Transforming
Europe's Rail Freight

D29.1

Technical definition of the standard IVG for checkpoints and related demonstrators

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1. Executive Summary

This document addresses *Task 29.1: Demonstrator definition and start of development* and the related sub-tasks within WP29 Standardised European Checkpoints (ERC). The main aim of the task was to define checkpoint demonstrators and suggest potential sites for them.

The demonstrator definitions and the deployment strategies presented in this report constitute the basis for future developments of the demonstrators, which will be carried out and evaluated in *Task 29.2: Demonstration and evaluation of the installed checkpoints*. Moreover, the definitions will also be an input for WP33, *Task 33.5: Showcase of Standardised European Railway Checkpoints*. The demonstrators shall consider the activities listed in the subtasks of task 29.1.

Moreover, the document elaborates on use case definitions and approaches for the automatic detection of information and damages. The necessary technical implementation of the algorithms and approaches has been discussed and the necessary information described. An operational analysis has been carried out in order to identify the data from checkpoints that are needed in the different use cases. Based on this analysis, a data requirements specification for parts of the conceptual data model has been produced. The specification includes information about trains, vehicles, ILUs, irregularities and cargo.

Additionally, in this deliverable, the level of harmonization has been investigated for main operational procedures addressed by the ERC concept. The topic of harmonization is addressed also in other parts of EU Rail; thus alignment activities are deemed essential and have been sought and will be further worked on. For WP29 the main alignment activities carried out thus far have been with WP2 regarding harmonized operational procedures, with WP5 regarding yard automation, with WP32 and FP1 regarding data exchange, with FP3 WP7 regarding ERC development and with System Pillar project HERD regarding diagnostics data.

Keywords: Standardised European Checkpoints (ERC), Demonstrator, Image analysis, Condition Monitoring Systems (CMS), Data exchange, Harmonization, Rail Freight Transportation

2. Abbreviations & Acronyms

Abbreviation / Acronym	Description
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
AI	Artificial Intelligence
ATTI	Agreement on freight Train Transfer Inspection
BAM	Bearing Acoustic Monitor
BIC	Bureau International des Containers et du Transport Intermodal
CDM	Conceptual Data Model
CMS	Condition Monitoring Systems
CV	Computer Vision
DAC	Digital Automatic Coupling
DPC	Detector-PC
ECM 3	process of maintenance ordering
EPCIS	Electronic Product Code Information Services
ERA	European Union Agency for Railways
ERC	European Railway Checkpoints
EU-Rail JU	Europe's Rail Joint Undertakings
EVN	European Vehicle Number
FP	Flagship Project (within Europe's Rail)
GA	Grant Agreement
GCU	General Contract of Use for Wagons
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite Systems
HB	Hot-box
HBD	Hot Box Detection
HOA	Hot Axle Box
HW	Hot-Wheel
HWD	Hot Wheel Detection
HERD	Harmonised European Railway Diagnostics (project within the System Pillar of the European Railway Joint Undertaking)
HNS	Hazardous and Noxious Substances
ILU	Intermodal Loading Unit, containers, swap-bodies and semi-trailers
IM	Infrastructure Manager
IVG	Intelligent Video Gate
KPI	Key Performance Indicators
LOBU	Loco On-Board Unit
LTE-M	Long-Term Evolution for Machines

MAWP	Europe's Rail Joint Undertaking Multi-Annual Work Programme
MVP	Minimal viable product
OCR	Optical Character Recognition
OTIF	Intergovernmental Organisation for International Carriage by Rail
RCMF	Railway Coordination Messaging Format
RFID	Radio Frequency Identification
RFIG	General Interest Railway Network
RID	Règlement Concernant le Transport International Ferroviaire Marchandises Dangereuses
RNE	Rail Net Europe
RU	Railway Undertaking
TAF TSI	Technical Specification for Interoperability relating to Telematics Applications for Freight Services
TCM	Train Composition Message
TE	Technical Enabler
TIS	Train Information System
TRL	Technology Readiness Level
UC	Use cases
UIC	International union of railways
UWB	Ultra-Wideband
VK	Vehicle Keeper
WILD	Wheel Impact Load Detector
WMS	Wayside Monitoring System
WOBU	Wagon On-Board Unit
WP	Work Package
WSEN	Wireless Sensor Elements
WSN	Wireless Sensor Network
WTMS	Wayside Train Monitoring Systems
XML	Extensible Markup Language

3. Background

The present document constitutes the Deliverable D29.1 "Technical definition of the standard IVG for checkpoints and related demonstrators" in the framework of the Flagship Project FP5- TRANS4M-R as described in the EU-RAIL MAWP.

Specifications for the checkpoint has previously been described in chapter 8 in Deliverable D25.1 *Report on the basic functional and technical specifications for the realisation of the technical enablers of Seamless Freight, also including the final specification input for FP1* (Hildebrandt et al., 2024).

It should be noted that the main overarching objective of WP29 has been to develop Railway Checkpoints that will assist with automating Freight Train Transfer detection and inspections at borders or other operational stop points. This includes digitalising and automating processes through the use of emerging technologies using OCR, sensors and other detection and identification technologies. The technological objectives are combined with evaluation of data sharing and exploitation possibilities as well as harmonized procedures and regulation across the European rail network.

Enabler 12 as described in the MAWP is addressed in this work package and the Technological Readiness Levels (TRLs) aimed for in this WP as described in the DoA of GA are the following:

- Digitalisation and partial automation of manual processes through innovative and emerging technologies, based on a process analysis (TRL 7)
- Interoperable IT-systems for data management and processing (TRL 7)
- Harmonized procedures and regulations

4. Objective/Aim

This document has been prepared to provide the output of Task 29.1: *Demonstrator definition and start of development*.

The aim of the task was to develop IVG checkpoints demonstrators for digitalisation and partial automation of manual processes through innovative sensors, Videogates and handheld devices, based on a process analysis as specified in Task 25.4; *Specifications for Standardised European Checkpoints*, and suggest potential sites for demonstrations.

The demonstrator definitions elaborated in this report will constitute the basis for future developments of the demonstrators, which will be performed and evaluated in Task 29.2: *Demonstration and evaluation of the installed checkpoints.* Moreover, the definitions will also be an input for WP33, Task 33.5: *Showcase of Standardised European Railway Checkpoints*, where the goal is to show that the IVG improves the dependability, effectiveness and reliability of rail freight transports with respect to the process analysis specified in task 25.4. The demonstrators shall consider the activities listed in the subtasks of task 29.1.

4.1. Task Description

Task 29.1 started in project month 13 (July 2023) and the outputs of this task are included in this document.

The following Table 4.1 gives the direct match of the task definition from the proposal with the output and a link to the section where more details can be found.

Table 4.1 Task descriptions and related output in the report

	Task definition from GA (Task 29.1)	Output of deliverable
Subtask 29.1.1	Definition of the demonstrators' characteristics including locations, characteristics and participants;	Chapter 5 Demonstrator's characteristics
Subtask 29.1.1	Propose deployment strategies and an implementation and roll-out plan for standardised European checkpoints;	Chapter 6 Deployment strategies
Subtask 29.1.2	High level definition of test cases; Use of image analysis techniques for automatic defect detection to improve maintenance processes and safety performance e.g. in train preparation phase;	Chapter 7 High Level Definition of Test Cases
Subtask 29.1.3	Define a Conceptual Data Model for a structured data exchange on checkpoints, including all needed concepts and relations between them and optimize their integration and the data flow as specified in task 25.4, incorporating the image analysis processes inside the gate, providing full digitalization on site including dangerous goods placard recognition and Optimize the gate for terminal entry/exit points where trains go at very low speeds and lack of installation space is a problem	Chapter 8 European Railway Checkpoint Conceptual Data Model Requirements
Subtask 29.1.4	Develop supporting methodologies in order to mitigate the identified regulatory barriers for harmonized procedures and regulations and as specified in task 25.4.	Chapter 9 Harmonized procedures and regulations

5. Demonstrator's characteristics

To fulfil the objectives of WP29, a series of Railway Checkpoints is used. These checkpoints can be existing facilities used for this purpose, or newly built facilities designed, installed, and operated within the context of FP5-TRANS4M-R WP29.

This section provides a description of the characteristics of the mentioned Railway Checkpoints used, including their locations, characteristics and the entities that are involved in their development and operation.

5.1. General overview

In the following Table 5.1, some of the characteristics of the Railway Checkpoints are summarised. The information is further developed in the next sections, describing the installations on each network.

Table 5.1 Railway checkpoints general overview

No	Country	Location of checkpoint/s (number)	Installation
1	Spain	Marshalling yard at border (2)	To be installed
2	Netherlands	Main line (6) marshalling yard (6)	Already installed
3	Sweden	Border (1)	To be installed
		Terminal (1)	Already installed
4	Germany	Marshalling yard (13)	Already installed
5	Austria	(50+)	Already installed

In addition to the railway checkpoints, for the use case of onboard sensors, a series of sensors is planned to be installed on a freight wagon to track different parameters of the vehicle, for more details see section 5.7.

5.2. Railway Checkpoints in Spain

In Spain, the installation of two Railway Checkpoints is being prepared. These checkpoints are not currently deployed, so they have to be built during the development of the project in order to collect the necessary data to carry out the demonstration.

5.2.1. Locations

The two Railway Checkpoints will be installed in a Marshalling Yard called Can Tunis located in the city of Barcelona.

In this Marshalling Yard the trains arriving from the national railway network (including cross-border traffic) managed by Adif are distributed to different facilities including maintenance workshops and a maritime freight port among others. Also, trains departing to the national network (including cross-border traffic) are configured within Can Tunis.

Can Tunis is laid out as various parallel marshalling tracks with exits at both ends as can be seen on Figure 5.1. The function of the Railway Checkpoints is to reliably assess and record what trains and wagons are located within Can Tunis at all times, therefore, the two Railway Checkpoints will be located at both ends of the Marshalling yard and will have cameras and sensors that cover all the tracks in that section.

Figure 5.1 Location of Railway Checkpoints in Can Tunis

Location 1:

On the western end (Location 1) there are 4 tracks exiting Can Tunis. Two of them head to the general network, and two other head towards the freight port facilities and other installations. Of the tracks heading to the general network there is a direct route to the border with France.

Location 2:

On the eastern end (Location 2) there are 2 tracks exiting Can Tunis. One of these tracks heads to a railway terminal called Morrot (cul de sac). The other also heads to Morrot, however, it has a turnout that can divert traffic towards the freight port.

In conclusion, there are in total 6 tracks to be monitored, four in Location 1 and two in Location 2. Additionally, some sensor or counter cold give additional information as to what route is taken by the train traversing the mentioned turnout.

With the recorded information gathered by both Railway Checkpoints the occupation of the Marshalling yard can be determined precisely at each time. Additionally, with the log of the entering and exit time of each vehicle, their time of stay can be measured. With this information, the capacity of Can Tunis can be further optimized, by controlling its occupation at all times and potentially charging occupation fees if applicable depending on the time of stay of each vehicle.

5.2.2. Characteristics

Indra's participation in Spanish demonstrator for European Railway Checkpoint will consist in the installation and development of several gates for several tracks, covering the locations described above. The characteristics detailed below aims to cover the following use cases and system functionalities, aligned with the objectives set for an ERC within the framework of the TRANS4M-R project.

European Railway Checkpoints at Marshalling Yards: As stated in 8.1.3, at shunting yards, automates wagon sequencing is a critical process that the ERC system aims to fulfil. In this sense, the ERC systems to be installed in the Can Tunis marshalling yard aims to optimize the management and occupancy of the facility, enhancing operational efficiency and ensuring accurate tracking of trains and wagons at all times. For this purpose, two gantries will be installed at the points described in the section below, equipped with cameras and additional sensors, the aim of which will be to identify all rolling stock compositions in transit at both operational points. Considering the above-mentioned requirements established by the ADIF Infrastructure Manager, the ERC system installed shall fulfil the following functionalities:

5.2.2.1. Train Arrival Data Capture

The ERC installation is illustrated by Figure 5.2, where the system must record each composition arriving at each point, this functionality includes the following functions listed below.

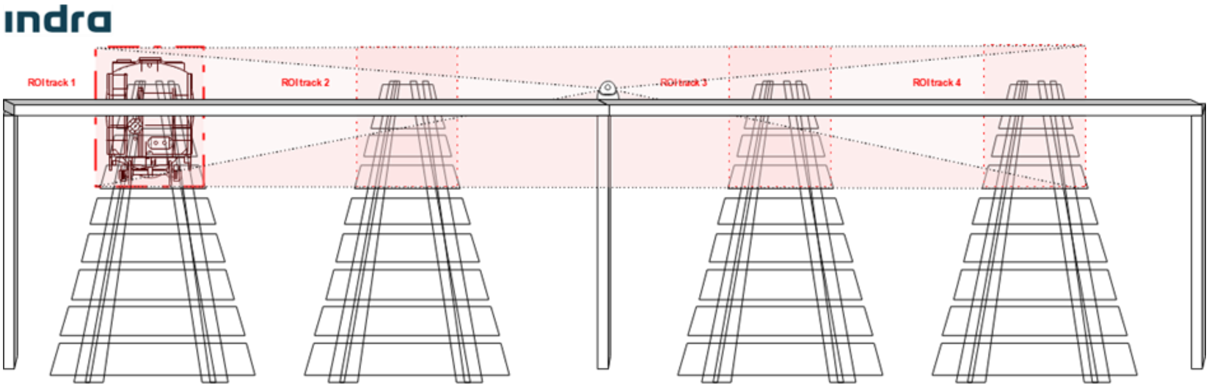


Figure 5.2 Intended ERC installation.

Rolling Stock detection

Comprises the following capabilities:

- Detect the position of trains and wagons on multiple tracks and in both directions.
- Determine on which track the rolling stock is running.
- Send trigger signal in order to enable the analysis on the detected rolling stock.

Train Identification:

ERC is able to automatically obtain train identification information, by interfacing with management systems

Wagon Identification

Reading of wagon numbers (UIC codes/European Vehicle Numbers) via image analysis at both points. The system must also record each wagon's position within the train using presence sensors and image analysis.

5.2.2.2. Safety and Hazardous Materials Management

The system must identify each hazard material arriving at both of the operational points. The system implements image analysis for detecting hazardous cargo and corresponding registration within the system.

5.2.2.3. Marshalling Yard Occupancy Monitoring

The system must perform a continuous monitoring of the 6 tracks (4 at the western end and 2 at the eastern end) to determine real-time occupancy of the infrastructure. Besides, the system must log and register the entry and exit times for each vehicle, enabling the calculation of stay duration.

5.2.2.4. Integration with Management Systems

Integration with existing traffic and yard management systems for data and operational synchronization.

5.2.2.4.1. Functional requirements

Based on the functionalities detailed above, the installation of 4 IVG gantries (2 gantries for each control point) equipped with cameras for detecting and analyzing information about the rolling stock, as well as additional sensors, is proposed for this demonstrator. The functional design phase of the gantries is still ongoing, therefore the structure and number of equipment represented is tentative, see Figure 5.3.

Figure 5.3 Preliminary design of the ERC in Can Tunis locations.

The installed gates fulfil the following installation requirements:

Requirement 01: Number of locations – European Railway Checkpoint in Can Tunis is intended to cover the operation of two locations, covering a total of four tracks.

The first location is in the south of the terminal, covering the entrance and exit of the RFIG tunnel and the entrance and exit of port ring 1. The installation would therefore cover traffic on 4 different routes.

The second location is to the north of the terminal, covering the entrance and exit of Morrot and the entrance and exit of ring 2 of the port. The installation would therefore cover traffic on 3 different routes. The exact location and layout is still to be confirmed after further planning.

Requirement 02: Detection cameras – To detect the presence of incoming rolling stocks to the gates, two cameras for detection are installed on each point. Each camera can detect the presence of a train in one direction and discerning the track where is located.

Requirement 03: Detection sensors – Installed to monitor the track occupancy and ensure the accurate detection of trains on specific tracks.

Requirement 04: Analysis cameras - Capture high-resolution images for rolling stock identification and dangerous goods identification. Sixteen cameras must be installed, two at each side of each gate, to ensure the resolution needed for the analysis is obtained.

5.2.3. Participants

Adif and Indra are collaborating on the implementation of the Railway Checkpoints in Spain.

Adif is Spain's main infrastructure manager, responsible for the administration of more than 11 000 km of railway. Its role in the development of the railway checkpoint is to provide the infrastructure where it is installed. Additionally, it has studied the different alternatives within its network to find the most suitable marshalling yard for the demonstration and is in charge of supervision tasks during the installation.

Indra is a global technology and consulting company specializing in advanced solutions in the fields of defence, transport, energy, and telecommunications. Regarding the European Railway Checkpoint development for the Spanish demonstrator, Indra's role focuses on providing the technological expertise and systems required for the implementation. Indra is responsible for designing, develop, deploy and integrating the software and hardware that will monitor and manage railway checkpoints, ensuring that the systems meet operational standards.

5.3. Railway Checkpoints in The Netherlands

5.3.1. Locations

At Railway yards ProRail has 6 IVG's in use: at Moerdijk (one), at Waalhaven (2) and at Botlek (3) mainly for number recognition and wagon counting to check the wagon lists.

The IVG at Moerdijk is located at a marshalling yard for freight trains. Here, trains coming from or going to the Rotterdam Harbor are marshalled. The gate is located at the entry/exit rail to the Moerdijk marshalling yard, meaning all trains entering this yard pass the IVG.

Hogebrug – one big portal with multiple cameras on the main line for monitoring passenger trains, see Figure 5.4.

Figure 5.4 Location of gate in Hogebrug, marked with a red circle.

Schiphol Airport – pantograph monitoring, see Figure 5.5.

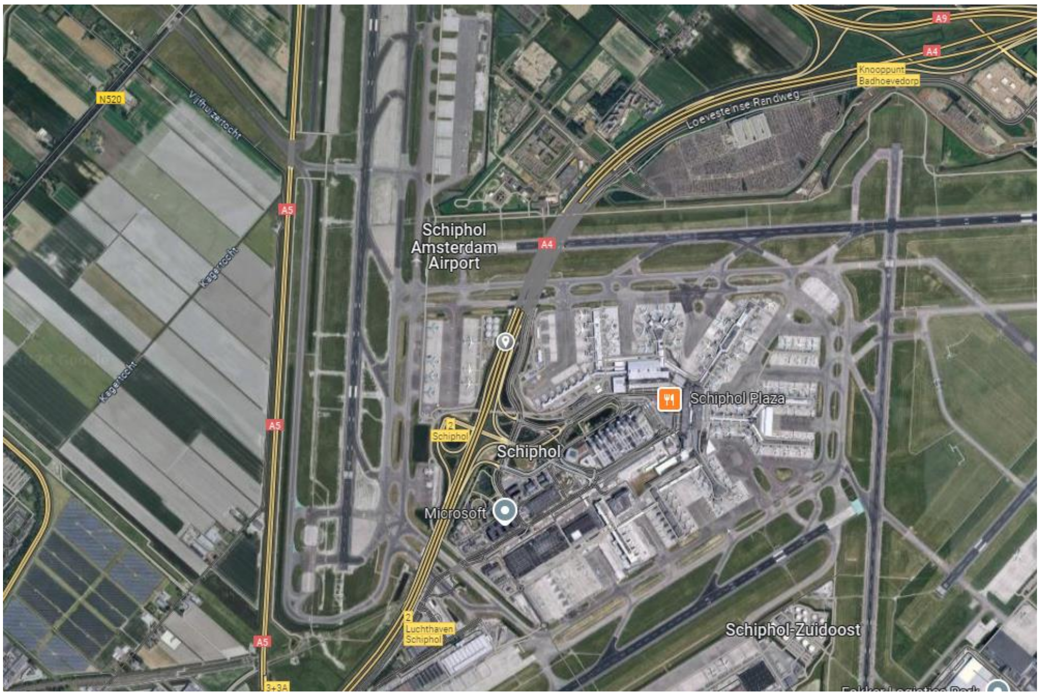


Figure 5.5 Location of gate at Schiphol Airport.

Moerdijk Zijdelijke randweg – one big portal with multiple cameras for monitoring of train wagons and brake detection, see Figure 5.6.

Figure 5.6 Location of gate at Moerdijk Zijdelijke randweg, marked with a red circle.

Both Hogebrug and Schiphol are currently active for monitoring passenger trains and pantograph monitoring but will in the future also be usable for freight train monitoring. Recently Videogates near the Hemtunnel and close to Zwolle are placed. These four IVG's are for inspecting passenger trains at the mainline. The Videogates for passenger trains are used for image recognition of pantograph defects, pantograph carbon strip wear and wheel defects (missing bolts, loose cables).

Moreover, two Videogates for freight trains are operational near the Port of Rotterdam at the “Havenspoorlijn” mainline. These Videogates are used for number recognition and wagon counting to check the wagon lists.

5.3.2. Characteristics

In Moerdijk (see Figure 5.6, Figure 5.7 and Figure 5.8) ProRail has a monitoring platform build together with the Port of Moerdijk. For ProRail it is an opportunity for monitoring train brake systems (overheating, stuck brakes, worn down brake systems etc) and monitoring wagons. For the wagons ProRail aims at building up systems that can recognize UIC numbers and identifying damages with video and image data. The video and image data can be, and already is used by AI programs by Twente University to detect both UIC numbers and Placards.

ProRail is using the IVGs for wagon number/wagon load recognition and administration (wagon numbers and cargo information), maintenance and damage detection of the brake-blocks of trains and of the pantographs with image recognition. Together with NS (the Dutch Railways), ProRail has developed a vision on Wayside Train Monitoring Systems (WTMS) in which ProRail test and develops a system for wheel profile measurements and acoustical camera's for recognizing wheel and bearing defects.

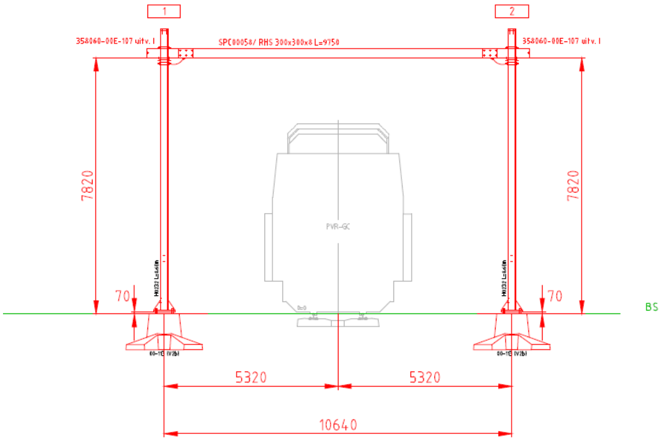


Figure 5.7 Sizing of IVG at Moerdijk

Figure 5.8 Photos of the IVG at Moerdijk

5.3.3. Participants

The construction of the Video-Gates started with the project Wayside train monitoring together with Port of Moerdijk (havenbedrijf Moerdijk). Financial costs were shared between ProRail and Port of Moerdijk. Data was shared and used by both parties.

NS (the Dutch Railways) is the owner of the portals at Hogebrug, Hoofddorp, Zwolle and the Hemtunnel, and uses IVG to predict and plan the maintenance of their passenger trains. ProRail has cameras attached at the portals at Hogebrug and Hemtunnel to detect carbon strip wear and damaged pantographs that can harm the overhead wire.

5.4. Railway Checkpoints in Sweden

5.4.1. Locations

In Sweden there is one IVG-gate installed in Sannegården, Gothenburg, about ten minutes by train from the port, see Figure 5.9. At the site there is a single track and a maximum speed of 70 km/h. The number of train passages is around 50 per day. Only freight trains operate on the line. The data captured here are mainly intermodal wagons on their way to or from the port.

