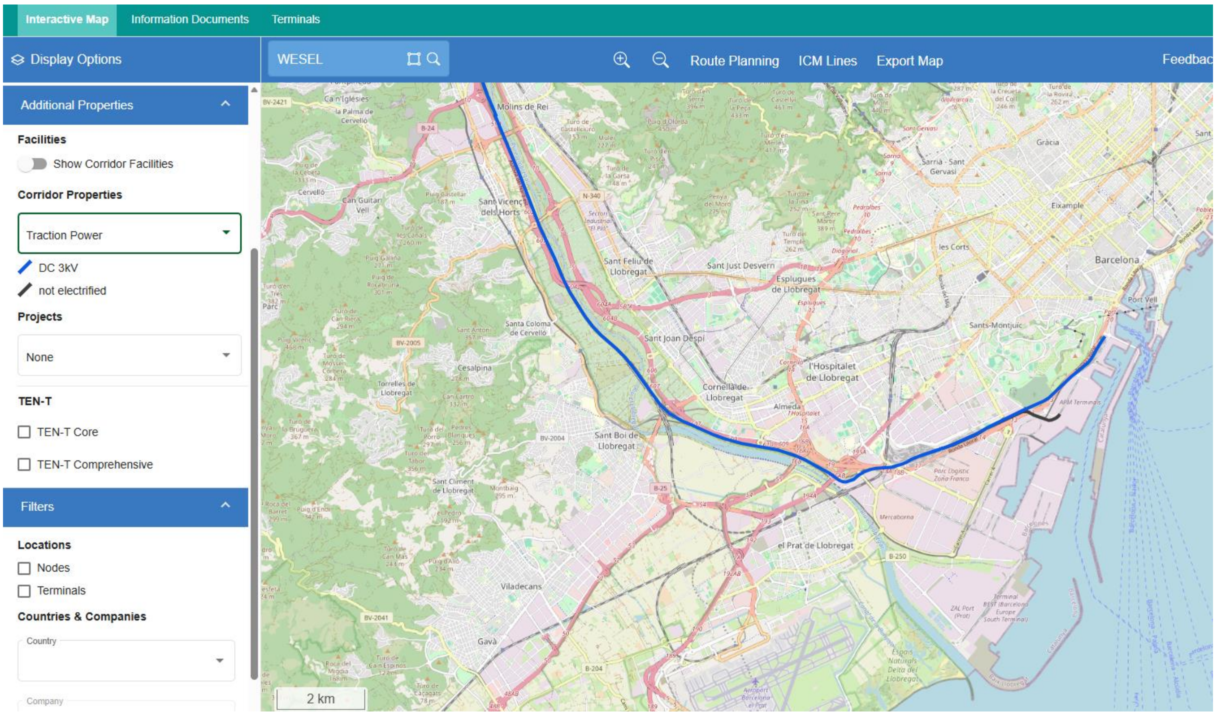


Traction Power: 3kV DC

BARCELONA



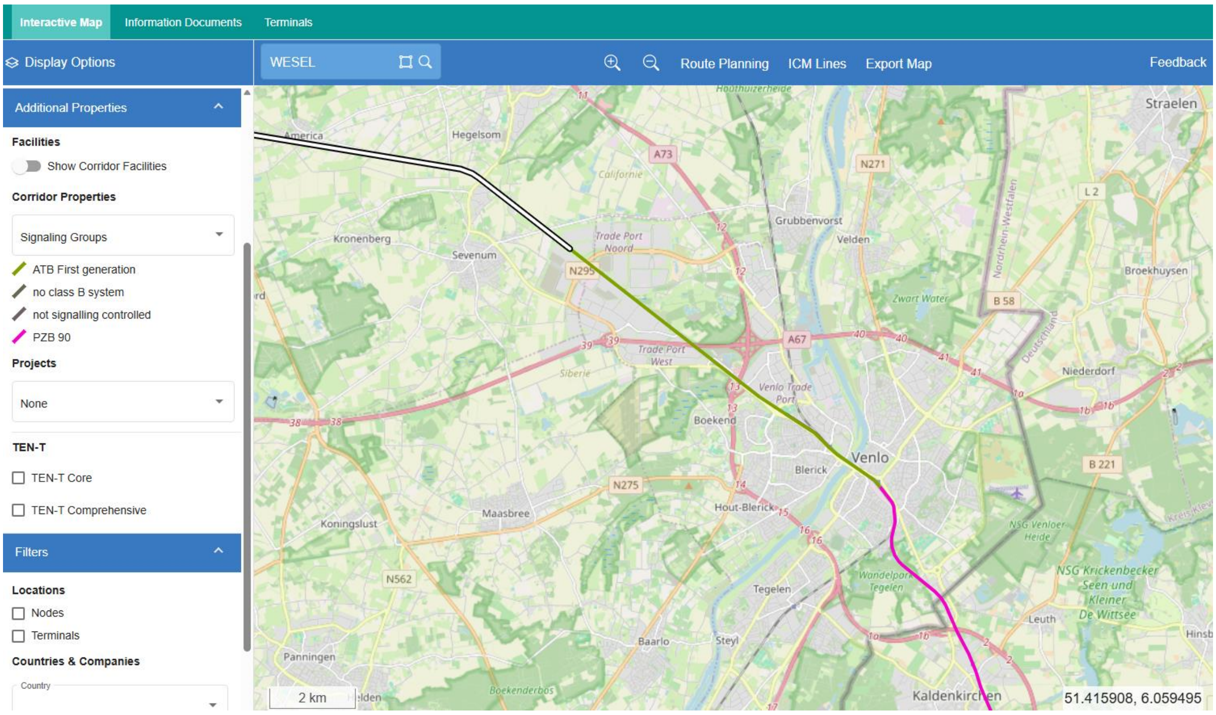
Signalling system: ETCS 2.3.0d