The gate was commissioned in the summer of 2020. Since its installation, the gate's image recognition has been improved and is now operating at an acceptable level, but there are still improvements to be made.

Figure 5.9 Installed gate at Sannegården

The other IVG is planned to be situated in the south, close to the Öresund bridge on the main line, see Figure 5.10. Here, there are a double track and branch line for turnarounds of regional trains in the Malmö region. At this site all freight trains passing to or from Denmark/Germany will be detected. Also, some regional passenger trains can be detected as an option. The planning to date is civil works, technical installations next spring and fine tuning and commissioning early autumn 2025.

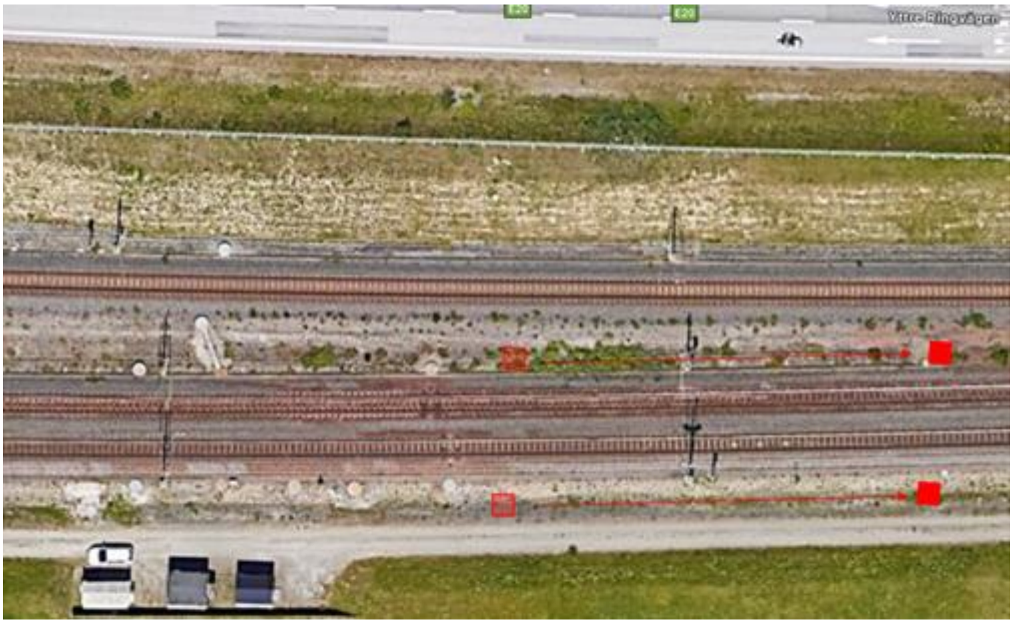


Figure 5.10 Illustration planned site at Svågertorp, Malmö.

5.4.2. Characteristics

The main purpose of the Swedish IVG-gates is to capture data for logistic reasons. A lower camera will be tested during the project to test capturing potential or real damages on the running gear area.

The gate consists of one or two towers, depending on single track or double, equipped with linear cameras and illumination. The images from the linear cameras are set together in a technical cabinet close by. The image analysis is done in a server in a shelter on site. The system will be integrated into Trafikverket's data servers and inside the firewall. All data processing will then be performed inside Trafikverket. The project partners can reach the images via Detector-PC (DPC).

The logistic data from the gates will be:

- Time stamp
- Train no
- EVN (European Vehicle Number)
- ISO container including BIC and ILU codes
- Tank container
- Trailer
- Swap body
- Dangerous goods 4-digit no from orange plate – *the commodity*
- Which wagon carries which container/swap/trailer

More items are under discussion and might be read, e.g. empty wagons. The intention is also to try to read hinterland marks on container.

The data produced inside Trafikverket will follow the Electronic Product Code Information Services (EPCIS) format. Standardised by GS1 (https://www.gs1.org/) and used in European RFID in Rail data exchange. And that format is also what Trafikverket aims to communicate with if possible. The format can easily be extended with new objects. Trafikverket has today some 400 RFID-readers installed among the tracks. Half of them are sensor stations where for instance hotbox and wheel damages are captured and warnings can be sent to rail operators via TMS.

Figure 5.11 is an illustration of how the data are processed through Trafikverket from RFID today. The IVG-gate will follow the same stream and will thus have access to the same cybersecurity and front-end-solutions as RFID. The interfaces to the stakeholders are well known and the adaptation for the stakeholders are easy.

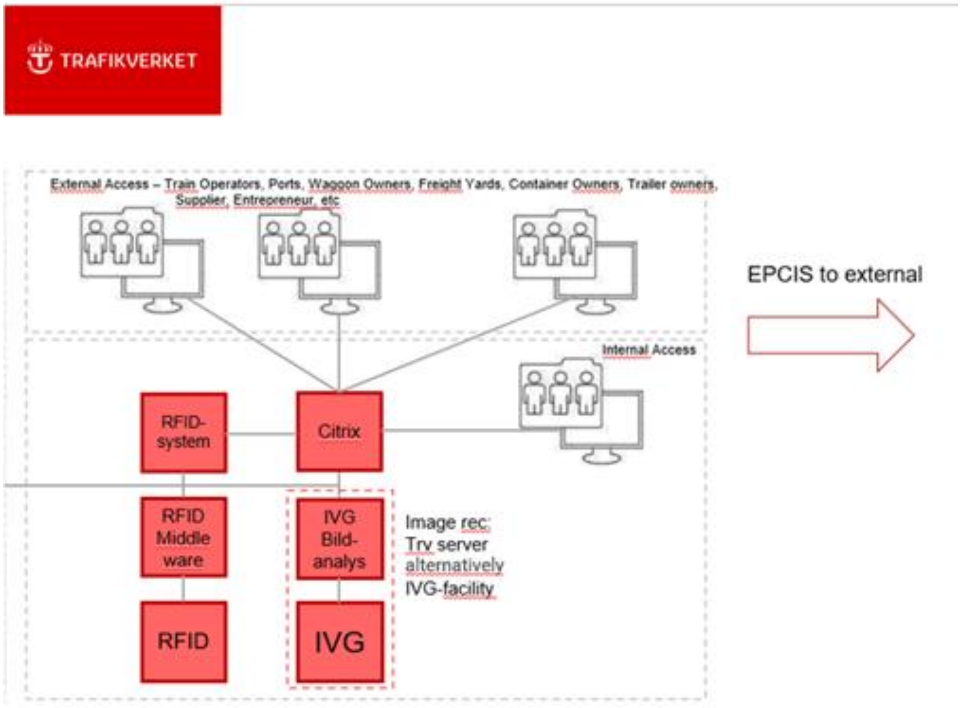


Figure 5.11 Processes of RFID data at Trafikverket today

5.4.3. Participants

The main project partners are Indra and Hitachi STS developing the Swedish gates. Hitachi for the technical solution and Indra for the image recognition. RISE is also an important participant dealing with data sharing to others. The port of Gothenburg and rail operators are involved.

5.5. Railway Checkpoints in Germany

5.5.1. Locations

DB Cargo has installed 13 IVGs in Germany. They are located at 8 different locations, see map in Figure 5.12. The IVGs are installed on the marshalling hump.

Figure 5.12 Locations of DB cargo's IVGs installed in Germany

5.5.2. Characteristics

With the help of nine cameras, the wagon is photographed from seven different perspectives. Line-Scan cameras are used for the sides and above, each of which photographs an image vector. By assembling the vectors, a complete picture of the wagon is created. The construction and image examples are shown in Figure 5.13. Using artificial intelligence, the UIC number of the freight wagons is detected by optical character recognition. In addition, RFID scanners are located next to the IVG, which are used as a second level of recognition for the UIC of the wagon. The passing freight wagons pass the IVGs at a speed of 0–20 km/h.

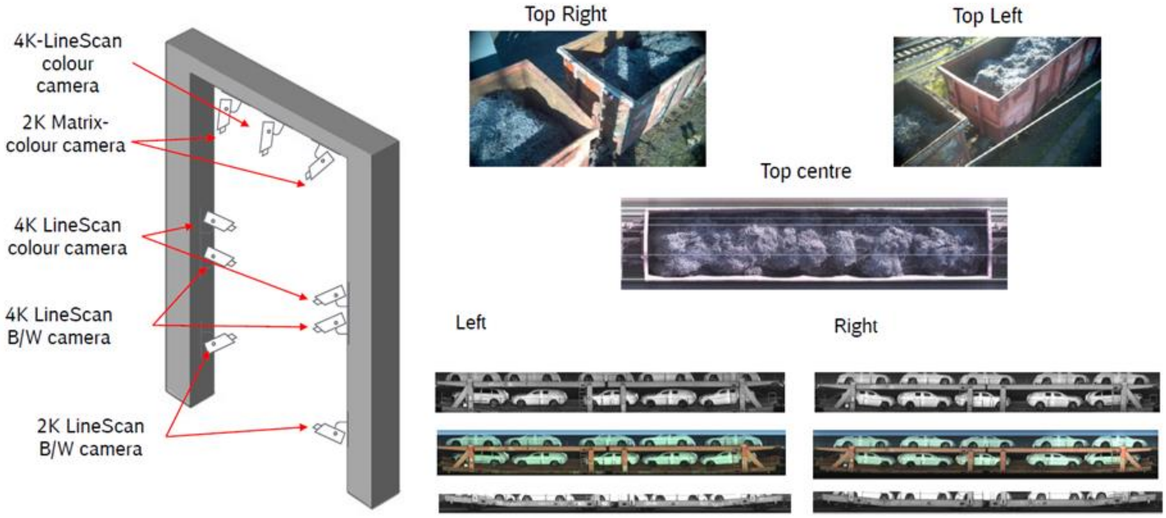


Figure 5.13 Standardized IVG of DB Cargo installed at 13 locations in Germany

The captured images of the freight wagons from the Videogates will then be analysed automatically as part of the data analysis using Artificial Intelligence (AI) in order to record the current condition of the freight wagons and identify any deviations from the standard condition. Therefore, the development of AI models is necessary.

5.5.3. Participants

The construction of the Videogates started with the project of Shift2Rail Fr8Rail III – WP3. During this project a first IVG at Nuremberg was tested and optimized. Afterwards DB built 12 more IVGs on the biggest marshalling yards in Germany. The whole construction phase was in cooperation with DB Netz (DB InfraGo) and the supplier LMT/Visy.

5.6. Railway checkpoints in Austria

5.6.1. Locations

ÖBB Infrastructure AG has installed more than 50 IVGs (ZLCP) in Austria, see map in Figure 5.14. In addition, there are more than 150 systems with HBD (*Hot Box Detection)*, HWD (*Hot Wheel Detection*) and derailment detectors.

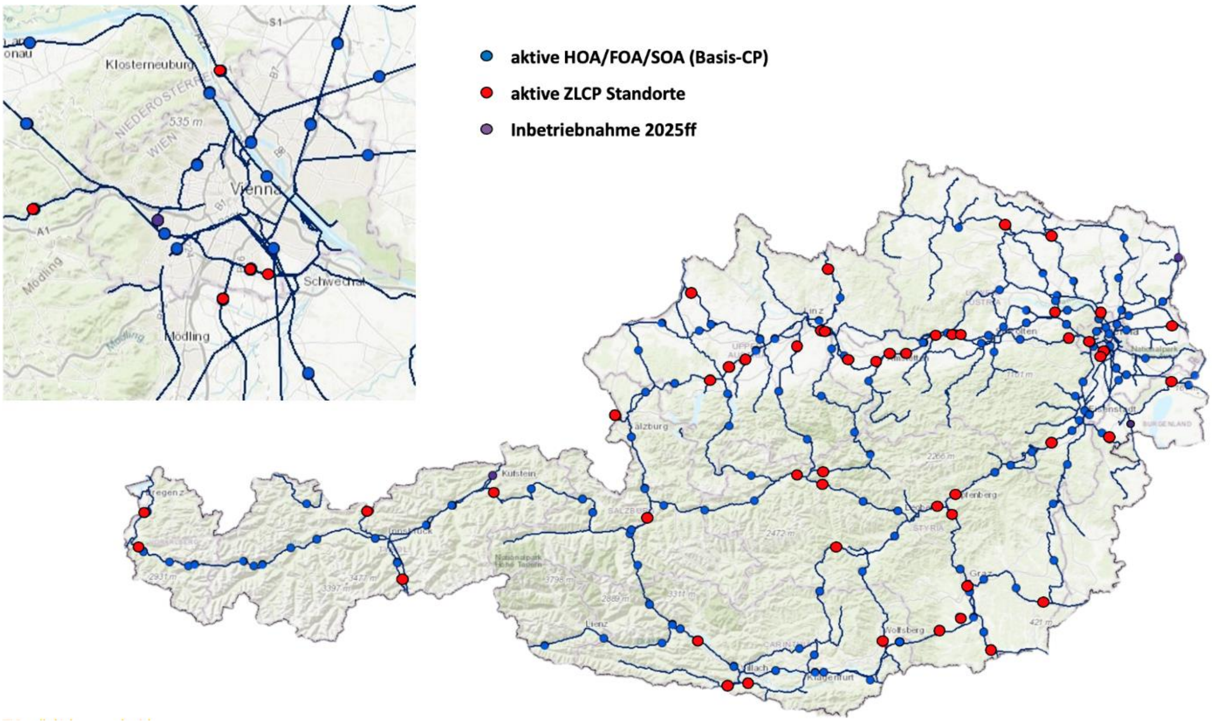


Figure 5.14 Location of gates installed by ÖBB Infrastructure AG in Austria

5.6.2. Characteristics

ÖBB Infrastructure has established a so-called vehicle fingerprint. The goal of ÖBB´s fingerprint is to optimise the maintenance of the rolling stock of different Railway Undertaking (RU)/Vehicle Keeper (VK). ÖBB Infrastructures WTMS measuring devices observe rail vehicles automatically and contact-free during operation.

With this analysis data, it is possible to reach technically improved maintenance of wheelsets. A large number of sensors and measuring systems along the railway lines permanently record the condition and running behaviour of vehicles during operation. Running gears are observed and checked for physical characteristics when passing at operational speed. With this data, maintenance measures can be optimally planned and therefore costs can be reduced.

The following benefits for RU and VK are provided:

- Monitoring during operation with speed up to 250 km/h
- Measurement data down to the level of individual wheelsets using RFID technology
- Early diagnosis of wheel damage without taking the vehicle out of service
- Condition-oriented wheelset maintenance
- High availability of rolling stocks

The service portfolio includes:

- Wheel out-of-roundness measurements including polar diagrams of the wheel shape
- Weekly reports of the last measured values
- Trendline of the maximum wheel roundness deviation (last 100 days)

Necessary requirements:

- Vehicle is equipped with RFID tags (Radio Frequency Identification) in accordance to EN 17230 for unique identification of the wheels. RFID readers are installed at the gates but handheld devices can also be used for detection of RFID tags.
- Concluded "vehicle fingerprint" licence agreement
- Order form for the respective vehicle

The data is provided with a push API directly to the RU and the data format is JSON.

The RU can also get following data:

- Data from wheel force measuring system (RMA)
- Hot axle box (HOA)
- Information on train composition
- Wheel loads
- Dynamic forces
- Axle bearing temperatures
- Brake disc temperature
- Fixed brake temperature
- etc.

5.6.3. Participants

ÖBB Infrastructure build this wayside monitoring system to protect their infrastructure and to provide critical train information to the RU. The main supplier for this system is VOEST Alpine.

5.7. Wayside and On-board Monitoring

Different demonstrators are ongoing and planned in different countries and locations in Europe as presented in previous sections, with varying emphasis on different operational procedures and use cases and hence different functionalities and technologies are incorporated. In this section technologies that are incorporated in the demonstrators are presented for wayside and on-board monitoring.

5.7.1. Wayside Monitoring - Overview Map

The demonstrator scenarios described in Chapter 5.8 represent a variety of possible routes. The central aim is to demonstrate the IVGs set up in practice. DB Cargo has drawn up an overview map to support this planning and to utilise possible synergies. Among other things, this map shows the IVGs in Europe, see example in Figure 5.15. Other Wayside monitoring systems are also integrated. Subsequently, the use and presentation is explained. The map was created on the ‘ArgGIS’ website and is accessible to all participants in Europe's Rail. So far, systems from Germany, France, Austria, Spain, the Netherlands, Switzerland and Sweden have been added. Further information can be added by DBC at any time.

Figure 5.15 Excerpt - Overview interactive WMS-map for Wayside-System in Europe

The identified wayside monitoring systems are shown by the black arrows. The rail network is represented by fine orange lines. Clicking on the arrows shows the type of system installed and the name of the location.

An analysis shows which areas of a freight wagon can be inspected with the installed Wayside monitoring systems.

5.7.2. Wayside detectors for the Swedish demonstrator

Trafikverket has currently (last update 2022-11-23) 178 wayside detectors dispatched along the railway network, see Figure 5.16. The network is composed of 3 main systems: Hot-Box/Hot wheels detectors, Wheel Impact Load detectors and Bearing Acoustics Monitors. The number of detector units is distributed as follows:

- SERVO/SATT, Hot-box/Hot-wheel detectors, 5 units
- FUES I, FUES II, FUES II+, Hot-box/Hot-wheel detectors, 23+55+31=109 units
- PHOENIX HB/HW, Hot-box/Hot-wheel detectors, 30 units
- PHOENIX WDD/WIM, Wheel Impact Load detector, 4 units
- Multirail SCHENCK, Wheel Impact Load detector, 26 units
- RailBAM, Bearing Acoustic Monitor, 4 units

Moreover, RFID readers are placed at each detector position in addition to the RFID readers placed on other strategic positions. With the help of the RFID reading, detector readings and alarms are connected to the right vehicle. The data generated from the different wayside systems is then gathered in Trafikverket's data management system for wayside monitoring called DPC III (DPC stands for Detector-PC). The gathered data is composed of general information about the passing train as well as common information related to the status of the wagons (wheel, axles, bearings) for detectors of the same type (i.e. HB/HW, Wheel Impact Load Detector [WILD] or Bearing Acoustic Monitor [BAM]).

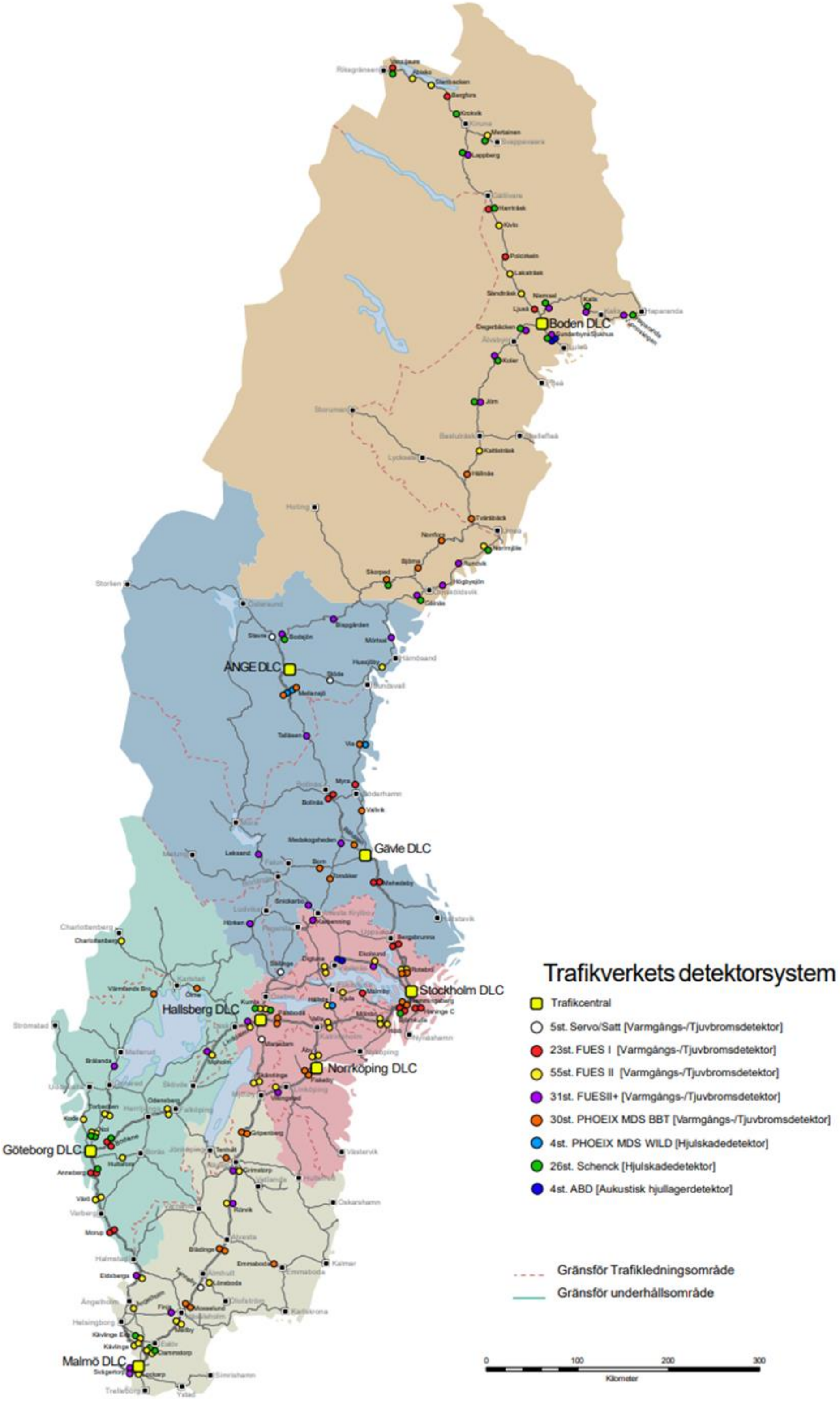


Figure 5.16 Swedish map of the location of the wayside monitoring systems

5.7.2.1. Short-term vision

To improve the automated inspections and transition towards a predictive approach for maintenance, the Infrastructure Managers must enhance the quality and quantity of data that should be shared between various stakeholders. To do so, the following actions should be taken:

- Improve the quality of the data and features extracted from each detector and assess the condition of the detector over time using basic statistical analysis. This analysis can be done inside the Wayside Management Database. This will enable better prediction and confidence interval for maintenance actions, as well as understanding why certain detectors deviate from their original behaviour and understand when they need re-calibration. The quality of the detectors can be verified by quantifying the deviations of the distributions at various locations using statistical features such as mean, spread, skewness or other relevant features.
- Update the wayside network with sensors that will allow an earlier detection of defect and remove older sensors with low accuracy and large spread in the data. For instance, it can be beneficial to use more Acoustic Monitors along the railway line at strategic positions.
- Combine information from the IVG for logistics with the wayside monitoring. For instance, a train transporting dangerous goods should have a clear indication if any abnormalities have occurred to any of the bearings or wheels. Specific rules could be made for different hazardous and non-hazardous transport.
- Develop the current IVG used for logistics towards fault detection using image-based analysis. Integrate the IVG data for automated inspection/condition monitoring with the wayside monitoring data to elevate the level of confidence of fault detection.

Some of the mentioned actions already have been implemented (such as the implementation of statistical analysis of various detectors from the Infrastructure Manager), while others may need a longer time before being initiated (for instance combination of IVG with other wayside systems).

5.7.2.2. Assessment of wheel impact load detectors

5.7.2.2.1. Wheel impact load detectors and regulations

Wheel flats and other types of wheel out-of-roundness can be detected by measurements of vertical wheel–rail contact force in wheel impact load detectors (WILDs). In this way, condition monitoring of measured force levels provides operators with information on the status of their wheel fleet. Various types of sensors have been deployed in commercial wayside WILD systems for indirect measurement of wheel–rail contact force. This includes strain gauge load circuits and fibre optic sensing technology for measurements of rail bending, and load cells for measurement of rail seat loads.

WILDs are typically placed on a tangent track with concrete sleepers on premium ballast and well-compacted subgrade to reduce dynamic wheel load variation due to irregularities in track geometry and sleeper support conditions. Trafikverket specifies regulations in terms of maximum track irregularities along the detector (gauge, cross level and twist), maximum sleeper deflection, and dynamic strength of the foundation. Further, there should be no curves, transition curves, switches & crossings, viaducts, severe rail surface irregularities (such as corrugation or squats), rail joints or broken sleepers within a distance of at least 150 m on either side of the detector. Regular monitoring (and rectification) of track geometry and calibration of the detectors are key for accurate measurements. In Sweden, around 30 WILDs are distributed across the country with a higher representation in the north. Most of these detectors are currently based on the measurement of rail seat loads.

Based on post-processing of the measured signals, the detectors provide information about the mean load and peak load generated by each passing wheel. The dynamic load contribution and the ratio are also evaluated. The dynamic load is the difference between the peak load and the mean load, while the ratio is the peak load divided by the mean load. The peak load is useful for operations with high axle loads to control that the wheels do not induce loads that could damage the track, while the ratio is mainly applied for unloaded wagons to detect wheel damage that could become harmful when the wagon has been loaded.

To prevent unacceptable deterioration levels and safety-related failures, alarm limits are prescribed. The UIC recommended alarm limit for peak load mandates an immediate stop of the train if the peak wheel–rail contact force exceeds 350 kN, with an alert level at 300 kN. The regulations (Asplund 2023) applied by Trafikverket can be distinguished into 'high' and 'warning' alarm levels:

- For a passenger coach or a freight wagon, the 'high' alarm level is 350 kN. If this level is exceeded, the train may continue at reduced speed to the nearest passing siding where the vehicle with the wheel tread damage must be decoupled from the train (Trafikverket, 2021).
- For locomotives, the 'high' alarm level is 425 kN.
- If a locomotive wheel generates a peak load exceeding 350 kN and the ambient air temperature is below -10 C°, train speeds in the interval 15 – 45 km/h should be avoided (Asplund 2023). 'Warning' levels are set at 280 kN (peak load), 180 kN (dynamic load) and 4.8 (ratio) independent of vehicle type.
- If the measured peak load, dynamic load or ratio exceeds a 'warning' level (but not the peak load 350 kN), cf. blue line in Figure 5.17, the train may continue without regulations to its destination. From there it is not allowed to continue operating

until the wheel has been rectified and approved by certified staff. This regulation holds unless it is found that the length of the wheel tread damage exceeds 60 mm.

5.7.2.2.2. Analysis of wheel impact load detector data

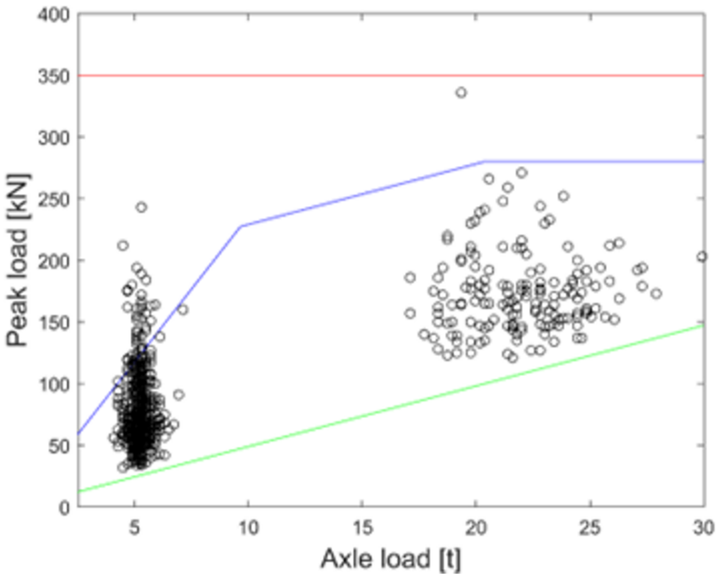
An analysis has been carried out by extracting data from six WILDs that are positioned between Luleå and Borlänge along the route for the so-called *Stålpendeln* (Mattsson, 2023). All these WILDs are of the same brand and are based on load cells for measurement of rail seat load. The maximum allowed axle load on the line is 25 tonnes. Data from the detectors were collected from December 2022 to March 2023.

The analysis started by examining a document containing information about wheel replacements in the workshop in Luleå. The document included information about when and for what reason a wheel was replaced. If the reason for replacement was a wheel flat, the length of the non-rounded part of the wheel flat had been measured in the workshop before wheel turning. As measurement of wheel flat length is notoriously difficult, flat lengths had generally been rounded up to the nearest 5 millimetres. For each detected wheel flat, data from the six WILDs was compiled for the corresponding wagons and the studied time period. In total, 823 detector passings by 149 different wheelsets (with at least one of the wheels on the axle being defective) were included in the analysis.

All data from passages at train speeds below 40 km/h were filtered out since the RFID tag used for identifying wheelsets was not considered accurate for those speeds. Only the highest peak load per axle and detector passage was included in the analysis. The wagons in the analysis were either loaded or unloaded. The analysis of unloaded wagons consisted of wagons with axle loads in the interval 4.5 – 6 tons and speeds between 69 and 120 km/h. The number of detector passages with unloaded wagons was 645. The loaded wagons, on the other hand, had a range of axle loads between 17 and 25 tonnes and speeds in the interval 64 – 90 km/h. The number of detector passages for the loaded cases was 159. Figure 5.17 illustrates a summary of peak loads for all detector passages included in the analysis. The blue line indicates the warning levels issued by Trafikverket. It is observed that most warning alarms were set off for unloaded wagons in the form of ratio alarms for wagons with axle loads of around 5 tonnes.

For different intervals of wheel flat length, and for loaded and unloaded wagons, the influence of train speed on measured peak loads has been investigated, see (Mattsson, 2023) and (Mattsson et al., 2024). A large scatter in measured loads was observed. Based on these measurements, no evident increase in peak load with increasing train speed for any of the wheel flat length intervals could be found. However, an expected trend indicating higher peak loads with increasing flat length could be distinguished.

There are several potential reasons for the large spread in the data. One reason could be differences in lateral wheel contact position relative to the position of the wheel flat while passing over the different detectors. For example, in one detector the contact position on the wheel might have been well aligned with the centre of the flat (with the maximum depth), while in another detector the wheel–rail contact might have occurred towards (or even outside of) the inner or outer edges of the flat. Based on simulation, it can be shown (not shown here) that the significance of wheel flat depth on the generated impact load is larger than the corresponding significance of flat length. However, the measured wheel flats may have had rounded edges, and the depths of the flats are unknown (although a geometric relation between length and depth of a new wheel flat without rounded edges can be assumed based on the chord theorem). Other reasons could be related to differences in the position within a sleeper bay (different track stiffnesses) where the flats made impact with the rail. Differences in wheelset design, wheel radius and unsprung wheelset mass, as well as variation in track stiffness between different detectors and irregularities in track geometry, are other factors contributing to the scatter in data.



The red line is the 'high' alarm at 350 kN.
The blue line indicates warning levels set by Trafikverket in terms of ratio (axle loads up to 10 tonnes), dynamic load (axle loads in the interval 10 – 20 tonnes) and peak load.
The green line illustrates the relation between mean load and axle load.

Figure 5.17 Influence of axle load [tonnes] on measured peak load for all 823 analysed detector passages. From Mattsson (2023).

5.7.2.2.3. Detector time history for a given wheel flat

For a given 75 mm wheel flat, all registered peak loads and mean loads in six different WILDs along the route of *Stålpendeln* have been studied, see Figure 5.18. The presented data covers the period from when the flat had recently been generated until the wheelset was taken out of service for repair. Two journeys in loaded conditions and three journeys in tare conditions are considered. A large variation in measured loads between different detectors during a given journey is observed. Further, a clear pattern in how the detectors measured relative to each other is noted, see for example differences in data from the detectors at Degerbäcken and Skorped. This indicates that besides the variation in speed and other influencing variables, the condition of the detectors might have affected the measured loads. The time since calibration, and measurement accuracy, may vary between individual detectors. In particular it may be argued that the ability of the detectors to measure high-frequency impact loads is uncertain.

In parallel, track foundation stiffness and track irregularities in the detectors along the route of *Stålpendeln* have been measured by track recording cars, see Figure 5.19 and Figure 5.20. For the WILD at Degerbäcken, it was found that measured vertical track stiffness is relatively uniform and that the track geometry is within the proposed tolerance limits. On the other hand, it is observed that the WILD at Skorped has irregularities within the detector area both in terms of track stiffness and track geometry, which could affect the vehicle dynamics while passing through the detector. In summary, the calibration of the detectors, as well as the measured variations in track stiffness and track geometry at the detector sites might have contributed to the scatter in measured peak loads.

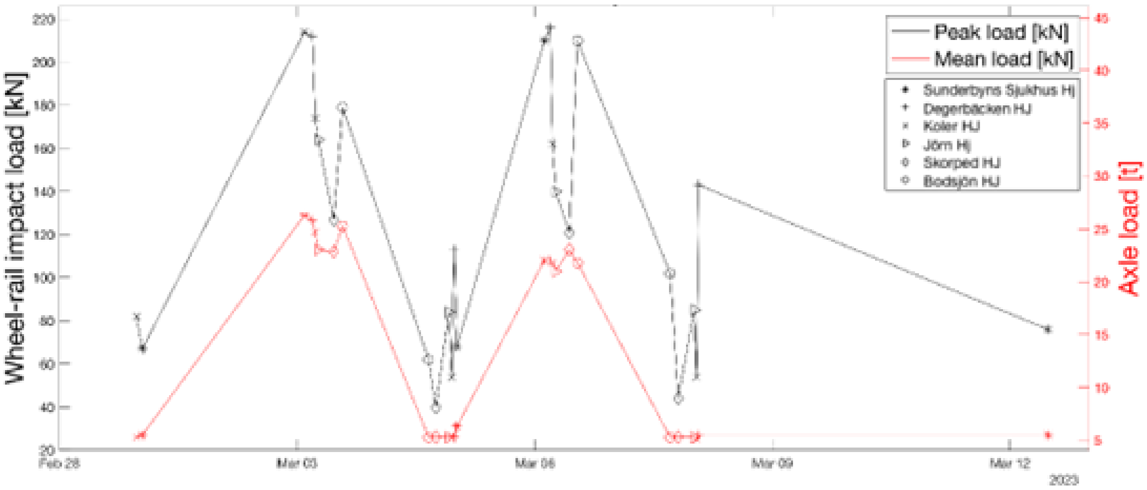
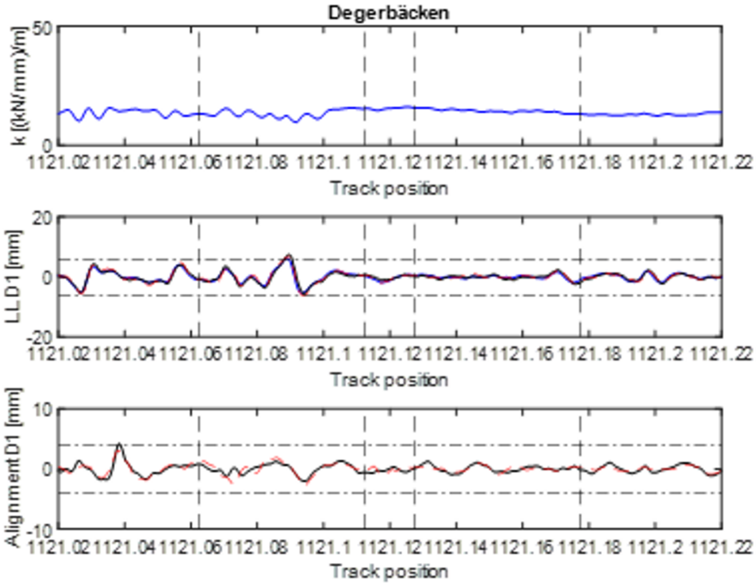
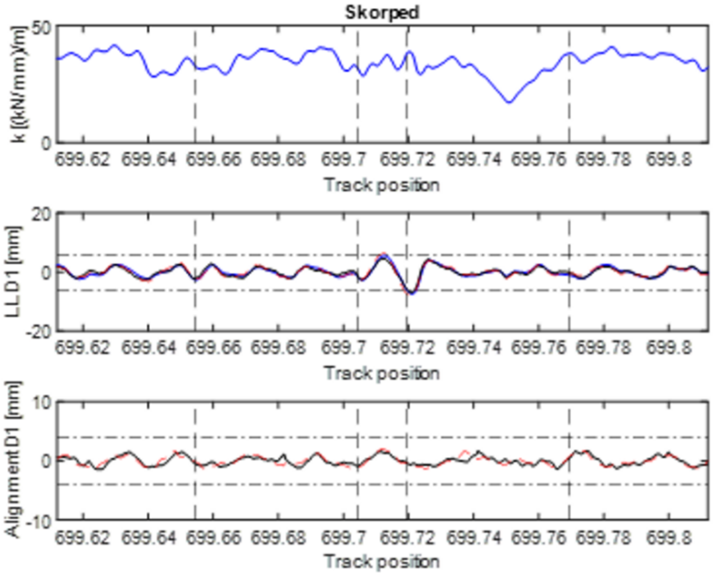


Figure 5.18 Peak loads and axle loads for one given wheel flat with length 75 mm measured in six WILDs along the route of Stålpendeln. From Mattsson (2023).



Blue curves were measured on 2022-06-07. Black (left rail) and red (right) curves were measured on 2023-05-31. The inner pair of vertical lines indicates detector area 1 (15 m), while the outer pair of vertical lines indicates detector area 2 (50 m on either side of detector area 1). Horizontal dash-dotted lines indicate suggested tolerances in terms of planned maintenance for tracks with maximum allowed speed up to 160 km/h.

Figure 5.19 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment (1 – 25 m) measured over a distance of 200 m in the WILD at Degerbäcken. From Mattsson et al. (2024).



Blue curves: 2022-10-05.
Black and red curves: 2023-08-13.

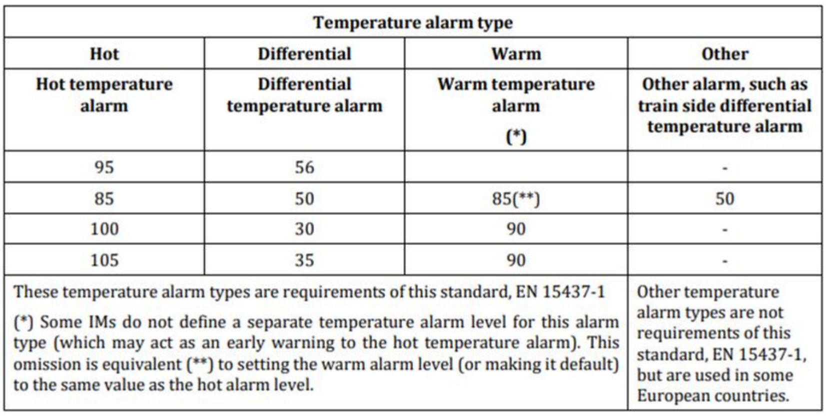
Figure 5.20 Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Skorped. From Mattsson et al. (2024).

5.7.2.2.4. Conclusions

The critical assessment of WILDs carried out in this work underlines that detector data needs to be reliable with a robust and transparent procedure for calibration and post-processing of data. To this end, detectors need to be calibrated regularly. A calibration of mean (quasi-static) load can be employed based on passages of axles with known axle loads (typically a fleet of locomotives) at low speed. The calibration of the dynamic load is more cumbersome as it can be expected that the detector measurements are dependent on the frequency contents of the load, load magnitude, temperature, etc. The calibration should be based on the traffic on the line (axle load, speed, passenger/freight etc.). Further, as illustrated in Figure 5.19 and Figure 5.20, irregularities in track geometry and track stiffness should be monitored and rectified.

5.7.2.3. Hot-box/Hot-wheel detectors

Classical hot-box/hot-wheel detectors perform condition checks of the passing railway vehicles, giving information about the state of the bearings with regard to their temperature. However, when a train passes by a detector, the value of each bearing temperature is compared with predefined static thresholds.



Temperature alarm type			
Hot	**Differential**	**Warm**	**Other**
Hot temperature alarm	**Differential temperature alarm**	**Warm temperature alarm (*)**	**Other alarm, such as train side differential temperature alarm**
95	56		-
85	50	85(**)	50
100	30	90	-
105	35	90	-
These temperature alarm types are requirements of this standard, EN 15437-1 (*) Some IMs do not define a separate temperature alarm level for this alarm type (which may act as an early warning to the hot temperature alarm). This omission is equivalent (**) to setting the warm alarm level (or making it default) to the same value as the hot alarm level.			Other temperature alarm types are not requirements of this standard, EN 15437-1, but are used in some European countries.

Figure 5.21 Examples of temperature alarm levels from EN 15437-1:2009

Depending on the level of this threshold (Figure 5.21), actions are specified to the driver to either stop the vehicle to a specified location or continue its route with a maximum allowable speed. Hence the HB systems are used more as inspection systems rather than condition monitoring systems.

To improve the usage of these systems and transition towards condition monitoring, the wayside data must be re-organized and re-defined to extract information related to the operation or condition of the bearings/brakes. The most natural way to re-organize the data is to split the data wagon-wise based on the wagon RFID number. The data from the HB/HW can be retrieved from the specific tag number and ordered with the timestamp. Moreover, each individual wheelset should be re-ordered from the first to last wheel to ensure following the correct axle through multiples trips.

To visualize the data from the HB detectors, a conceptual plot from the wheel temperatures from each axle as function of time (or detector passage) and sub-divided in travel numbers is displayed in Figure 5.22. To observe anomalies related to the condition of the bearings, it can be assumed that the time-signatures of each wagon wheel will follow the same behaviour under normal operating condition, which will serve as the main hypothesis.

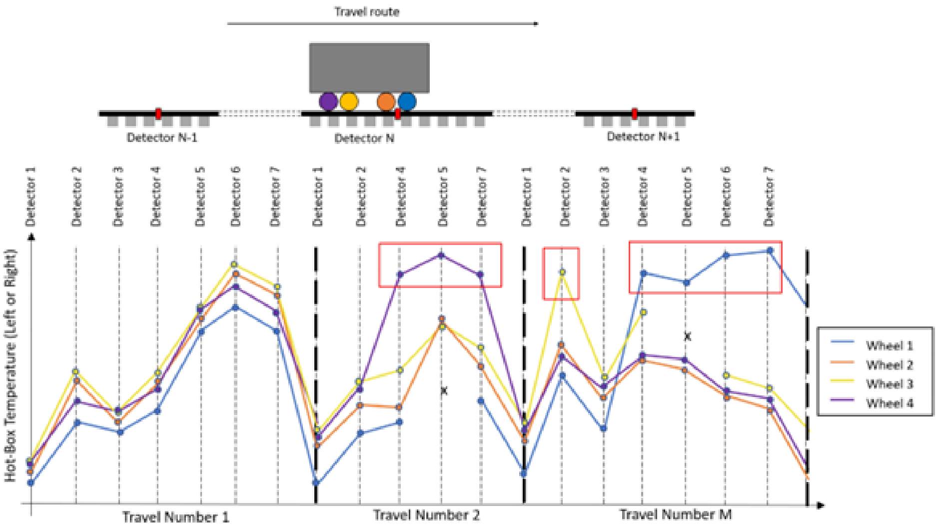


Figure 5.22 Overview of the data arranged in specific time-signatures for a specific wagon.

For the operators, the main goal of using the time-signatures is to extract information related to the status of the bearings. Although it can be tedious to understand with what the change of behaviour is related to, finding anomalies in the time signatures from Figure 5.23 could help optimize the maintenance actions by flagging suspicious bearings that start to deviate from their normal operating conditions.

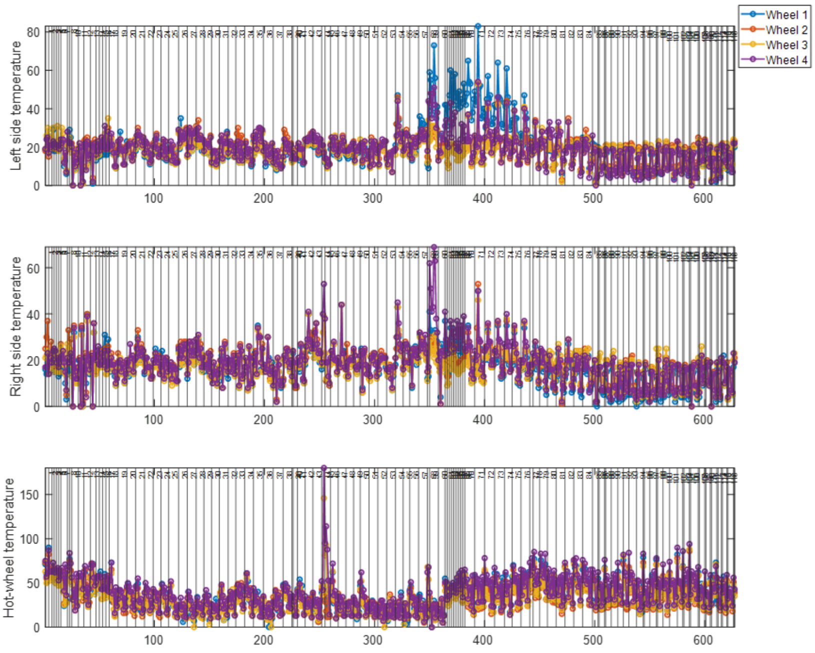


Figure 5.23 Example of anomalies that appear for the same wagon type.

To gain a bit more insight of all the anomaly types that can occur in time signatures, some classical examples of anomalies observed for the same wagon type are displayed in Figure 5.24.

- In case (a), there is a strong change of behaviour of wheel 3 and 4 in comparison to wheel 1 and 2 in terms of signature, maximum value and spread. This behaviour should be flagged as an obvious anomaly. However, after further investigation, it was observed that the Hot-wheel temperature displayed a strong increase from 50 to 250°C within 4 detector passages. Hence the wheel temperatures radiated from the wheels onto the axle-box, leading to a false anomaly (from the bearing perspective). This is a common issue with HW leaking on axle-boxes that could lead to false alarms.
- In case (b), wheel 1 shows a clear increase of temperature at the second and third passage but behaves normally afterwards. This is a type of anomaly that indicates a change of behaviour in the bearing which is not so common within the analysed data set. In addition, the reason behind this change of behaviour is unknown unless it could be correlated with on-board sensors.
- In case (c), the anomaly observed from wheel 1 is just an increase of the mean value over several days, but with the same signatures as for the other wheels. This is probably one of the most common anomalies observed in the test data.
- In case (d), the anomaly is similar to (c), but with a higher spread in the signature over the travel day. It is probably the second most occurring anomaly after type (c).