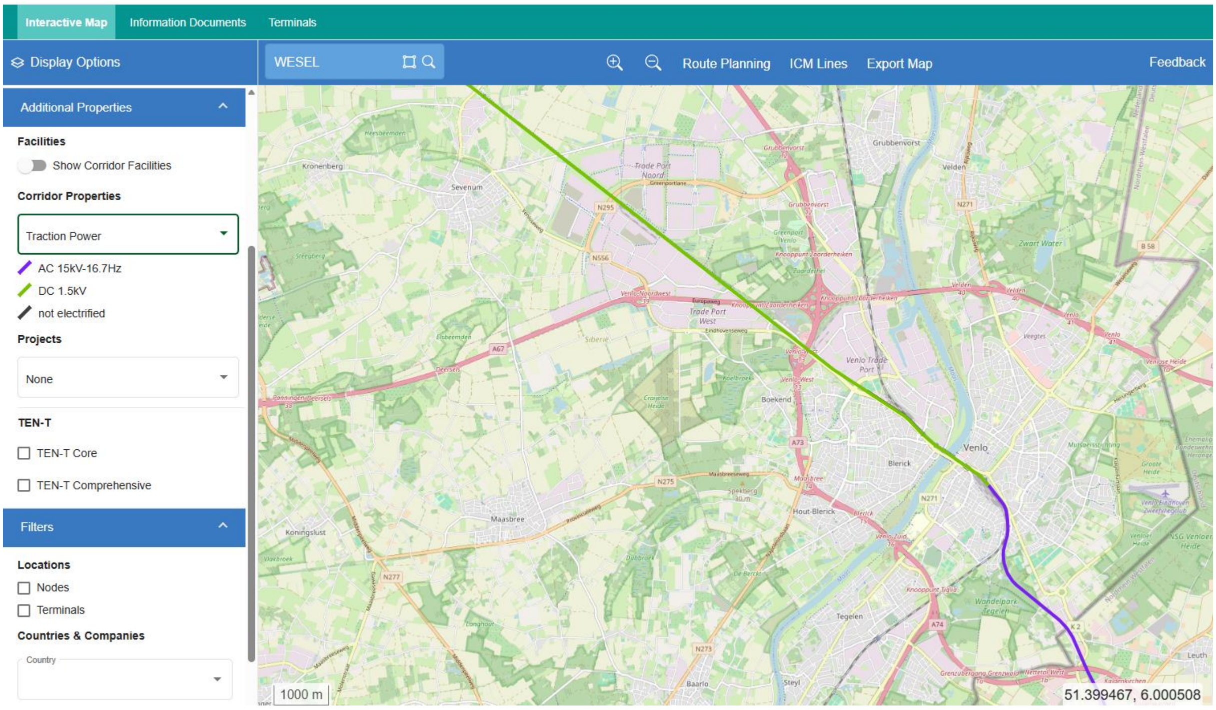
Traction Power: 3kV DC

Track gauge: 1668mm and 1435mm up to France

VENLO

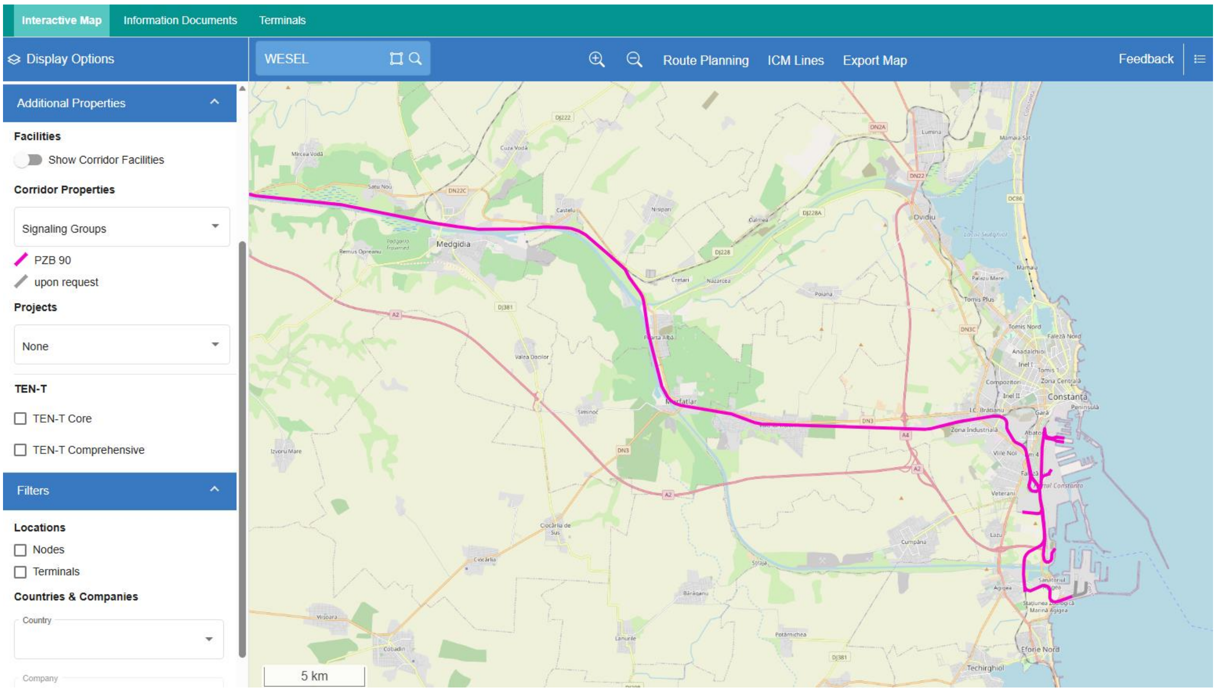


Signalling system: ATB, PZB 90