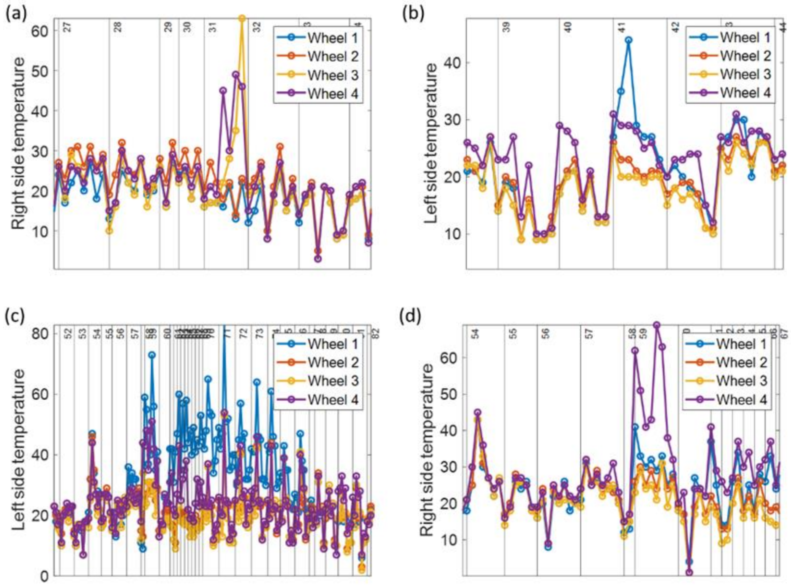


Figure 5.24 Example of anomalies that appear for the same wagon type.

Hence it could be relevant to explore further this concept and try to detect these anomalies in an automatic way. To increase further the understanding of these anomalies, a better communication between the various stakeholders of the railways industry (e.g. operators and infrastructure manager, but also maintenance companies) to help labelling the data and understand the deviations of the bearings during operation.

Instead of inferring limits on the temperatures as described in Figure 5.21, it could also be relevant to extract features related to the evolution of the temperature in relation to the train average to mitigate the environmental effects. It can be suggested to calculate the K-Values to each bearing in the wagon by comparing the bearing temperature with the train temperature on the same side as follows:

$$K_b = \frac{(T_b - Q_{2t})}{(Q_{3t} - Q_{1t})}$$

Where T_b is the temperature of the bearing, Q_{1t}, Q_{2t} and Q_{3t} are the 1st quantile, median value and 3rd quantile of all the bearing on the same side of the train respectively. An increase of the K-Value of the bearing over a value of 2 could be considered as a Bearing-of-interest (BOI). An example of the K-Value is calculated the left side of the wagon shown in Figure 5.25. It shows than the condition of bearing 1 behaves abnormally from the detector passage 350 to 440 with a clear increase of the K-value in comparison to the other bearings on the same side of the wagon. Hence this bearing could be flagged as an anomaly and this information could be transferred to either the operator or the inspection/maintenance team in order to have a specific focus on this bearing when performing inspection tasks. However, the alarm level related to the K-value cannot be set as high as for the absolute temperature levels. It could be relevant to set the alarms on the K-value based on:

- The absolute value of the K-Value (K>threshold to be defined)
- The number of occurrences of a certain period of time, i.e. 10 occurrences over a one-week period

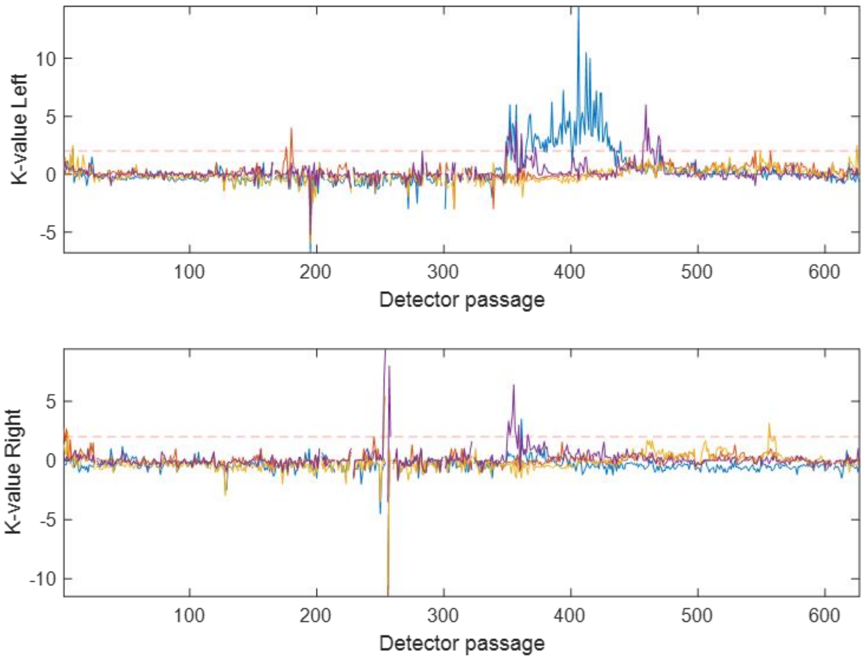


Figure 5.25 K-Value of the wagon bearing as function of the detector passage

Even though the K-value can be of interest to improve the inspection of wagons, some drawbacks must be discussed:

- Since the K-Values uses the difference between the 1st and 3rd quantiles on the same train side, a low variation of temperature on the same train side will tend to overestimate the K-Values. Hence it could be relevant to scale the K-Value with the temperature range.
- The calculations of the quantiles are performed for all wagons on the same side. However, not all the wagons are the same (locomotives, freight), meaning that there will be variation based on the wagon type and loads. Hence it would be more appropriate to compare with the wagons of the same type on the train.
- The change of gradient (increase of temperature over a travel day) cannot be observed with the K-Values alone. As a result, an extracted feature associated with the change of gradient could complement the K-values to describe the different types of anomalies
- The K-values do not give information about the root-cause of the changes in the behaviour of the bearing. Correlation between the HW detectors, the WILD detectors and/or the Acoustic Bearing Detectors could help identify the root cause of variations of bearing anomalies in specific cases.

One the short term, these anomalies detected from the HB/HW could support the Intelligent Videogates by transferring the information extracted from the HB/HW time signatures. For instance, information related to stuck brakes or bearing leakage could be send from the Wayside Monitoring Systems (WMS) to the IVG to correlate the information. On the long term, the hot-box detectors could also help create a life status index of the bearings that will help the operators identify bearings of interests and perform appropriate maintenance actions when their behaviour starts to deviate, but still within the limits of the detectors alarm common thresholds.

5.7.3. On-board sensors for the Spanish demonstrator

The sensor On-board the wagons are not attached to any specific location as the wagons will circulate entering and leaving the Spanish use case, around Can Tunis. However, the goal of this paragraph is to mention a complementary system which is bringing some useful data for the operations inside the terminal and from the events occurring in the mainline.

Physically, the On-board system proposed by CEIT consists of a set of Wagon On-board units (WOBU) and Sensor Nodes (shown in Figure 5.26) should be located in the appropriate spots of the wagons, as seen in Figure 5.27.

Figure 5.26 Wagon On Board unit (WOBU) and Sensor Node.

Figure 5.27. Location of a set of Wagon On-Board unit and sensors

Thanks to the support of RENFE and ADIF, certain needs have been identified by the various stakeholders involved in freight transport. The On-board system proposed by CEIT can cope with these issues. The features or functionalities that this On-board system can provide are related to the logistics and operation, wagon monitoring and cargo monitoring.

In order to carry out these functionalities, the system architecture shown in Figure 5.28 is proposed. Wireless Sensor Network (WSN) architecture is the most practical option for this type of application. Unlike wired alternatives, it allows for economical installations in remote and challenging environments. To address the diversity among stakeholder requirements, various network topologies can be used with this system. In this use case, we have considered a star network for the WSN within the wagon and another star network for communications among wagons and the locomotive/checkpoint.

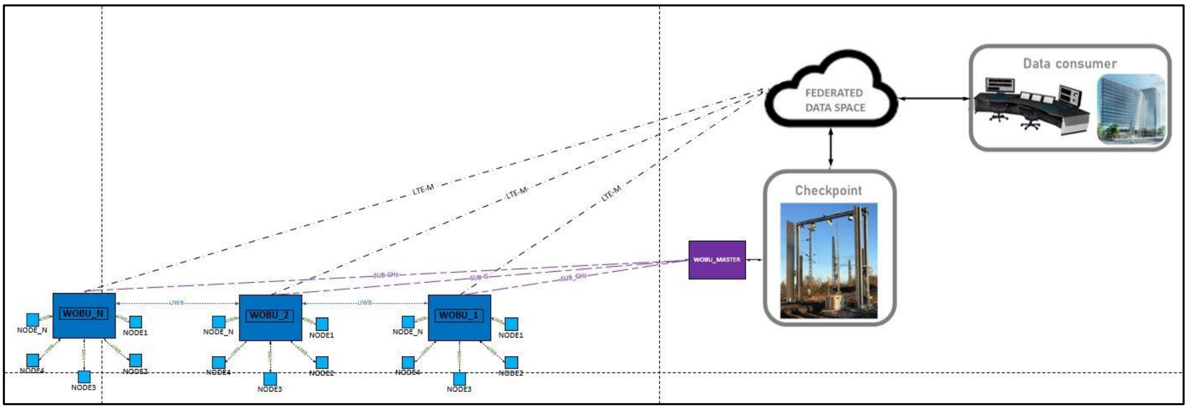


Figure 5.28 Proposed On-board system architecture

For communications inside the wagon, Impulse Radio Ultra-Wideband (IR-UWB) is considered the most viable technology for WSNs due to its high time-domain resolution, low power consumption, and cost-effectiveness. Additionally, its low-power spectral density allows UWB and narrowband systems to coexist. Moreover, this technology enables precise ranging estimations, allowing us to accurately determine the distance between nearby wagons.

For communications between wagons and the locomotive, a sub-Gigahertz wireless communication link has been implemented. This radio link provides a 16 km range, spread spectrum communication, and high interference immunity with minimal current consumption. Note that, by integrating a sub-Gigahertz receiver at the checkpoint, the data generated on each wagon can be received by the checkpoint.

Finally, when the checkpoint is not within the range achievable by the sub-Gigahertz link or there is no locomotive available, the data is sent by means of a Long-Term Evolution for Machines (LTE-M) technology. This way, the data can continuously be monitored by end users.

Each component installed on the wagon will have its own 2100 mAh battery, whose durability will depend on the duty cycle. This duty cycle is represented in Figure 5.29.

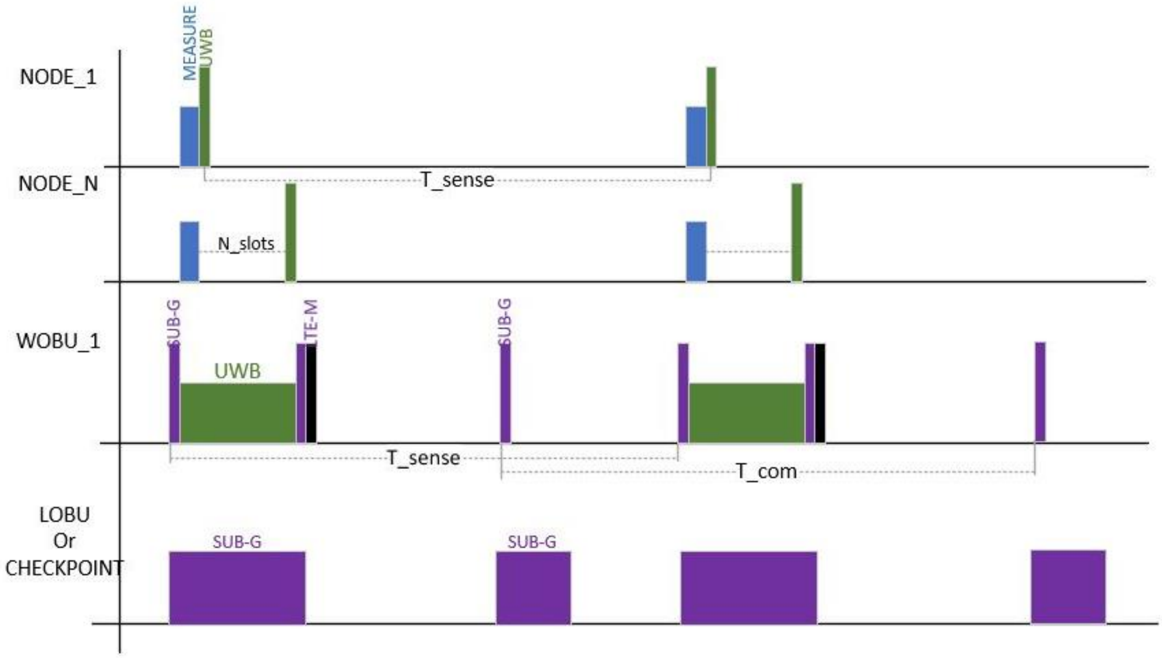


Figure 5.29 Operation mode of each component within the On-board system.

On one hand, each time T_{sense}, the Sensor Nodes will wake up, acquire data, process it, and transmit the operation results through UWB to the WOBU. Therefore, the WOBU must be awake in order to receive the data from all the Sensor Nodes within the wagon. Once the Sensor Node has finished transmitting, it returns to sleep mode. Similarly, when the WOBU has received data from all Sensor Nodes, it forwards the data to the locomotive/Checkpoint through sub-Gigahertz or to the cloud using LTE-M, and then returns to sleep mode.

On the other hand, each time T_{com}, the WOBU establishes communication with the Loco On-Board Unit (LOBU) to receive commands for reconfiguring Sensor Nodes or the WOBU itself, or to perform operations among wagons, such as Train Integrity or Train Composition.

The physical components within the On-board system are:

- **Sensor Node:** These are its main functionalities:
  Detection of Hot Axle.
  Detection of Blocked Brakes.
  Automatic Brake Test.
  Monitoring of container load.

- **WOBU (Wagon On-Board Unit):** These are its main functionalities:
  Manage the network of Sensor Nodes deployed in the wagons using UWB.
  Geolocation using GNSS (Global Navigation Satellite Systems).
  Localization between wagons using UWB.
  Train Composition.
  Train Integrity.
  Communicate with the LOBU system using the sub-Gigahertz link to configure and/or transmit the information generated by the elements of the wagon (WOBU or nodes).
- **WOBU_MASTER:** These are its main functionalities:
  Manage the network of WOBUs using the sub-Gigahertz link.
  Redirect all information generated in each wagon to the LOBU
  Redirect all requests generated in the LOBU to each WOBU.
- **LOBU (Loco On-Board Unit):** It is responsible for configuring the operating mode of each wagon, collecting the data sent by each WOBU, temporarily storing it, and sending it to a cloud database or tablet:
  Communication with each wagon is done via the sub-Gigahertz link.
  Data is sent to the cloud database using a communications modem (3G/4G).
  Data is sent to the tablet via WiFi.

Note that WOBU_Master and LOBU must be always powered on and thus they require to be supplied by an external power source.

5.7.3.1. Participants

CEIT, Renfe and Adif are collaborating together on the implementation of the OnBoard sensors within FP5-TRANS4M-R in WP29.

Adif's role within this demonstrator is to provide the infrastructure where the tests will be carried out. It will ensure the tracks it owns for the circulation of the train where the sensors are installed.

CEIT provides the technology and the protypes that compose the OnBoard sensors system. These elements could be transferred to an industrial partner and/or operator that could deploy and maintain the elements installed in the RENFE's wagons, trains and management system. RENFE, as operator is providing the physical location, participating in the validation and assessment.

5.8. Demonstration scenarios

The aim of the demonstration is to show the technological progress in the development of IVGs, checkpoints and comparable Wayside Monitoring Systems (WMS) on the European railway infrastructure. Against this background, the following requirements and risks were collected in workshops. Their assessments resulted in two demonstration scenarios, which are to be carried out in combination. They require the least planning effort and are the most financially favourable variants. In addition, they have low risks, as they enable a large coverage and there is a large selection of traffic that can be used for the demonstration.

5.8.1. Requirements

In this chapter, we outline the process of identifying the key requirements for the successful implementation of Intelligent Videogates (IVGs) in demonstration scenarios. These requirements were identified in several workshops and bilateral discussions with the partners of WP 29 and WP 25. The requirements address both technical and operational aspects, ensuring that the IVGs can meet the diverse needs of stakeholders involved in cross-border rail operations. By systematically identifying these requirements, the chapter provides a foundation for the design, deployment, and evaluation of IVG demonstrators, ensuring that they align with project objectives and real-world operational conditions. Table 5.2 shows the requirements for a demonstrator of IVGs.

Table 5.2 Requirements for the demonstration of IVGs

	Requirement	**Specification**
Mandatory	The developed use cases work	TRL 8 (in ER JU standard, see below) At least on the own infrastructure. (E.g. DB Cargos AI-Model that analyses bogies works on the German IVGs.) GA5 p.221
Mandatory	The construction of IVGs is completed	Every IVG that should be part of the demonstration, no matter if it's a prototype or complete version, regardless of the technology that the IVG consist of
Mandatory	Real-Time data is collected	The data that is generated by the IVG is immediately available for the intended use in the IT-Systems (has to be defined: 1 minute /30 minutes?)
Mandatory	Standardized data formats are used	e.g. images in JPEG or code in JSON to have comparable data GS1 RFID reader and tag communication
Mandatory	The KPIs that are to be improved have to be defined and can be monitored	e.g. staff cost (due to less inspection time), overall data accuracy / reliability
Should have	Q4 2025	The demonstration should take place during this time
Should have	Cross-border traffic should pass through relevant IVGs	Main concern here was connecting main line between France and Spain where an IVG is to be installed
Should have	Responsibility for the train on each route section is fixed	Who is responsible for train movements on which route section is regulated
Should have	All parties participating in Seamless are involved in the demonstration	
Should have	The collected data is comparable	e.g. the Cameras on the IVGs have the same angles
Should have	The train journey has a realistic story	The train should be as close to a regular traffic as possible. A Demonstration or Test train wouldn't represent real conditions.
Should have	On the route to Italy the "Mediterranean corridor" should be used	
Should have	Events are held at checkpoints to generate political and industry attention	
Should have	The IVGs can recognize whether the folding tops of e.g. Shimmns wagons are loose	

Should have	By passing the IVGs, train composition data is gathered and is comparable, UIC code is recorded when train passes IVG	
Should have	The GPS location data of the train is tracked and available	
Should have	Dangerous goods get identified and are marked in the train composition	
Should have	Integrate other WMS data	Hot Box, Derailing sensors, RFID tags
Should have	In Spain: the IVGs in Can Tunis and at the border with France are passed	
Should have	The IVG near Malmö is passed	

This table outlines a set of requirements for the successful implementation and demonstration of Intelligent Videogates (IVGs). The requirements are classified into two categories: Mandatory and Should Have. These classifications indicate the priority level of each requirement—Mandatory requirements are essential, while Should Have requirements are desirable but not critical for the project's success.

5.8.1.1. Mandatory Requirements

These are critical for the successful operation and demonstration of IVGs.

Use Cases Functionality (TRL 8 Standard):

The developed use cases must function at a Technology Readiness Level (TRL) of 8, meaning that the technology must be tested in its final form and under expected conditions (operational environment). This should be achieved at least on the infrastructure of the party developing the technology.

Completion of IVGs Construction:

All IVGs involved in the demonstration, whether they are prototypes or fully functional versions, must be completed. The technology used in these IVGs may vary, but every IVG must be ready for the demonstration.

Real-Time Data Collection*:*

Data generated by the IVGs must be immediately accessible in real-time for use in the relevant IT systems. The specific time frame for data availability needs to be defined (e.g., within 1 or 30 minutes).

Standardized Data Formats*:*

Data must be standardized, such as using JPEG for images and JSON for code, to ensure comparability across systems. GS1 standards for RFID reader and tag communication should be followed to enhance compatibility.

Defined KPIs (Key Performance Indicators)*:*

The KPIs for the demonstration must be clearly defined, and it must be possible to monitor them. KPIs may include metrics such as reduced staff costs due to less inspection time or improvements in data accuracy and reliability. KPIs in FA5 have been prepared within D1.5 and will be evaluated after demonstrators and addressed to in D1.6.

Should Have Requirements

These are desirable to enhance the quality of the demonstration but are not strictly necessary for it to take place.

Timeline (Q4 2025)*:*

The demonstration is ideally scheduled for Q4 2025.

Cross-Border Traffic*:*

IVGs should be installed and operational at key cross-border points.

Responsibility for Train Movements*:*

The parties responsible for train movements along different sections of the route must be clearly defined.

Involvement of All Project Participants*:*

All participants involved in the Seamless project should take part in the demonstration.

Comparable Data Collection*:*

Efforts should be made to ensure that data collected from different IVGs are comparable. For example, the camera angles of IVG cameras should be consistent across locations.

Realistic Train Journey:

The train journey should mimic real-world conditions as closely as possible, rather than using a purely test or demonstration train.

Mediterranean Corridor:

On the route to Italy, the "Mediterranean corridor" should be used.

Events at Checkpoints:

Checkpoints along the route should host events to generate political and industry attention, drawing interest to the demonstration.

Recognition of Wagon Components (e.g., Loose Folding Tops):

The IVGs should be capable of identifying if components of wagons, such as the folding tops on Shimmns wagons, are loose.

Train Composition Data:

The IVGs should gather and provide comparable data on the train composition, including the recording of UIC codes (unique identifiers for railway vehicles).

GPS Location Tracking:

The GPS location of the train should be tracked and made available.

Dangerous Goods Identification:

Dangerous goods being transported should be identified and clearly marked in the train composition data.

Integration with Other Monitoring Systems (WMS):

Data from other monitoring systems such as Hot Box detectors, derailing sensors, and RFID tags should be integrated into the IVG system.

Spain-Specific Requirements:

The IVGs located in Can Tunis and at the French border in Spain should be part of the demonstration.

IVG in Malmö:

The IVG near Malmö should also be included in the demonstration.

5.8.1.2. Summary

The Mandatory Requirements are focused on ensuring the IVGs are fully operational, collect real-time and standardized data, and meet specific performance targets. The Should Have Requirements are more about optimizing the demonstration's effectiveness and realism, such as involving all participants, covering relevant international routes, and generating political or industry interest. Achieving both sets of requirements ensures a comprehensive and effective demonstration of IVG capabilities.

5.8.2. Scenarios

5.8.2.1. Custom Train

The "Custom-Train" scenario represents a train specifically operated for the purpose of a demonstration, designed to meet as many requirements as possible for the involved stakeholders. This customized approach allows the train to access all selected IVGs, ensuring that each relevant demonstration point can be reached. Flexibility in border crossings is a key advantage, as the train can be routed through any necessary border, enabling the participation of all involved nations and stakeholders.

However, this scenario comes with significant disadvantages, primarily due to the high costs associated with booking a dedicated train path. Since this train is not part of a commercial operation, it does not generate revenue from its journey. This leads to financial losses, despite any funding or subsidies that may be available within the broader project framework. Thus, while the "Custom-Train" offers maximum flexibility and inclusivity, it requires careful consideration of its substantial financial implications.

5.8.2.2. Demonstrator Train

In this scenario, the demonstration collaborates with the ongoing "Digital Automatic Coupling" (DAC) project, which already conducts test runs and has additional demonstration journeys planned. These DAC test trains can be partially rerouted to locations advantageous for the IVG demonstration. This provides an opportunity to redirect the test trains to key demonstration sites. Upon arrival, the train composition would need to be split, with the individual railcars decoupled and processed over a hump yard for the demonstration.

However, there are significant limitations. Only one demonstration can fit within the designated timeframe, and this is scheduled towards the end of the period, with the possibility of further delays. A key risk is that the proposed rerouting of the DAC train may not receive the necessary approvals, potentially preventing the train from reaching locations critical for the IVG demonstration. This introduces uncertainty into the scenario, as the success of the demonstration depends on obtaining the required routing permissions.

5.8.2.3. Block train

Several standard block train services are used to cover all participating parties or relevant IVGs with a network of trains. The advantage is that the train planning has already been finalised, resulting in lower costs and planning effort. On the other hand, multiple trains make the data generated by the IVGs during the demonstration more difficult to compare than if the data came from one train. This is due, for example, to the fact that the trains consist of different freight wagons and therefore no actual comparison is possible. Or because the trains are operated by different railway undertakings, whose different processes also result in non-comparable data.

The combination also allows the weaknesses of one scenario to be offset by the strengths of the other. While block train traffic is particularly suitable for the IVGs on the line, single wagon traffic is better suited to cover the IVGs in the marshalling yards.

5.8.2.4. Single Wagon

In the single wagon scenario, existing single wagon services are to be used for demonstration purposes. If these trains are formed at marshalling yards where IVGs are available, the captured data can be used for the demonstration. The advantage of the scenario is the large number of single wagonloads. Among the existing regular services and the one-off planned services, there will be sufficient opportunities during the demonstration period. It also offers the advantage of lower financial outlay compared to a scenario in which a train is planned exclusively for the demonstration.

The recommendation for action is therefore clearly to press ahead with the development of the block train and single wagon scenarios. The next step in the planning and preparation of these scenarios is to complete the requirement specification. This must include:

- the IVGs that are to be part of the demonstration,
- the technological use cases to be demonstrated,
- the KPIs that are to be improved,
- and the success indicators of the successfully completed demonstration.

The routes must then be detailed and suitable train services identified. The selection of KPIs should be based on KPIs from a previous funding project, Shift2Rail. In addition, KPIs must be defined for the technologies to be demonstrated. For example, the time the train is stationary at a border crossing or whether damage recognised at an early stage reduces maintenance costs. It is then important to clarify how the data exchange will take place during the demonstration.

5.8.3. Risk analysis

In the following section, a thorough risk analysis is conducted for each scenario to ensure that all potential risks are identified and assessed. This structured approach prevents the omission of risks that may arise in later stages and allows for a comprehensive comparison of scenarios. The risk assessment for each scenario is further enhanced by assigning weights to the risks using a preference analysis. The weighting is based on the severity of each risk in relation to the project's success. Table 5.3 illustrates the quantification of risks associated with the "Custom Train" scenario, as presented in a detailed risk analysis. Furthermore, the eight identified risks are ranked according to their potential impact on the project.

5.8.3.1. Custom Train

The unweighted score column in Table 5.3 reflects the rank order of each risk within the "Custom Train" scenario.

Table 5.3 Risk analysis for scenario I – Custom Train

1) Custom Train	**Risk**	**Weighting**	**Probability of occurrence**	**Extent of loss**
A	Time delay	18%	2	3
B	Delay of the IVG construction	18%	4	3
C	Different gauges	4%	5	4
D	Non-comparable data	25%	2	4
E	Limited budget	14%	5	5
F	No revenue from the train	14%	5	3
G	Large planning effort	4%	5	2
H	No coverage of all participants	4%	1	3
U	**Sum**	**100%**	**29**	**27**

These scores are assigned based on a structured evaluation of the risks, which can be explained as follows:

Risk of Delays:

The likelihood of a delay occurring is assessed as low, given that the train is scheduled for the fourth quarter of 2025 (Q4 2025). Should a delay occur, the potential damage is considered medium, as there is flexibility for the demonstration to be rescheduled to the first quarter of 2026 (Q1 2026). Furthermore, delays in the construction of IVGs are considered independent of the specific scenario being analysed. The probability of occurrence for this risk is rated as high (4 out of 5), due to the extended testing periods required. The impact of this delay, however, is rated as moderate since other parties might still be able to demonstrate their IVGs.

Technical Compatibility Issues:

A significant risk emerges if the Spanish IVG is involved in the demonstration. Spanish rail infrastructure uses a different track gauge than the rest of Europe, making it impossible for the train to pass through Spanish IVGs in its current composition. This risk is evaluated as high, with a score of 4, due to the operational challenges posed by this incompatibility. However, mitigation strategies are possible, such as transporting goods (e.g., containers) using an alternative train system to bypass this technical barrier.

Data Compatibility:

From a technical perspective, the issue of incomparable data presents a moderate risk. In this scenario, data collected from different sources may be in varying formats, which could complicate analysis. However, the "Custom Train" scenario is designed to ensure that the content of the data is comparable across different platforms. Despite this, the risk remains significant because one of the primary objectives of the demonstration is to prove data comparability. Therefore, ensuring uniform data formats is critical.

Budget Overrun:

The risk of exceeding the project's budget is considered very high. This is because booking the required train path incurs substantial costs, which may exceed initial budget forecasts. The financial consequences of this scenario are also rated as severe, as an inability to secure the necessary budget could prevent the demonstration from taking place. Additionally, this scenario does not generate revenue since the train journey itself is not commercialized. Even if the train operates without transporting goods, the lack of revenue generation increases the likelihood of insufficient funds for the journey.

Planning Complexity:

The planning complexity for the "Custom Train" scenario is guaranteed to be the highest among the assessed scenarios. Significant effort is required to ensure that the train journey is scheduled, planned, and executed successfully. This includes coordination with multiple stakeholders, train operators, and infrastructure managers to ensure the journey can occur as planned.

Involvement of Participants:

The risk of not involving all participants is rated as highly unlikely. The comprehensive nature of the planning process ensures that all relevant stakeholders and participants are taken into account during the scheduling of the train journey. While this risk is considered minimal, it still requires attention to ensure full coordination across all involved parties.

5.8.3.2. Demonstrator Train

In the following Table 5.4 the Demonstrator Scenario is evaluated.

Table 5.4 Evaluation of Demonstrator Scenario

2) Demonstrator	Risk	Weighting	Probability of occurrence	Extent of loss
A	Time delay	18%	5	5
B	Delay of the IVG construction	18%	4	1
C	Different gauges	4%	5	1
D	Non-comparable data	25%	2	4
E	Limited budget	14%	3	4
F	No revenue from the train	14%	5	3
G	Large planning effort	4%	2	2
H	No coverage of all participants	4%	5	5
U	**Sum**	**100%**	**31**	**25**

The risk evaluation for the DAC collaboration scenario is as follows:

Risk of Delays:

A delay is considered highly probable in this scenario, as the considered train will drive in 2026. The timeplan is not settled now, so another delay in the construction phase of the wagons is possible. This could lead to the demonstration not taking place at all, posing a significant risk to the success of the project. However, similar to the "Custom Train" scenario, delays related to the construction of the IVGs or gauge changes do not directly affect this scenario, as it is independent of these variables.

Technical Compatibility:

The risk associated with gauge compatibility, which is a concern in other scenarios, is not relevant here. Additionally, the comparability of data is assured since only a single train will be used for the demonstration, reducing the complexity of data formats and ensuring consistency.

Budget Overrun:

The likelihood of reaching the budget limit is low in this scenario. Unlike the "Custom Train" option, there are no significant cost drivers such as track bookings or extensive personnel hours for route planning. However, since the demonstrator does not generate any revenue, it still represents a moderate financial burden. While this may not directly affect the IVG group within the European Rail Joint Undertaking (EU-Rail JU) framework, it places financial strain on the DAC project.

Planning Complexity:

The planning effort is considered low, as rerouting the train to IVG-relevant locations is reported to be straightforward, according to DAC project managers. This reduces the complexity of logistical coordination and scheduling, making the scenario easier to implement compared to the more resource-intensive "Custom Train" scenario.

Participant Coverage:

A major limitation of this scenario is that it does not cover all participants. The impact of this is significant, as only two of the five intended participants with IVGs can be included in the demonstration. This reduces the overall scope and inclusivity of the scenario, which is a critical disadvantage compared to other options.

5.8.3.3. Block Train and Single Wagons

In the following Tables 5.5 and 5.6 the Block Train and Single Wagon Scenarios are evaluated.

Table 5.5 Evaluation of Block Train Scenario

3) Block Train	Risk	Weighting	Probability of occurrence	Extent of loss
A	Time delay	18%	2	3
B	Delay of the IVG construction	18%	4	3
C	Different gauges	4%	5	4
D	Non-comparable data	25%	4	4
E	Limited budget	14%	1	4
F	No revenue from the train	14%	1	1
G	Large planning effort	4%	3	2
H	No coverage of all participants	4%	2	3
U	**Sum**	**100%**	**22**	**24**

Table 5.6 Evaluation of Single Wagon Scenario

4) Single Wagon	Risk	Weighting	Probability of occurrence	Extent of loss
A	Time delay	18%	2	3
B	Delay of the IVG construction	18%	4	3
C	Different gauges	4%	5	4
D	Non-comparable data	25%	4	4
E	Limited budget	14%	1	4
F	No revenue from the train	14%	1	1
G	Large planning effort	4%	3	2
H	No coverage of all participants	4%	2	3
U	**Sum**	**100%**	**22**	**24**

The risk evaluations for the "Block Train" and "Single Wagon" scenarios are identical due to the similar requirements and structure of both scenarios. The detailed assessment is as follows:

Risk of Delays:

The likelihood of delays in these scenarios is considered low. The scheduling of these commercial freight services is stable and well-established, reducing the chances of significant disruptions. However, delays in the construction of IVGs could still affect these scenarios in the same way as Scenario 1 ("Custom Train"), as all relevant IVGs must be available for the demonstration to proceed effectively.

Technical Compatibility:

The risk of gauge compatibility (Risk C) is also assessed similarly to Scenario 1, since the same IVGs will be covered. As these are commercial trains, there are no additional technical compatibility concerns beyond those already identified.

Data Comparability:

A significant risk arises in these scenarios regarding data comparability. Since the trains will be using different types of freight wagons, this could lead to the generation of inconsistent data, particularly regarding wagon conditions. Unlike Scenario 1, where data uniformity was ensured by using a single train, these scenarios involve heterogeneous train compositions, making the comparison of data more challenging. This compromises the ability to reliably compare condition data across wagons and may affect the demonstration's outcomes.

Budget Overrun:

The risk of exceeding the budget limit is very low in these scenarios. The largest cost driver, route planning, has already been completed, and since the demonstrations make use of existing commercial traffic, there is minimal financial risk involved. Even in the event of unplanned costs, the impact would be minor, as ER JU does not bear the financial burden of these commercial operations.

Planning Complexity:

While the planning effort is less than in Scenarios 1 and 2, it is still notable. The main challenge lies in identifying and coordinating multiple suitable commercial train services for the demonstration. While this is less complex than custom-planning an entire train, it still requires significant coordination to ensure that the demonstrations align with the availability of these services.

Participant Coverage:

One of the key advantages of these scenarios is their ability to cover all participants with minimal difficulty. However, a critical risk remains: the demonstration may fail to achieve its full objectives. The use of commercial services may limit the ability to showcase new technologies and advancements in data exchange, which could affect the overall impact of the demonstration. Thus, while the participant coverage is extensive, the technological goals might be partially compromised.

5.8.3.4. Scenario comparison

The average risk of the four scenarios in direct comparison has been presented. Scenarios 3. and 4. have the same average risk and overlap. They also have a lower risk than scenarios 1 and 2. According to these results, scenarios 3. and 4. are best suited for the demonstration. For this reason, it can be stated that the demonstrator should ideally be based on existing transport operations. This means that the aim of presenting the technology of IVGs can be brought to the fore. However, there are advantages and disadvantages here. On one hand, the data can only be made partially comparable, as in some cases it will not be the same wagons with the same load that are recognised by the IVGs. On the other hand, this offers the advantage of demonstrating the actual application in day-to-day business.

5.8.4. Route suggestions

On the basis of the existing and planned locations of IVG System in

- Malmö (Sweden)
- Rotterdam (The Netherlands)
- Can Tunis (Spain)

and the existing systems in

- Germany (DB)
- Austria (ÖBB)
- The Netherlands (ProRail)

The route is designed in such a way that as many systems as possible are travelled through. Corresponding routes can be seen in the following Figure 5.30. On the one hand, the connection between Malmö and Hamburg could be chosen to compare the Swedish systems with the German systems. In the further course, a journey can also be made across the border between Germany and the Netherlands. Corresponding comparisons can be made via the locations Rotterdam and Hagen, Seelze or Hamburg in Germany. A combination with Swedish transport would also be conceivable.

In addition to covering the southern part of Europe, a train connection between Germany or Austria and Spain would be conceivable. It should be noted here that transhipment takes place at the Spanish-French border and the wagons would not be comparable, but the load would be. Therefore, container transport should be used especially in this case to ensure comparability.

Figure 5.30 First route options for demonstrator based on existing traffic

5.9. Conclusion

This chapter presents and describes various systems for use as checkpoints. In addition, the necessary information on locations, modes of operation and characteristics was provided.

Based on the locations and possible uses, the results of the initial analyses for a Europe-wide showcase were presented. Various implementation options were considered and opportunities and risks derived. Based on these analyses, it was shown that a showcase consisting of several parallel demonstrators is practically feasible. This concept serves as the basis for the further development of the demonstrators and the showcase in conjunction with WP 24 and 33.

6. Deployment strategies

Chapter 5 covered the first part of Subtask 29.1.1 i.e. definition of the demonstrators' characteristics; this section covers the second part of the subtask i.e. to propose deployment strategies and an implementation and roll-out plan for standardised European checkpoints. These strategies are prior to carrying out the demonstration, further strategies that might arise will be represented in future deliverables related to the upcoming task 29.2. The task will result in installation reports and test execution for each of the considered countries (D29.3-29.7). In addition, DBC will have a Live-Demo of Video Gates showing process optimization in a yard (D29.8). In total, task 29.2 this will result in a common deliverable *D29.2. Demonstration and Evaluation of standardised European Railway Checkpoints at borders or other operational stop points.*

6.1. Main line provided by ProRail

On the main line, trains typically drive faster compared to marshalling yards. This makes it impossible for the human eye to detect UIC codes, hazmat signs or damages to the wagons. However, trains with wheel flats or damages pantographs can seriously harm the infrastructure when driving at high speed over the main line.

Railway Checkpoints can be placed over single railways and detect when a train is running at this specific part of the railway infrastructure. The portal can be placed using a concrete slat and should be high enough so trains can pass by and cameras can be placed at multiple angles. This makes it possible to detect damages and identify the train. This way, further damage to the train and serious damage to the infrastructure can be prevented. Moreover, the railway safety can be guarded.

6.2. Marshalling yard

6.2.1. Infrastructure management process optimization provided by Adif

Marshalling yards are generally configured as a series of parallel sidings on which different train configurations can be assembled. If Railway Checkpoints are installed at the points where all trains pass through, i.e. at the entry/exit points of trains, a reliable record can be obtained of which vehicles are using the infrastructure at any given time. This information can be used to optimize the use of the infrastructure in various ways.

By knowing the use of the infrastructure, different improvements can be planned, and the capacity can be studied in detail for future improvement or expansion works. Additionally, by making use of the track occupation register the infrastructure manager can charge fees to railway undertakings that park their trains for extended periods of time, thus discouraging track occupation and indirectly reducing infrastructure occupancy, leading to increase availability while exploiting the infrastructure and improving its profitability.

The deployment of this type of system can be studied and carried out on a case-by-case basis, being independent for each Marshalling Yard. In short, it is not necessary to make an extensive plan for a national rail network, and it is possible to start with a pilot and evaluate its profitability and impact on the Marshalling yard operation for future deployments.

6.2.2. Maintenance ordering and condition monitoring provided by DB

As part of the European Shift2Rail funding programme, the maintenance ordering process (ECM 3) at DB Cargo has been successfully digitalised. In DB Cargo's workshops, the wagons are now inspected digitally on the screen using the images from the IVGs instead of having to go onto the track. Employees have been trained and instructed accordingly, and processes have been adapted and established.

A new digital tool is to be added to the digital workplace: an AI-based assistance system. This should further optimise and improve daily work in the future. The aim is to alert employees specifically to damage or defects in the freight wagon. To achieve this, the AI must be able to reliably recognise damage in GCU Appendix 10, ideally also in Appendix 9, further elaborated in section 9.1.

However, the AI is currently not in a position (at least due to the AI Act and the current guidelines) to automatically recognise damage by comparing it with intact freight wagons. The very large number of different types of freight wagons and graffiti makes the comparison even more difficult.

By introducing AI as an assistance system, the damage recognised by the AI can be successively incorporated into the commissioning process. At the same time, this also leads to greater acceptance of the AI among employees, as the support can be slowly expanded.

Prior to individual AI models being allowed to assist employees, however, they are subjected to tests and approval processes. An assistance system with repeated and erroneous suggestions poses a massive risk for the use and also the willingness of employees to further develop the AI.

By continuously using and expanding the AI models for damage detection, we will establish the basis for reliable, continuous condition monitoring of freight wagons. This will then enable a wide range of applications in the areas of operation, control and maintenance

6.3. Border crossings provided by Trafikverket

Today rail operators and IM's share data according to TAF/TSI regulation. The data concerns solely data of the handed over train to another IM or rail operator. It contains data needed for the incoming operator and allows them to plan and check the composition of trains including length, gross weight and, if applicable, where dangerous goods are in the train.

The checkpoints, however, will add other needed information of the train passing a border. It can be BIC/ILU codes for loading units and information about which wagon that carries each loading unit. This is highly requested from stakeholders. Ports and terminals can plan their activities more efficient; shippers can get more detailed and quality assured shipping information in real time. IM's will get more secured and qualified information and besides that the train information will be automated registered from the checkpoint.

The aim of the checkpoints in terms of benefits for border crossings and handover procedures, is to speed up the activity and make it more automated. This will make the dwell times shorter and eliminate human mistakes. Of course, that demands high accuracy of the readings.

6.4. On-board sensors provided by CEIT and Renfe

Given the different needs of each client, it would not make sense to develop a single product capable of covering all possibilities for all types of clients. Therefore, the aim is to develop a portfolio of functionalities to meet the specific needs of each one. In other words, the plan is to develop a technological asset in the form of an on-demand service based on an embedded digital system for the logistics of future railway freight transport. To implement this business model, the goal is to develop and integrate a wide range of technologies into a single system capable of meeting all the requirements of any type of client. Then, depending on the specific needs of each client, the system can be adjusted to that particular need and bill for the specific service.

Since this idea is too ambitious to be implemented in a first phase, the plan is to scale back some of the system's functionalities to allow for short-term development. In this way, CEIT would be able to evaluate the proposed On-board system's performance in a small pilot test. Moreover, CEIT would identify any difficulties that may arise during installation, such as those related to mechanical installation, legislation, objections that wagon operators might raise, etc. Then, in future stages, CEIT would be able scale up the system to a larger fleet.

Figure 6.1 shows a diagram of the proposed deployment of the On-board system. Note that, for this use case, we will be able to equip up to four wagons.

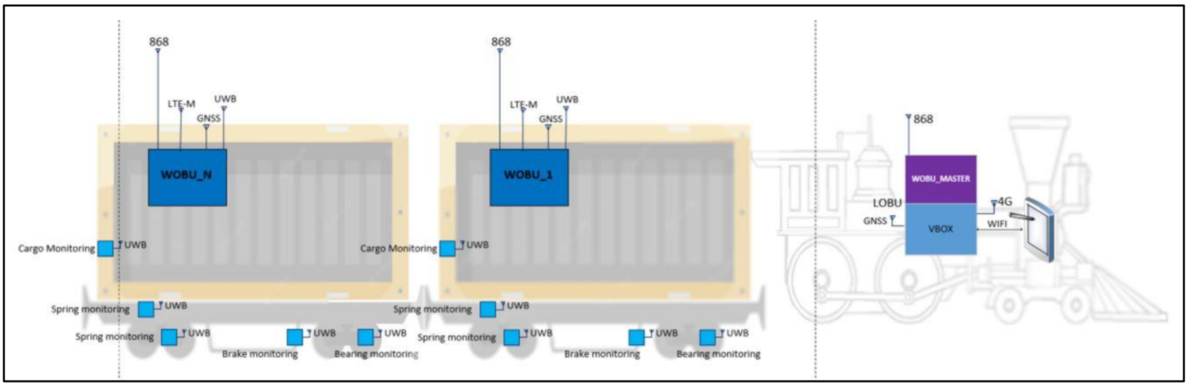


Figure 6.1 Proposed system deployment

The On-board system proposed by CEIT is a modular wireless system that is attached to the wagons using strong magnets, without requiring mechanical installation or maintenance actions by RENFE during the implementation of this operation.

We aim to install 1 WOBU and up to 5 Sensor Nodes on each wagon. These sensors will measure parameters such as acceleration, angle, temperature, humidity, etc. These sensors must be located in the proper places so that they are able to detect anomalies or failures. The functions they will perform include Spring monitoring, Bearing monitoring, Brake Test and Cargo monitoring. The information gathered by the Sensor Nodes Will be sent to the WOBU within the wagon. The WOBU will organize all this data, add geolocation information, and transmit it to wherever it is required, i.e. checkpoint, locomotive or cloud.

6.5. Conclusion

As a conclusion to the section on Railway Checkpoints deployment strategies, we can see that, depending on the location of the installation, the information collected will have different applications and can be used for different processes.

Some examples given are the use of the information for rolling stock maintenance, optimization of terminal operation, prevention of infrastructure damage and optimization of border handover processes.

Being so location-dependent, each company will have to consider what use they want to make of the information when deciding the location of the checkpoints, the sensors they consider installing and the number that will be necessary to meet their needs.

7. High Level Definition of Test Cases

7.1. Design Plan for AI development

The following chapter provides an approach for the development of Use cases (UC) in the context of Europe's Rail and addresses subtask 29.1.2. The development is divided into the phases shown and executed as a looping process. The most important data in such a development are also shown. Figure 7.1 shows the UC development phase in more detail.