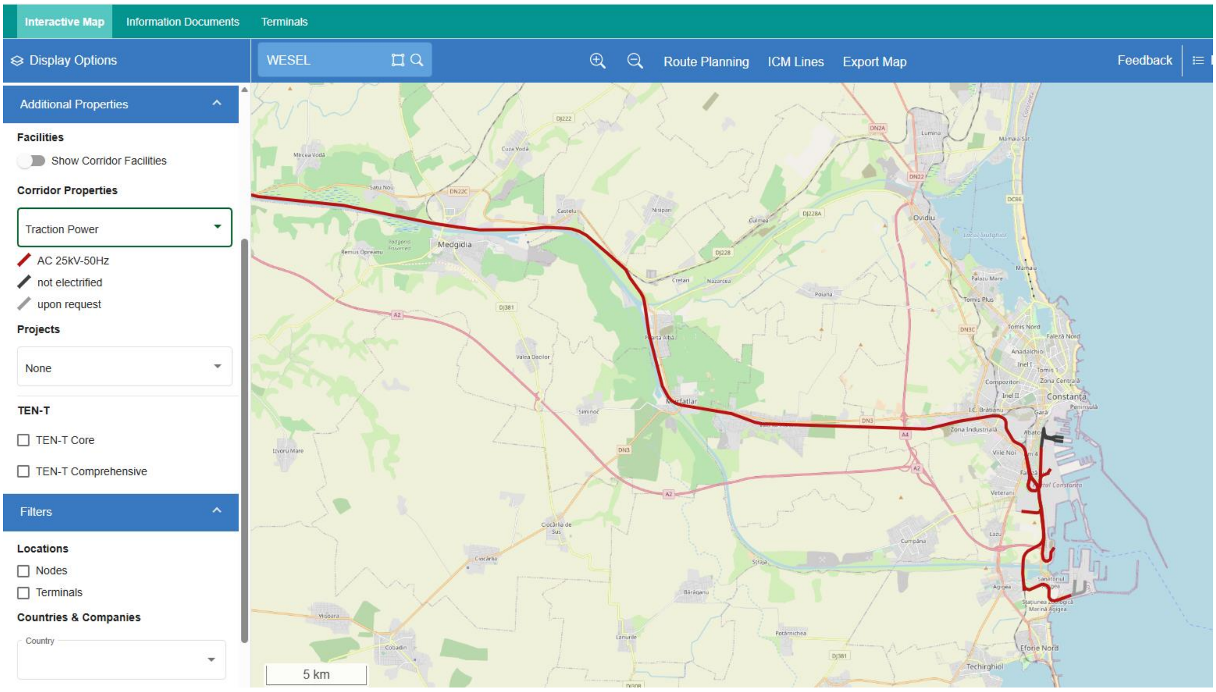


Traction Power: 1,5kV DC/15kV AC 16 2/3 Hz

CONSTANTA



Signalling system: PZB 90



Traction Power: 25kV AC 50Hz