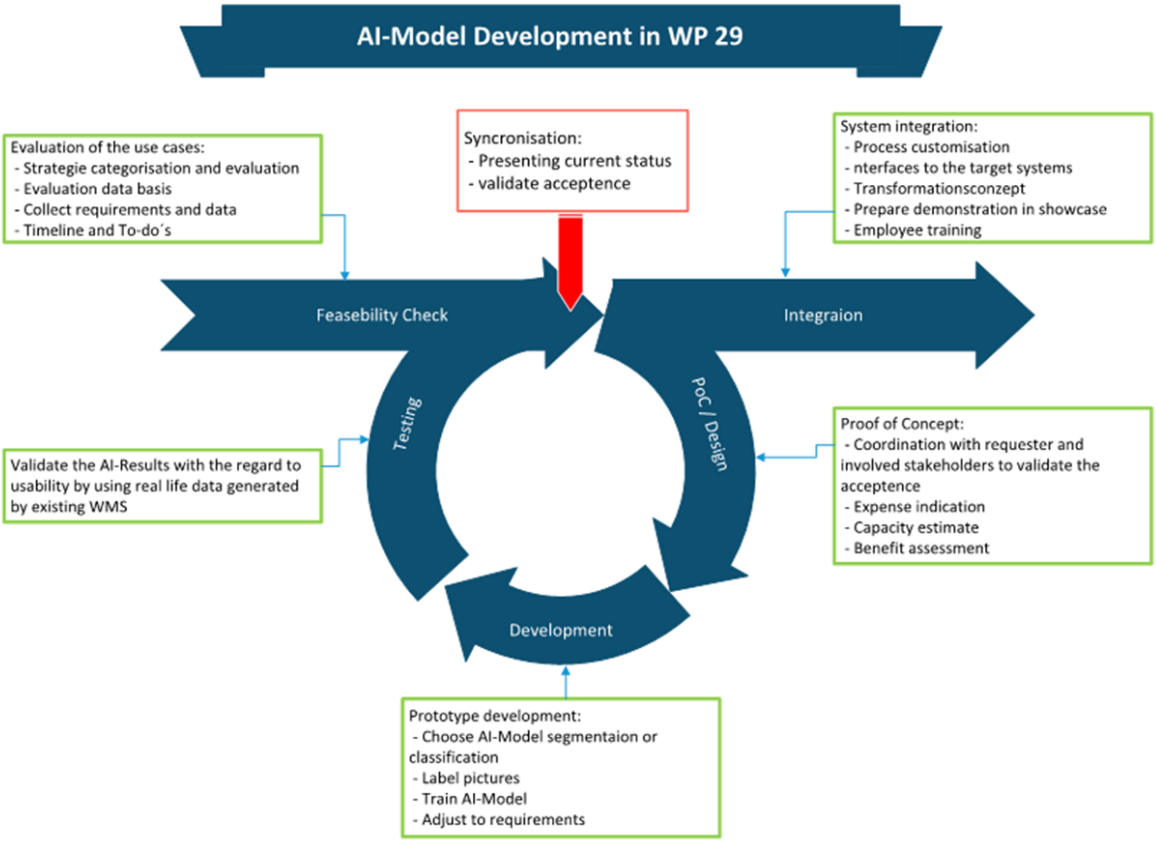


Figure 7.1 Design plan for AI development in WP29

The blueprint for AI development can be structured as a multi-phase process, ensuring a smooth progression from concept to deployment. The development follows a logical sequence, starting with the Feasibility Check and concluding with Integration. The core phases—PoC/Design, Development, and Testing—are intertwined in an iterative loop, which allows for continuous refinement.

1. Feasibility Check

The Feasibility Check is the initial phase, where the viability of the AI project is evaluated. This step is crucial for determining whether it makes sense to proceed further, both from a technical and business perspective. Key activities include:

- **Problem Definition**: Clearly identifying the problem that the AI solution is intended to address.
- **Data Availability**: Assessing whether sufficient, high-quality data is available to train and validate the model.
- **Technology Review**: Evaluating the tools, frameworks, and infrastructure needed for AI development, and checking if they align with project goals.
- **Risk Assessment**: Considering potential risks, such as regulatory, ethical, or privacy concerns, and gauging the overall project feasibility.
- **Timeline:** Check and plan the effort of the development with regards to meet the time plan of the project.

By the end of this phase, a feasibility report is generated, which helps in deciding whether to move forward with the AI project.

2. PoC/Design (Proof of Concept and Design)

If the project passes the Feasibility Check, the next step is to create a Proof of Concept (PoC). This phase demonstrates that the AI solution can solve the problem in a limited, controlled setting. Key tasks include:

- **Model Design**: Selecting initial algorithms and architectures that are likely to solve the problem.
- **Prototype Development**: Building a simple prototype based on a subset of data to validate core functionalities.
- **Feedback Loop**: Gathering insights from the PoC, assessing its performance, and making adjustments to the design or model.

The PoC helps identify early-stage technical challenges and provides a foundation for future development.

3. Development

Once the PoC has shown promising results, the project moves into the development phase, which is tightly integrated with testing. Here, the focus shifts to building a more robust, scalable version of the AI solution. This phase includes:

- **Model Training**: Scaling the model using a full dataset and applying necessary data preprocessing and feature engineering techniques.
- **Labelling**: To train on a full dataset, the labelling process should be prepared.

- **Algorithm Optimization**: Tuning the AI model to improve performance metrics such as accuracy, speed, and efficiency.
- **Iterative Improvements**: Constantly refining the solution based on feedback from testing and real-world data.

4. Testing

Testing is a critical part of the development loop. It involves evaluating the AI solution's performance across various metrics to ensure it meets the desired objectives. The key aspects include:

- **Model Validation**: Testing the model on unseen data to assess its generalization capabilities.
- **Performance Evaluation**: Measuring metrics such as accuracy, precision, recall, and F1-score, as well as computational performance.
- **Debugging and Error Analysis**: Identifying and resolving issues that arise during testing, such as bias, overfitting, or data imbalance.

The **PoC**, **Development**, and **Testing** phases form a continuous loop, where feedback from testing drives further development and model refinement.

5. Integration

Once the AI model has passed all tests and demonstrates satisfactory performance, the final phase is integration. In this phase, the AI solution is incorporated into the broader system or workflow where it will operate. Key activities include:

- **Deployment**: Integrating the AI model into the production environment, ensuring it can interact with other systems and data pipelines.
- **Monitoring**: Implementing tools to continuously monitor the model's performance and ensure it behaves as expected in real-world scenarios.
- **Maintenance and Updates**: Establishing a process for maintaining and updating the model, including retraining as new data becomes available.

This blueprint provides a structured approach to AI development, where each phase builds on the previous one, ensuring that the final solution is well-tested, scalable, and ready for real-world application. The iterative loop between **PoC**, **Development**, and **Testing** allows for flexibility and continuous improvement throughout the project lifecycle.

7.2. Use Cases

7.2.1. Condition monitoring – Bogie Analyzer

7.2.1.1. AI-assisted condition monitoring

As it is not economically viable to have half a million images per day analysed by humans, AI models are used to automatically recognise certain features and objects in the images. These features can be specific types of damage, such as holes in wooden floors or tears in roof tarps. Such models are trained by selecting a large number of images and making them available for training. This assumes that the defects occur relatively frequently. In many cases, there are not enough images of a particular damage, or the information to be obtained from the model must be explainable. An example of this is the thickness of brake pads where geometric methods have to be used.

Localisation of important objects

No matter which method is used, the object has to be located in the image. As the resolution of the linescan cameras is very high, around 35 times that of a 4K television, small objects are first roughly localised. This is done using an AI model that performs simple object detection/recognition. The following shows the main zones of a freight wagon that should be considered. The corresponding use cases for AI models are then derived from the components, as shown in excerpts and Figure 7.2.

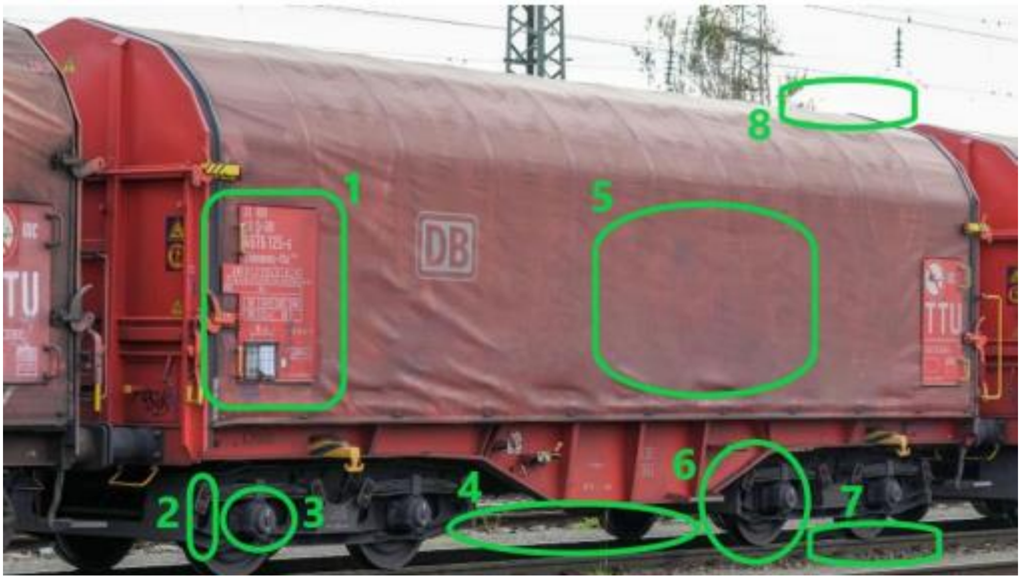


Figure 7.2 Typical locations for AI-(damage)-detections

1. Rolling-Stock Identification
2. Brake pad diagnostics / Bogie Analyzer
3. Hot runner detection
4. Impact detection
5. Graffiti recognition
6. Detection of out-of-round wheels
7. Wheel load measuring points
8. Profile measurements for protruding parts

7.2.1.2. Example of the Bogie Analyzer

The bogie analyzer as a relevant topic for analysing damage does not only apply to freight wagons. In order to make these approaches usable for all units, the topic is being developed in coordination with FP3. The agreements and cooperation are documented in WP7 and D7.3.

Object detection

To analyse brake pads, for example, the wheelset areas are detected first, see Figure 7.3. The first AI model is responsible for recognising them and returns the coordinates of the recognised areas. In a second step, these areas are analysed in more detail by another segmentation model.

Figure 7.3 Object detection of the wheelset areas

Segmentation

A second model analyses the cut-out wheelset area in more detail. This is necessary because the segmentation models cannot work with the original resolution of the whole wagon. Most AI models have a limited input size of 1024x1024 or 2048x2048 pixels and prefer square images. The higher the resolution, the more hardware resources are required to run such models. The output is in the form of contours surrounding the objects to be detected (Figure 7.4). The thickness of the brake pads can be derived from these contours using an undisclosed algorithm.

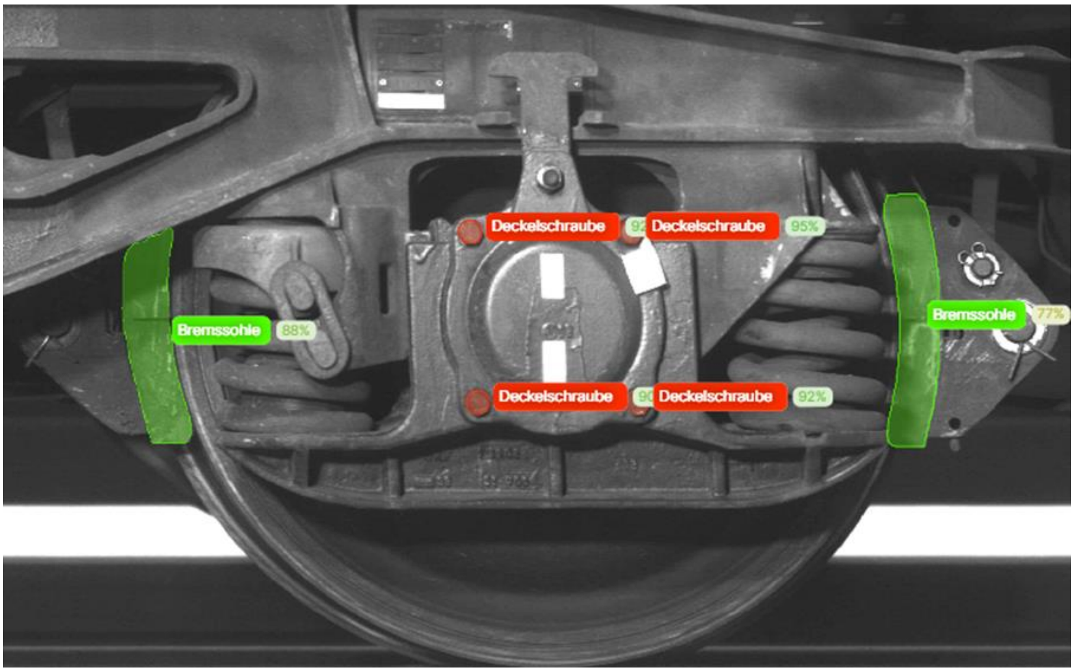


Figure 7.4 Segmentation of the cover screws and brake pads

Analysing the geometry

The geometric analysis is necessary because the segmentation model does not say anything about the condition of the brake pads. The AI therefore does not decide whether the pads are sufficiently thick or damaged. The thickness is determined by analysing the geometry of the segments. This analysis includes various plausibility checks and smoothing of the inner and outer contours of the pads (Figure 7.5).

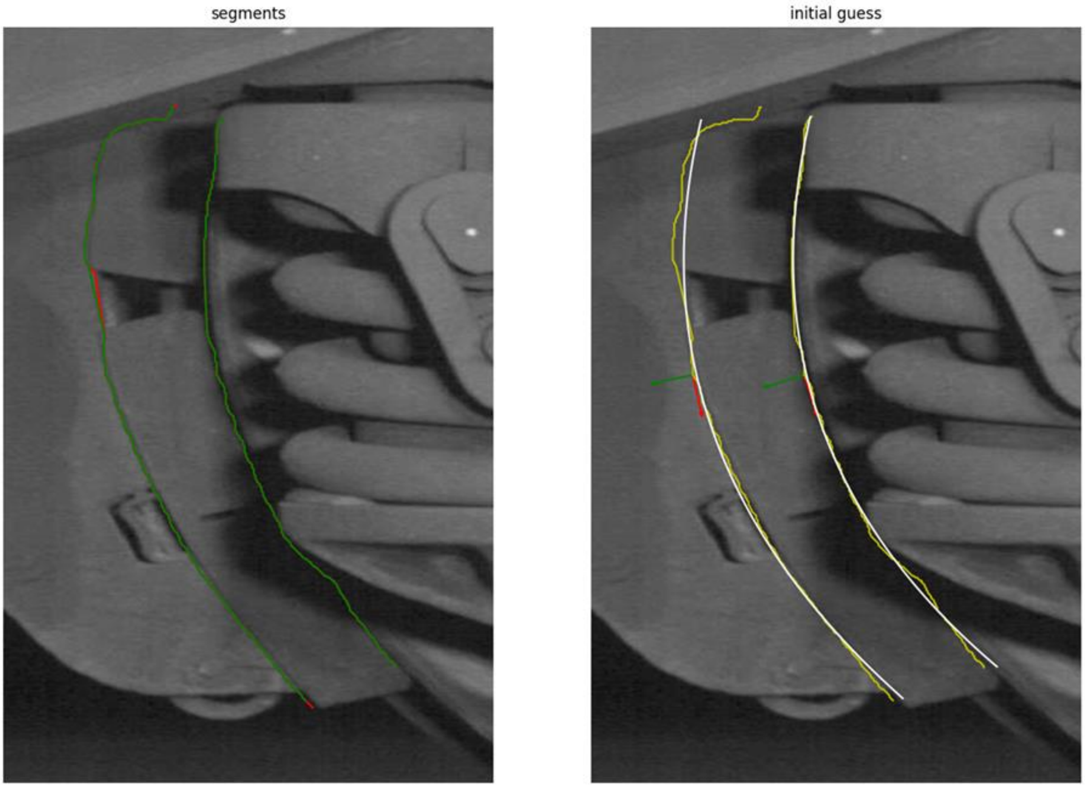


Figure 7.5 Left: Segmentation (AI). Right: Smoothing of the segment edges

As line scan images can be subject to stretching and compression along the x-axis of the image, reference geometries such as bolts (Figure 7.6) are used to give a more accurate indication of the ratio of pixels to millimetres. The cover bolts are detected using the same segmentation model as the brake blocks and were chosen as a reference because their spacing is standardised across the different bogies.

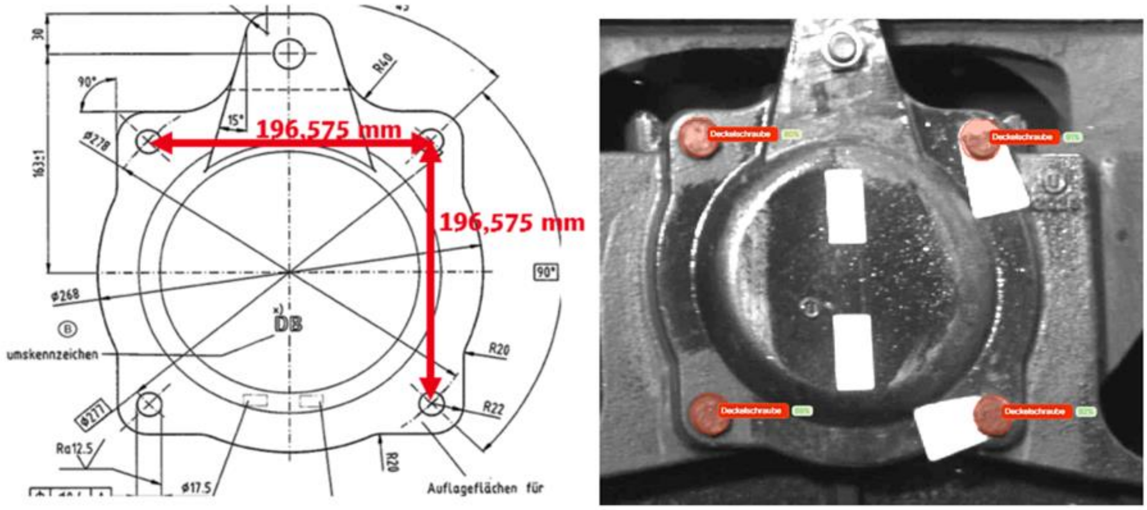


Figure 7.6 Reference geometries for determining the pixel to millimetre ratio

Advantages of AI

After testing various ‘traditional’ image processing methods, such as edge detection, the use of AI to recognise components has shown two major advantages.

Robustness against variation

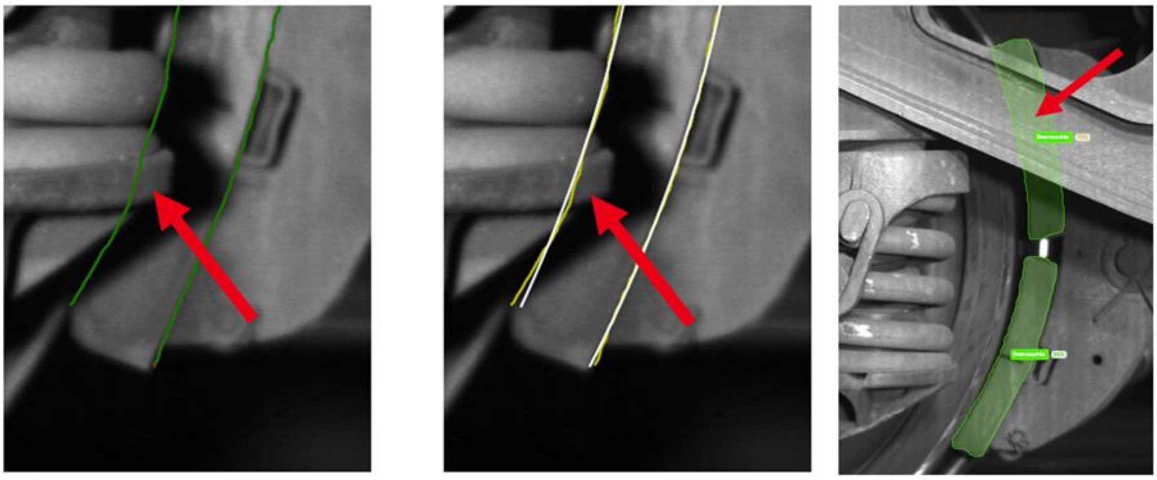


Figure 7.7 Segmentation and examples of how AI benefits shadowed and obstructed object detection

The models have learnt to deal with varying image quality and to reliably recognise obscured, shadowed or generally poorly visible objects (Figure 7.7). In addition, like humans, the AI is able to understand that components obscured by other elements still exist and can 'visualise' their outlines (Figure 7.7, right). This increases robustness for the subsequent post-processing algorithms.

Expandability of the models

Another key advantage is that the existing segmentation model can be extended to other use cases and components without increasing the cost of running the model. This is because it makes no significant difference whether the model recognises one or more components. The runtime, and therefore the cost in production, remains constant. The current segmentation model has already been extended to other use cases, such as lift-off protection (lifting T) and damper ring (Figure 7.8). In both cases, the angle of the components is critical to their function.

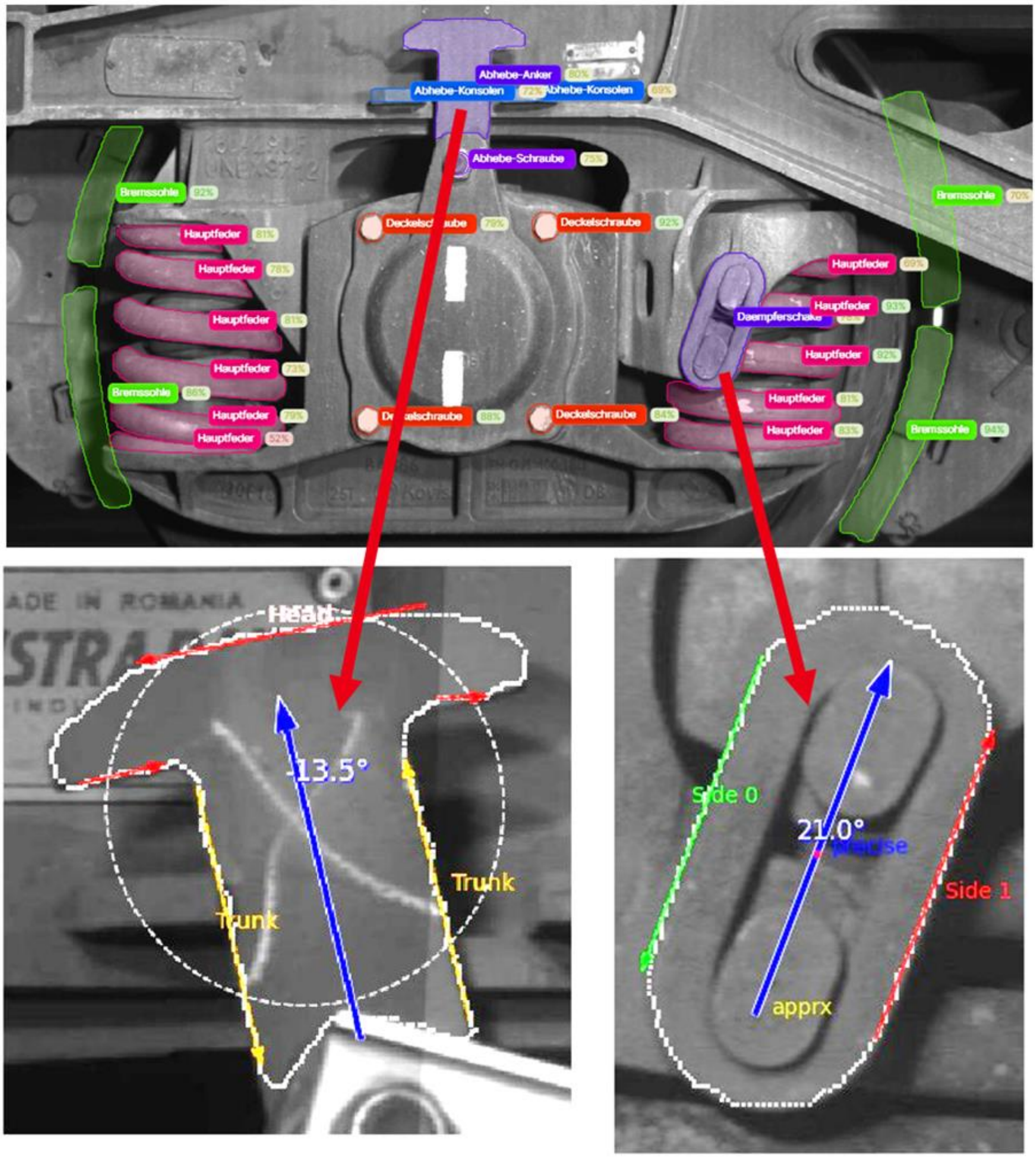


Figure 7.8 Left: Lifting T. Right: Damper ring

7.2.2. On-board systems

The aim with an On-board system is to digitalize the entire train and to obtain meaningful information for the operation, maintenance and logistics. In the scope of this WP, the information gathered by the On-board system can be sent to the locomotive, to the checkpoint, or directly to the cloud. Therefore, this system can function autonomously within the train and provide valuable information to a platform accessible by different end users. However, the On-board system lacks certain functionalities or capabilities that the checkpoint would cover, and vice versa. Since the checkpoint can only analyze the train when it passes through, and the On-board system continuously monitors the wagon regardless of its location, it would be useful to relate this data with the information generated by the checkpoint. The On-board system can provide complementary information that cameras might not capture due to technological or operational limitations.

The functions of the On-board system are to track the wagons, identify anomalies or failures during operation, and provide valuable logistical information. Table 7.1 shows a list of the operations the On-Board system can perform, along with the parameters associated with each functionality. It can also be seen what type of alarm would occur and whether the data generated by the On-board system can be related to the data from the checkpoint (checkpoint column). In this column, the term “yes” means that the data generated in the On-board system might be related to the data from the checkpoint. On the other hand, the term “no” indicates that, there are functions, such as spring monitoring, brake testing and cargo monitoring, that the checkpoint is not able to perform. Note that each of these data will be associated with a timestamp and a geolocation information so then it can be compared with the data from the checkpoint. The geolocation information is also very meaningful and it is a recommended feature to include in the design, implementation and integration of the On-board sensors. A good example of On-board system and its connection to the wagon, train and infrastructure, is the one proposed by CEIT, which is described in section 5.2.4.

Table 7.1 List of parameters generated by the On-board system

Type	Components	Measurements	ALARM	Checkpoint	GCU code
Condition monitoring	Flat Wheel monitoring	- Chord length. (mm) -Height (mm)	Excessive flatness in a wheel	Yes	1.3.3
	Bearing monitoring	-Temperature (°C). -Maximum vibration frequency along XYZ axes (Hz). Amplitude (mG)	ID of the hot axle or brake blocked	Yes	1.8.3
	Spring monitoring	-Maximum vibration frequency along XYZ axes (Hz). Amplitude (mG)	Spring ID failure	No	2.5.2
Operational & logistics	Automatic Brake test	-Amplitude along XYZ axes, brake release 0 (mG). -Amplitude along XYZ axes, brake applied (mG). -Amplitude along XYZ axes, brake release 1 (mG).	Brake ID system failure	No	3.1.5 3.3.1 3.3.2 3.3.3
	Kingpin test	-Lock/unlock	Coupling system failure	Yes	N/A
	Wagon Composition	-WOBU ID and its position within the train	N/A	Yes	N/A
Cargo monitoring	Freight status	-Temperature (°C). -Humidity (%). -Pressure (hPa)	N/A	No	N/A

From an efficiency standpoint, there is no advantage in continuously sending raw data or parameters related to these operations. Therefore, the data must be meaningful and enable us to compare how the checkpoint and On-board systems interpret the results. In the use case that CEIT is proposing with RENFE and ADIF, the aim is to compare the data generated by the On-board system with the data acquired by the checkpoint (which ADIF is responsible for in the Spanish use case). Next, some functions that the On-board system from CEIT will perform are described in detail, along with how the alarms are generated.

Flat wheel detection example

A wheel flat is a type of defect where the wheel loses its original round shape in a section of the disc, as can be seen in Figure 7.9. They are characterized by the chord length (L) and the height (H). They are usually caused by loss of adhesion during braking (wheel lock-up) or during acceleration (wheel slip).

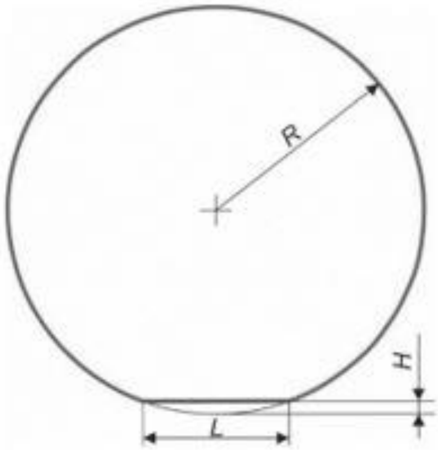


Figure 7.9 Wheel flatness definition.

This type of defect is a source of vibrations, which can lead to a loss of comfort and an increased likelihood of component failure due to fatigue, and therefore must be continuously monitored. This will give us insight into the flatness trend, while the checkpoint will verify it when the train passes through.

Wagon Composition example

This functionality is a pivotal aspect of freight train operations. Train composition refers to the strategic organization and assembly of wagons to form an efficient transport unit. In the realm of freight trains, the proper composition of the train holds paramount importance in terms of safety, efficiency, and operational profitability.

The significance of train composition lies in its ability to optimize various aspects of freight operations. By carefully arranging and identifying the wagons that comprise the train, logistics managers can ensure the optimal distribution of weight, efficient load balancing, and improved overall train performance. This facilitates effective resource allocation, load planning, and cargo management, leading to streamlined logistics processes and enhanced operational efficiency. Also, it has implications for rail infrastructure, an efficient cargo distribution strategy reduces the stress on the tracks and other infrastructure elements, minimizing wear and tear.

Moreover, train composition plays a crucial role in ensuring seamless connectivity between the wagons, enabling efficient coupling and decoupling operations. The ability to accurately identify and track the wagons within the train formation is essential for efficient operations, as it facilitates real-time monitoring, identification of specific cargo, and efficient utilization of resources.

In the developed system presented by CEIT in previous sections, each wagon is equipped with a Wagon On-Board Unit (WOBU) that stores essential information such as wagon identification, type, number of bogies, and available functionalities. This WOBU functionality is triggered upon request from the Driver Desk, which may be located either in the Locomotive or in the Cloud. The Driver Desk initiates a discovery process, which communicates with the connected WOBU. In response, each WOBU provides its persistent information along with the distance to nearby WOBUs. These data are processed to establish the current composition of the train by providing either the Driver Desk or the Cloud with the WOBU ID and its position within the train.

Whenever the train goes through the checkpoint, it can verify the composition by identifying each wagon, i.e., it is a checking to find out if the composition is still correct. The checkpoint cannot provide the composition to the user during marshalling operations. Therefore, by merging the information provided by the On-board system and the checkpoint, we can first support the user with the automatic composition information, which is then verified at each checkpoint the train encounters.

Brake test

The brake test involves verifying the functionality of each brake. The brakes are applied from the locomotive to confirm they engage correctly throughout the train. This involves observing if the brakes respond uniformly on each wagon. This operation is crucial in the preparation phase of the train, prior to the start and it is often performed by walking the length of the train to visually inspect the brake cylinders. After applying the brakes, they are then released to ensure they disengage properly. Again, workers check each car and axle to verify that the brakes have released as expected.

The On-board system can address this issue by performing an Automatic Brake Test. For this, the Sensor Nodes must be installed as shown in Figure 7.10. This test aims to avoid the worker from having to verify through visual inspection whether the brake has applied and released. The operation involves the driver applying and releasing the brake while the onboard system measures accelerations. This allows the embedded algorithm to determine if the brake has been applied and released properly. Finally, the operation result is communicated to the driver to check whether the Brake Test was successful or an alarm was generated, specifying which brake is failing.

Figure 7.10 Installation of the Sensor Node on the brake structure.

Note that in this case, as in the train composition operation, the Automatic Brake Test cannot be performed by the checkpoint due to the fact that the checkpoint may not be located in the appropriate place to carry out this operation. Therefore, the checkpoint can confirm that the Automatic Brake Test was conducted properly by checking if the wheels are not blocked.

7.2.3. Rolling stock and ILU identification

The Use Case proposed by Indra is an AI-based system for the automation of code identification task, both for the rolling stock (UIC code) and the containers (ILU code),

Automation of rolling stock and ILU code identification is a topic of great interest in the railway industry. Every rolling stock and every ILU are identified with a different code that is used to track each element of a freight train composition.

These codes must be read and registered every time a freight train enters or leaves a railway yard, a station, crosses a border or a control point. This code registration task is manually done by operators and represents large costs due to the time required to check the codes, the possibility of human errors and the risk to operators due to the harsh conditions of railway environments.

The automation of this task has been already studied from different technological perspectives, being Optical Character Recognition (OCR) based on classical Computer Vision (CV) techniques and Radio Frequency Identification (RFID) the most relevant in the previous works.

RFID offers advantages such as simplicity, low computational load, and reliability, but the technology requires that both the track and each individual wagon and container be equipped with a transmitter or receiver, a process that falls outside the scope of control for the company responsible for the inspection and which is invasive to the existing railway tracks and rolling stock.

OCR based on cameras installed alongside the railway tracks solves the problem of having to install any devices on the trains and does not interfere with the tracks. The challenge of this solution is that the variability of the use cases is quite high, as the codes can be located in different parts of the train or even appear fragmented on different parts of the container, present irregular lighting conditions, or have different formats due to the lack of strict standardization.

Classical CV techniques, as the used in previous FR8Hub (WP4 deliverables 4.1 and 4.2) (Kordnejad et al. 2018; Kordnejad et al., 2019), and FR8Rail III (WP3 deliverables 3.1, 3.2 and 3.3) (Kordnejad et al. 2020; Kordnejad et al. 2021; Kordnejad et al. 2022) works for code detection within the European Intelligent Video Gate (IVG) initiative, work very well when working conditions remain consistent. However, when conditions are as variable as in this case, as explained above, the system is unable to function properly in all situations.

In this type of Use Case, where the variability of conditions (lighting conditions, code can be located in different parts of the rolling stock, different code formats and damages on codes) is high, AI-based systems truly stand out due to their strong generalization and ability to adapt to environmental conditions, allowing them to continue functioning correctly.

The method proposed to detect and recognise the codes is based on AI (CV and DL) techniques to combine the best of each, obtaining a robust and reliable system. The method is divided in 3 different phases:

1. First, an AI model based on Convolution Neural Networks (CNN) is used to detect and classify the different codes in the image.
2. Then, the crop of each code is processed by a second AI model to recognise each character (OCR). Different models are used for each type of code.

3. Finally, a post processing module applies deterministic rules to compose the code and asset the code is correct.

This solution has been already tested with images from Gothenburg's IVG, outperforming the results of previous works on preliminary laboratory tests, carried out under determined specific conditions. No benchmark has been yet defined in the scope of the project, so that quantitative evaluations cannot be developed under a correct frame of reference.

This Use Case not only provides a robust system with better metrics in code identification, but it is also a scalable solution in which parallel analysis models for other types of codes or elements could be implemented using the same images.

7.2.4. Identification of dangerous goods

It is a legal obligation (Network Statement 2024/2025 **Article 58 of the Railway Act (Spoorwegwet)**) for rolling stock operators to indicate where wagons carrying dangerous goods are located in the train/wagon sequence. The infrastructure manager needs to have this information in order to guard the safety of the railway system and its surroundings. The indication of dangerous goods is currently done manually and are also indicated on the wagon itself, with "hazardous materials signs".

Hazardous materials can be indicated with (hazmat) signs. These are diamond-shaped signs with information on the type of hazmat. The signs have distinctive colours and inscriptions to identify classes and subclasses. Some practical examples are shown in Figure 7.11 and a simplified overview of all classes is shown in Figure 7.12. The hazmats are also displayed in an orange sign (see Figure 9.2in section 9.1.3). These orange signs contain a number that contains information on the substance (UN number) and the degree of danger. The UN number is the only required information. However, it can be useful to detect the hazmat signs as well. They can function as a backup or to boost confidence when predicting the UN number.

Using the IVG we can visually inspect the wagons to locate and identify all hazmat signs on a wagon. This is done by processing the collected image or video data using an AI algorithm. We can locate the signs on the image and then classify the signs. This can be done per class or subclass (see Figure 7.12). Depending on the algorithm's total implementation, the recognized signs can be matched to the wagon number, or a total list of recognized signs can be created.

There are some challenges, for example, the hazmat signs in Class 2.2 and Class 3 are nearly identical (red with a flame symbol) and the only distinguishing feature is the number on the bottom of the sign. Furthermore, it is unknown beforehand how many signs are present per wagon, so the locating task is important. Some of the signs appear deformed due to the wagon's shape or the camera's angle (see top right example in Figure 7.11), which is also a challenge for the algorithm.

To create a robust algorithm that works in different circumstances, this data represents the real situation, contains all the classes, and has a variation in background/lighting/angles. To evaluate this, the system should be able to:

- Correctly classify the type of hazmat sign displayed on a wagon, with performance assessed by e.g. measuring overall accuracy, as well as sensitivity to true positives and false positives.
- Accurately determine the location of each sign on the wagon, with performance assessed by e.g. evaluating how well the predicted locations overlap with the actual locations.

Figure 7.11 Examples of Hazmat signs, data provided by DB Cargo.

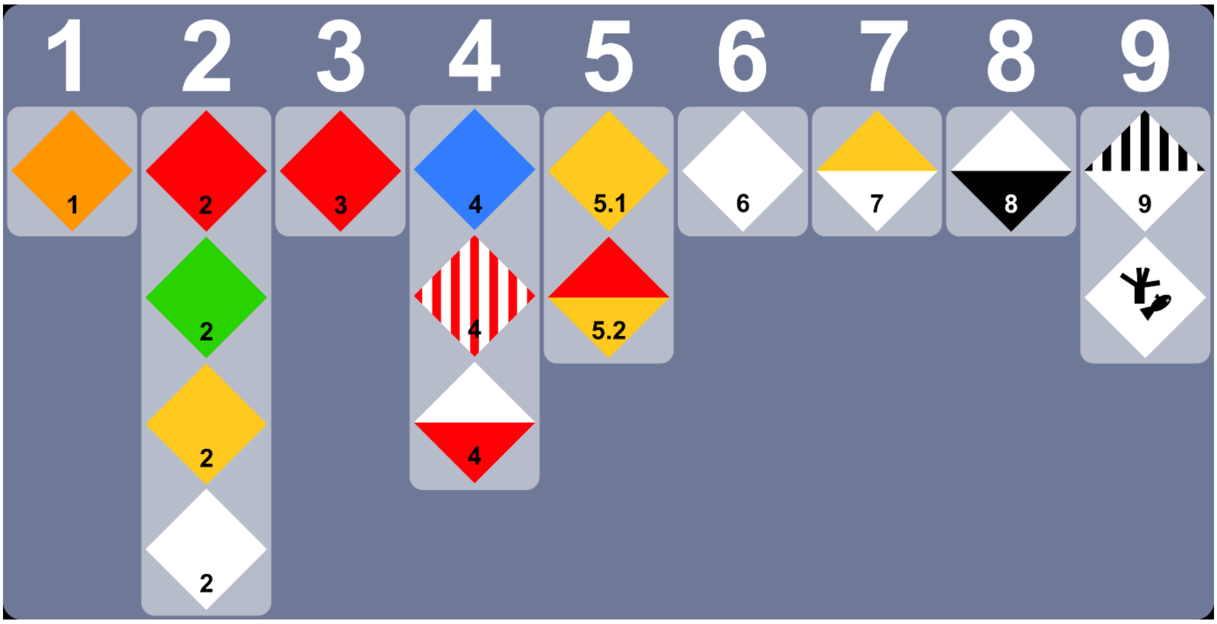


Figure 7.12 Simplified visualization of placards in their classes, image created Omtzigt, C.E.S & de Bourbon de Parme, C.H.R.S.(2024)

7.2.4.1. Requirements for the AI model

The model should (requirements set by ProRail in cooperation with University of Twente):

- Identify the hazmat signs correctly in 99.9% of all passing wagons;
- Identify the location of the hazmat signs on each wagon in 99.9% of all passing wagons;
- Indicate the level of confidence for each detection

7.2.4.2. Target process (Source, transfer and destination of data)

The IVG output shall be sent to the asset owner within 1 minute after the last wagon passed and contain at least the following information:

- Number of wagons including loc(s)
- Per wagon the recognized hazmat sign

The data shall be sent to a broker where several clients/users can subscribe to receive the data (e.g. asset owner of neighbour country, or all countries in the trains path).

The data must be sent in JSON format with at least the following fields:

- Timestamp (seconds since Epoch)
- Number of wagons
- Number of locs
- Array of wagons:
- Order number

- UIC number
- Hazmat sign, or array of signs in case of multiple signs

7.2.4.3. Criteria for the demonstration

The demonstrator shall be located on a railway yard where:

- At least 200 train passages can be registered
- At least two parallel tracks in front of the camera
- Possibility to have a ground truth (actual values) (manual or automatic)

The outcome of the demonstration shall be a match with the ground truth (actual values) showing that the criteria mentioned in 7.2.4.2 are met, measured from the systems in the asset owners' office.

7.2.4.4. Data sharing

As mentioned in 7.2.4.2 the data from the IVG shall be sent to a broker, where several clients/users can subscribe to receive (parts of) the data. These users can be the asset owners on the path of the train, or the train operators (limited to their own trains).

7.3. Conclusion

In Chapter 7, approaches for the automatic detection of information and damage were generated. The necessary technical implementation of the algorithms and approaches is discussed and the necessary information is described. Relevant aspects of the chapter primarily describe the requirements to be achieved and the current development progress. The use case-related documentation is framed by a generally derived procedure for co-operation on this topic within the framework of the EU-Rail FP5 environment.

8. European Railway Checkpoint Conceptual Data Model Requirements

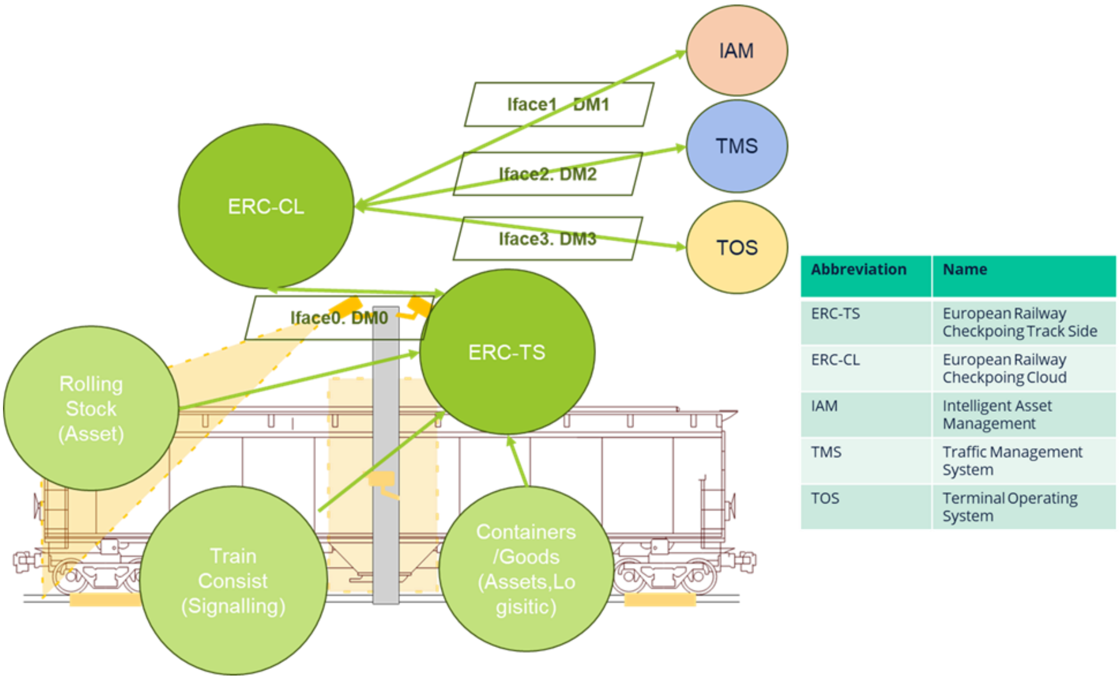
In work package 30 (WP30) of Motional, which is flagship project 1 (FP1) of Europe's Rail, a conceptual data model (CDM) for railway data is being developed. This model, which will improve the possibilities to exchange data between different systems and organisations, will be based on requirements from all the flagship projects within Europe's Rail. In this chapter, the CDM requirements related to the European Railway Checkpoints (ERC) are described. First, in section 8.1, an operational analysis is performed in order to identify the data from checkpoints that are needed in different use cases. Second, in section 8.2, a requirements specification based on the operational analysis is presented. There, datatypes and semantics of the identified data are detailed. Finally, some conclusions are presented in section 8.3.

8.1. Operational Analysis

In this section, based on the operational needs reported in Deliverable 25.1, an Operational Analysis will be performed in order to allocate the different functions addressed by the ERCs. Those functions will be considered to determine the variables (entities and attributes) needed to build the CDM. Different **use cases** will be specified, identifying and grouping the needed information based on the nature of the data.

Deliverable 25.1 presented several processes at operational stopping points within the rail network, such as borders, terminals, and marshalling yards. These processes were identified as being of interest, as they presented a number of operational needs identified as candidates for digitalisation using the ERC system. By addressing these operational needs through the ERC system, the efficiency of tasks at operational stopping points, such as borders, terminals, and marshalling yards, is significantly enhanced, improving rail operations and overall network performance.

These specific use cases, addressed by the ERC, will have associated information, which will be generated or consumed by the different subsystems included within the ERC, as well as external systems within the railway system. Figure 8.1 illustrates the Data interfaces associated with ERC.



Abbreviation	Name
ERC-TS	European Railway Checkpoing Track Side
ERC-CL	European Railway Checkpoing Cloud
IAM	Intelligent Asset Management
TMS	Traffic Management System
TOS	Terminal Operating System

Figure 8.1: ERC Data interfaces.

Table 8.1 intends to summarise the operational needs identified on each operational stop point.

Table 8.1 Operational Stop Points needs (D25.1).

Operational Stop Point	Operational Digitalization Needs
Borders	*Automation of technical inspections, reduction of stop times, integration of IVG (intelligent Videogates) technologies, train composition identification, damage detection, monitoring of hazardous goods.*
Terminals	*Optimization of loading and unloading times, automatic identification of ILUs (intermodal loading units), monitoring of train status (wheels, brakes), automation of entry and exit controls.*
Shunting Yards	*Automation of wagon sequencing, detection of wear and damage on wagons and axles, monitoring of infrastructure status, integration of train and wagon recognition systems.*
Connection to Traffic Management	*Real-time data exchange with main traffic management systems, synchronization between infrastructure and operators, monitoring and adjustment of schedules, incident control, route optimization.*

Based on the previous analysis, this section will describe the operational activities carried out on each stop point. These operational activities intend to describe the processes carried out on each stop point identifying the activities where data is generated or consumed by the ERC. These data are intended to be part of the conceptual data model.

8.1.1. Cross Borders

Cross-border inspection processes for freight trains involve technical checks and operations to ensure the train's safety, compliance, and integrity before it continues its journey. These operations can be allocated as operational capabilities for the ERC system.

- ***Technical Wagon inspections:*** Performed by the Railway Undertakings (RU). This process ensures the technical reliability of the wagons, as governed by the General Contract of Use for Wagons (GCU), Appendix 9 and 10, and the Technical

Specification for Interoperability (TSI) concerning Telematics Applications for Freight (TAF TSI).

Associated Data:

- Irregularities: Data from checkpoints (image analysis, weighing in motion, or wheel impact load detection), which identifies certain types of irregularities, adhering to the standard described in Annex 1 of Appendix 9 of GCU (2024).
  Source: Checkpoints.
  Destination: Railway undertaking via data-sharing systems.
- Temperature of bearings: Measured using thermal imaging cameras or hot-box detectors.
  Source: Checkpoints, On-Board sensors.
  Destination: Railway undertaking via data-sharing systems, Data platform.
- Pantograph damage: Obtained making use of image analysis at checkpoints.
  Source: Checkpoints.
  Destination: Railway undertaking via data-sharing systems.
- Wagon outline dimensions: Measures using image analysis at checkpoints.
  Source: Checkpoints.
  Destination: Railway undertaking.
- Locomotive type: RFID readers and checkpoints provide data on locomotive types, ensuring the correct locomotives are used based on GCU and TAF TSI guidelines.
  Source: RFID readers, checkpoints.
  Destination: Railway undertaking.

- ***Train Composition Verification:*** The RU must verify the train's composition by checking the train number, locomotive numbers, wagon numbers, and the sequence of wagons. This also involves checking the intermodal loading units (ILUs), such as containers and swap bodies. The readability and visibility of all important signs, labels, and pictograms on the wagons are checked to ensure compliance with regulations.

Associated Data:

- Train numbers: Data obtained from the traffic management system or image analysis carried out at checkpoints.
  Source: Traffic management systems, checkpoints.
  Destination: Railway undertaking.

  - Locomotive types: Data from RFID readers or checkpoints is used to verify locomotive types and numbers.
    Source: RFID readers, checkpoints.
    Destination: Railway undertaking.
  - Vehicle numbers: Obtained from RFID readings or image analysis at checkpoints.
    Source: RFID readings, checkpoints, On-Board sensors.
    Destination: Railway undertaking, Data platform.
  - Position of wagons in the trains: Using RFID readers, axle counters, or image analysis processed information to verify the sequence and placement of wagons.
    Source: RFID readers, axle counters, image analysis, On-Board sensors.
    Destination: Railway undertaking, Data platform.
  - Total number of vehicles: Using RFID readers or image analysis processed information to confirm the total number of vehicles in the train.
    Source: RFID readers, image analysis, On-Board sensors.
    Destination: Railway undertaking, Data platform.

- ***Brake Test:*** A brake test must be performed on the train. If the last brake test occurred more than 24 hours ago, a full brake test is required. If not, a shorter brake test may suffice. In cases where the locomotive is changed at the border, a new full brake test is required. Due to the fact that this operation must be performed with the train stationary, the ERC system would not cover the operational need and associated activities but would only receive data from brake tests performed by the on-board system and use image analysis to check that wheels are not blocked.

- ***Incident Detection and Hazardous Material Check:*** Inspectors check for damage, rust, broken parts, or signs of hazardous materials that may pose a risk to safety. This also includes ensuring that all hazardous materials are properly documented and labelled. For freight carrying dangerous goods, the focus is on the safe containment and labelling of these goods.

  Associated Data:
  - Information about dangerous goods (substances, hazards): Obtained through image analysis at checkpoints.
    Source: Checkpoints.
    Destination: Railway undertaking.

  - Position of wagons in the trains: Using RFID readers, axle counters, or image analysis processed information to verify the sequence and placement of wagons.
    Source: RFID readers, axle counters, image analysis, On-Board sensors.
    Destination: Railway undertaking, Data platform.
  - Total number of vehicles: Using RFID readers or image analysis processed information to confirm the total number of vehicles in the train.
    Source: RFID readers, image analysis, On-Board sensors.
    Destination: Railway undertaking, Data platform.

8.1.2. Terminals

At terminals, control operations at entry and exit of intermodal loading units must be carried out according to the analysis described in D25.1. This operation centres on automating the management of intermodal units (such as containers and swap bodies) entering and exiting rail terminals, increasing the efficiency in terminal's operatives, and improving control and security.

Allocating these operations as operational capabilities for the ERC system results in the following:

- ***Automated Gate Operations***: At arrival or departure of intermodal loading units in terminals, ERCs are meant to capture the loading unit's identification details. This identification helps to the scheduling of arrivals and departures.

  Associated Data:
  - Wagon numbers (European vehicle numbers): Data obtained from RFID readers or image analysis.
    Source: RFID readers, checkpoints, On-Board sensors.
    Destination: Terminal management system, Data platform.
  - Timestamps: Time of passage through gates can be captured via wayside monitoring systems, providing precise entry and exit times of wagons or intermodal units.
    Source: Wayside monitoring systems (time of passage), On-Board sensors.
    Destination: Terminal Management System, Data platform.
  - Train numbers: Captured through traffic management systems, this data helps to ensure that corresponding intermodal units are properly scheduled.
    Source: Traffic management systems.
    Destination: Terminal management system.

  - Position of wagons in the trains: obtained from RFID readers, image analysis or On-Board sensors to capture the sequence of wagons.
    Source: RFID readers, image analysis, On-Board sensors.
    Destination: Terminal Management System, Data platform.
  - Position of loading units on wagons: obtained from image analysis to identify the exact position of intermodal loading units on each wagon of the composition.
    Source: image analysis.
    Destination: Terminal Management System, Data platform.

- ***Weight and Dimension Checking***: ERC systems might integrate weighbridges and dimension scanners to automatically verify the declared weight and size of each intermodal unit and gross weight of each wagon. These checks are critical for ensuring that the units meet safety and regulatory requirements, especially when dealing with hazardous materials or oversized cargo.

  Associated Data:
  - Wagon outline dimensions: Information obtained through image analysis at checkpoints to ensure that intermodal wagons comply with safety and regulatory requirements.
    Source: Image analysis at checkpoints.
    Destination: Terminal Management System.
  - Length of trains: This data, captured via checkpoints or wayside monitoring systems, ensures that the entire train and all its units meet the terminal's operational limits in terms of length.
    Source: Checkpoints, wayside monitoring systems.
    Destination: Terminal management system.
  - Gross weight of wagons: This data, captured via checkpoints or wayside monitoring systems, ensure that the train's weight meets the terminal operation limits in terms of weight.
    Source: Checkpoints, wayside monitoring systems.
    Destination: Terminal management system.
  - Wheel defects: Collected through image analysis, weighing in motion, or wheel impact load detection.
    Source: Image analysis, weighing in motion, wheel impact load detection.
    Destination: Terminal Management System.
  - Temperature of bearings: Collected via thermal imaging cameras.
    Source: Thermal imaging cameras, On-Board sensors.
    Destination: Terminal management system, Data platform.

- ***Data Logging and Integration with Terminal Systems***: Every movement of an intermodal unit (whether entering or exiting the terminal) must be logged automatically into the terminal's management system. This provides real-time visibility of the unit's location within the terminal and updates inventory records.

  Associated Data:

  - Timestamps: Capturing the exact time when an intermodal unit enters or exits the terminal is essential for logging and real-time tracking. This data can be provided via wayside monitoring system triggers.
    Source: Wayside monitoring systems, On-Board sensors.
    Destination: Terminal management system, Data platform.
  - Wagon numbers (European vehicle numbers): Unique identifiers for wagons, captured by RFID readers or image analysis.
    Source: RFID readers, image analysis, On-Board sensors.
    Destination: Terminal Management System, Data platform.
  - Position of wagons in the trains: Obtained by processing RFID readers or image analysis data.
    Source: RFID readers, image analysis, On-Board sensors.
    Destination: Terminal Management System, Data platform.
  - Total number of vehicles: Obtained by processing RFID readers or image analysis data.
    Source: RFID readers, image analysis, On-Board sensors.
    Destination: Terminal Management System, Data platform.
  - Train number: Obtained from the Traffic Management System.
    Source: Traffic management system.
    Destination: Terminal management system.
  - Locomotive types: RFID readers and checkpoints provide data on locomotive types, ensuring the correct locomotives are used based on GCU and TAF TSI guidelines.
    Source: RFID readers, checkpoints.
    Destination: Terminal management system.

8.1.3. Shunting Yards

In shunting yards, automated wagon sequencing is a critical process where incoming trains are disassembled, and wagons are reorganized based on their destination, cargo and other operational requirements. The goal of the ERC systems is to automate operational processes, enhancing both speed and precision, while minimizing human intervention and the associated risks.

- ***Train Arrival and Data Acquisition***: When a train arrives at the shunting yard, the first step in the wagon sequencing process involves gathering detailed information about the train and its wagons. Here, ERC systems might use sensors to capture essential data which includes wagon numbers or loading unit details.
  The yard management system automatically cross-references the incoming train's composition with pre-existing schedules and load plans. The automation of this initial step eliminates manual data entry, significantly reducing the possibility of human error and expediting the data acquisition process.

  Associated Data:

  - Train numbers: Data from the traffic management system provides the unique identifier for the arriving train. This allows the yard management system to cross-reference the train with pre-existing schedules and operational plans.
    Source: Traffic management system.
    Destination: Yard management system.
  - Wagon numbers (European vehicle numbers): Captured through RFID readers or image analysis at the entry points capture the individual wagon numbers as part of the train arrival process.
    Source: RFID readers, image analysis at entry points, On-Board sensors.
    Destination: Yard management system, Data platform.
  - Total number of wagons: Obtained by processing data from image analysis or RFID readings.
    Source: Image analysis, RFID readers, On-Board sensors.
    Destination: Yard management system, Data platform.
  - Position of wagons in the trains: Obtained by processing data from RFID readers, axle counters, or image analysis.
    Source: RFID readers, axle counters, image analysis, On-Board sensors.
    Destination: Yard management system, Data platform.
  - Wagon outline dimensions: This data is captured through image analysis systems as the train arrives, ensuring that any wagons requiring special handling or specific routes through the yard due to size are identified early in the process.
    Source: Image analysis.
    Destination: Yard management system.
  - Locomotive types: RFID readers and checkpoints provide data on locomotive types, ensuring the correct locomotives are used based on GCU and TAF TSI guidelines.
    Source: RFID readers, checkpoints.
    Destination: Yard management system.
  - Timestamps: Captured when the train arrives provide a precise record of when the data acquisition process begins.

  Source: Checkpoints (upon train arrival), On-Board sensors.
  Destination: Yard management system, Data platform.
  - Information about dangerous goods (substances, hazards): Obtained through image analysis in order to log any dangerous or hazardous materials being transported in the wagons.
    Source: Image analysis at checkpoints.
    Destination: Yard management system.

- **Technical wagon check at yard exit:** Before leaving the shunting yard, the wagons of the compositions generated must undergo a technical inspection to verify that their condition complies with the established regulations, in the case of the GCU regulations, Annex 1 of Appendix 9.

  Associated Data:
  - Irregularities: Data from checkpoints (image analysis, weighing in motion, or wheel impact load detection), which identifies certain types of irregularities, adhering to the standard described in Annex 1 of Appendix 9 of GCU (2024).
    Source: Checkpoints.
    Destination: Railway undertaking and Yard Management system.
  - Temperature of bearings: Measured using thermal imaging cameras or hot-box detectors.
    Source: Checkpoints, On-Board sensors.
    Destination: Railway undertaking and Yard Management System.
  - Pantograph damage: Obtained making use of image analysis at checkpoints.
    Source: Checkpoints.
    Destination: Railway undertaking and Yard Management System.
  - Wagon outline dimensions: Measured using image analysis at checkpoints.
    Source: Checkpoints.
    Destination: Railway undertaking.

8.1.4. Workshops

- ***Integration with wear detection systems and wagon tracking:*** Once the wagons are recognized by the ERC system, they are processed through a series of automated **wear detection sub-systems**. These sub-systems are designed to assess the condition of critical wagon components such as wheels, brakes, axles, and couplers.
  As the wagon passes through the detection systems, the sensors gather data on the condition of each component, which is then automatically analyzed by the

system. Any detected anomalies (such as cracks in the axles, thinning brake pads, or worn wheel treads) are flagged in the system for immediate attention.

Associated Data:

- Irregularities: Damages or other irregularities identified on wagons or intermodal loading units, associated to the ones described in the Annex 1 of Appendix 9 of GCU (2024). These aspects might be identified by the checkpoint or wayside monitoring systems
  Source: Checkpoints or wayside monitoring systems.
  Destination: Workshop management system, Data platform.
- Wheels damage: Data from checkpoints (image analysis, weighing in motion, or wheel impact load detection) and wheel impact load detectors.
  Source: Checkpoints, wheel impact load detectors.
  Destination: Workshop management system.
- Temperature of bearings: Measured using thermal imaging cameras or hot-box detectors.
  Source: Thermal imaging cameras, hot-box detectors, On-Board sensors.
  Destination: Workshop management system, Data platform.
- Pantograph damage: Obtained making use of image analysis at checkpoints.
  Source: Checkpoints (image analysis).
  Destination: Workshop management system.
- Wagon numbers (European vehicle numbers): Captured through RFID readers or image analysis at the entry points capture the individual wagon numbers as part of the train arrival process.
  Source: RFID readers, image analysis at entry points, On-Board sensors.
  Destination: Workshop management system, Data platform.

  - Status of Axles: Acquired with onboard sensors and sent to a Data Platform.

  Source: Onboard sensors.
  Destination: Data platform.
  - Status of Springs: Acquired with onboard sensors and sent to a Data Platform.

  Source: Onboard sensors.
  Destination: Data platform.
  - Status of Brakes: Acquired with onboard sensors and sent to a Data Platform.

  Source: Onboard sensors.
  Destination: Data platform.
  - Status of the Kingpin or twistlock: Acquired with onboard sensors and sent to a Data Platform.

Source: Onboard sensors.
Destination: Data platform.

- Status of the cargo: Acquired with onboard sensors and sent to a Data Platform.

Source: Onboard sensors.
Destination: Data platform.

8.2. Data requirements specification

This section is a specification of the requirements on the data that were identified in section 8.1. These requirements are intended to be used in the development of the conceptual data model. In the specification, each identified entity (train, vehicle, intermodal loading unit, and so on) is described in a separate table, which is a list of the attributes of the entity, along with their datatypes and semantics (interpretation, unit of measurement, standard to follow, and so on). Most attributes are non-mandatory, although it is desirable to include as many as possible in each entity instance. Mandatory attributes are indicated in the text between the tables.

Relationships between entity instances are also described in the text between the tables. The descriptions include multiplicity constraints on the relationships. When interpreting these constraints, it is important to bear in mind that entity instances do not refer directly to physical objects, but to occasions when such objects were registered by a checkpoint or a WOBU. For example, a constraint saying that a vehicle is part of at most one train does not prohibit that a physical vehicle is (over time) part of several physical trains.

All entity instances can be associated with metadata indicating where and when the data were registered, see Table 8.2. If an entity instance is not directly associated with such metadata, there must be metadata associated with an entity instance that (directly or indirectly) “encloses” it. For example, if metadata are missing for an irregularity, there must be metadata available at the corresponding intermodal loading unit, vehicle (locomotive or wagon) or train, and those metadata shall be regarded as associated with the irregularity, too. This way, it must be possible to find a timestamp for each entity instance, as well as (unless a checkpoint ID can be found) a latitude and a longitude. In addition to the metadata listed in the table below, it must be possible to associate individual attributes of all entity instances with *measures of uncertainty*, such as confidence intervals and confidence scores.

Table 8.2 Metadata for an entity instance.

Metadata		
Attribute	*Datatype*	*Semantics*
Checkpoint ID	String	Unique ID of the checkpoint where the data were registered
Latitude	Floating-point number	The latitude where the data were registered, in decimal degrees
Longitude	Floating-point number	The longitude where the data were registered, in decimal degrees
Timestamp	String	The point in time at which the data were registered, expressed in the timestamp format generally used by the CDM

The attributes of trains are listed in Table 8.3. For each train, it is mandatory to include a train ID and the total number of vehicles.

Table 8.3 The train entity.

Train		
Attribute	*Datatype*	*Semantics*
Train ID	String	If available, an internationally unique ID for the train, adhering to the standard generally used by the CDM and possibly based on the element TrainID in ERA (2024) If no such ID is available, a unique ID based on the timestamp and the location of the registration of the data
Total number of vehicles	Integer	The total number of vehicles in the train, including both locomotives and wagons
Length	Floating-point number	The length of the train in metres

Each train consists of one or several vehicles, and each vehicle is part of at most one train (see above for an explanation of how to interpret these constraints). That is, a vehicle can be registered without being part of a train (for example, at a yard). A vehicle is either a locomotive or a wagon. Table 8.4 lists the attributes that are associated with all vehicles, while Table 8.5 lists the attributes that are specific for wagons. If a vehicle is part of a train, it is mandatory to include its position among the vehicles of the train. Likewise, if such a vehicle is a wagon, it is also mandatory to include its position among the wagons of the train.

Table 8.4 The vehicle entity.

Vehicle		
Attribute	*Datatype*	*Semantics*
Vehicle number	String	ID consisting of twelve digits and adhering to the standard for European vehicle numbers as described in Appendix 6 of EU (2018), including (for locomotives) that the second digit indicates locomotive type
Position among vehicles in train	Integer	Index of the vehicle among the vehicles of the train (if it is part of a train), counting the initial vehicle in the train's direction of movement as number 1

Table 8.5 The wagon entity.

Wagon		
Attribute	*Datatype*	*Semantics*
Position among wagons in train	Integer	Index of the wagon among the wagons of the train (if it is part of a train), counting the initial wagon in the train's direction of movement as number 1, as in the element WagonTrainPosition in ERA (2024)
Gross weight	Floating-point number	The gross weight of the wagon in kilograms
Payload weight	Floating-point number	The weight of the payload of the wagon in kilograms
UN numbers	List of strings	The UN numbers (four digits) from the orange-coloured plates of the wagon, as described in OTIF (2023)
WOBU ID	String	Unique ID of the WOBU of the wagon

Each wagon may carry zero, one or several intermodal loading units (ILUs). The zero ILUs case occurs if (a) the wagon is an intermodal wagon that is empty (unloaded) for the time being or (b) if the wagon is not an intermodal one (and thus cannot carry any ILUs). The attributes of ILUs are listed in Table 8.6. It is mandatory to include the position on the wagon for each ILU.

Table 8.6 The intermodal loading unit entity.

Intermodal loading unit		
Attribute	*Datatype*	*Semantics*
Loading unit code	String	If available, an ID consisting of four letters and seven digits, adhering to the compatible standards for ILU codes or BIC codes, as described in UIRR (2011) If no such ID is available, any other ID for the loading unit
Position on wagon	Integer	Index of the loading unit within the wagon, counting the initial loading unit in the train's direction of movement as number 1
Type	String/enum	Loading unit type, chosen from a closed set of types (*container*, *semi-trailer*, *swap body*, *other*)
UN numbers	List of strings	The UN numbers (four digits) from the orange-coloured plates of the loading unit, as described in OTIF (2023)

Each vehicle and ILU may be associated with one or several irregularities (damages or other problems). The attributes of irregularities are listed in Table 8.7. It is mandatory to include an irregularity code for each irregularity. Note that irregularities do not directly include any measured values (for example, temperatures or sizes), but give information about damages and other problems indicated by the measurements that have been made. *However, the conceptual data model should preferably be designed in such a way that any measured value that is not included in this requirements specification can be added as an attribute to trains, vehicles, ILUs and cargo.*

Table 8.7 The irregularity entity.

Irregularity		
Attribute	*Datatype*	*Semantics*
Irregularity code	String/enum	If available, a code identifying the irregularity, adhering to the standard described in Annex 1 of Appendix 9 of GCU (2024) For irregularities related to pantographs, no standardised codes are available, so one of the following strings (or a shortened version thereof) should be used instead: • *carbon strip thin* • *litz wire incorrectly mounted* • *height limiter not working* • *two pantographs up* • *carbon strip skew* • *push-up force too high* • *push-up force too low* • *litz wire on knee joint incorrectly mounted* • *auto drop-down air hose defective* • *roof plate defective* • *object in pantograph*
Position	String/enum	Code identifying the axle and/or the side of the vehicle or intermodal loading unit where the irregularity has been found (for example, “1L” for the left-side wheel that is closest to the front, “2” for the second axle, “R” for the right side – everything based on the examination plate that is located in the left back of the wagon)

Each wagon and intermodal loading unit may carry cargo. The attributes of cargo are listed in Table 8.8.

Table 8.8 The cargo entity.

Cargo		
Attribute	*Datatype*	*Semantics*
Temperature	Floating-point number	The temperature of the cargo in °C
Relative humidity	Floating-point number	The relative humidity of the cargo in percent
Pressure	Floating-point number	The pressure of the cargo in hPa

8.3. Conclusion

Chapter 8 highlights the fundamental role of the development of a Conceptual Data Model (CDM) and its implication in the functionalities of the European Railway Checkpoint (ERC) system for the improvement of operational processes in the rail freight environment, the digitalisation of these processes and the improvement of interoperability and harmonisation in the sector.

In Chapter 8, an *Operational Analysis* has been developed, based on the conclusions obtained in D25.1, "*Report on the basic functional and technical specifications for the realisation of the technical enablers of Seamless Freight, also including the final specification input for FP1*", by means of which a series of use cases and operational activities of various operational points of the railway system have been identified. For these activities, a specification of requirements associated with the data involved has been developed. These requirements must be considered in the development of the CDM to ensure seamless integration and interoperability. The specification includes information on trains, vehicles, ILUs, irregularities and freight.

Future work, in coordination with WP32 and FA1 (Transversal Topic), will establish the necessary guidelines for integrating this data model into the development of the systems. In turn, this integration will be evaluated in the different demonstrators associated with WP29.

9. Harmonized procedures and regulations

As described in chapter 5 different demonstrators are ongoing and planned in different countries and locations in Europe. The demonstrators have varying emphasis on different operational procedures and use cases and hence different functionalities and technologies are incorporated. Thus, there is no one solution fits all, but in order to achieve as high degree of standardisation as possible for the development of the Checkpoints, a **Minimal Viable Product (MVP)** was specified in Task 25.4 and summarized below with all mandatory requirements.

Functional Requirements

- The camera resolution is high enough to enable OCR reading of the smallest character on the wagon/container passing the camera on the track.
- The system shall identify for each wagon the following: EVN (European Vehicle Number) of passing vehicle, BIC/ILU codes of containers, orange-coloured plates, placards and ideally other cargo information (owner, weight, etc.) of the wagons passing the camera on the track.
- The system must identify dangerous goods signs on containers on wagons passing the camera on the track.
- The system is expandable with other sensors/measurement systems (RFID, Hotbox, wheel profile measurements).
- The system should identify:
  The position of each wagon.
  The direction in which the train is moving.
  The total count of wagons.
- The system needs to identify itself so that downstream systems know the origin of the data.

Non-functional requirements

- The system detection rate reaches 95% on a benchmark basis.
- The system needs to put the information into a common well-known format.
- The system works 24/7 in all weather conditions and for trains/wagons that pass by until 140km/h, that break, stand still or accelerate in front of the camera.
- The system is installed at relevant sites for capturing rolling stock traffic.
- The system shall not interfere with the normal train operation.
- The system follows existing European regulations (for example GDPR).

In order to identify regulatory barriers for harmonized procedures and suggest supporting methodologies to mitigate them, the current main procedures in existing gates are described in the next step. Subsequently, suggestions are proposed for aspects of the procedures that could be harmonized for all gates and as a basis for further standardisation.

9.1. Operational procedures, identification of regulatory barriers and supporting methodologies

This section describes the current main procedures for the existing gates and identifies relevant regulations and regulatory barriers for the procedures.

9.1.1. Maintenance ordering

Current operational procedure described by DB:

During Fr8Rail IV – WP 2 (https://cordis.europa.eu/project/id/101004051) the traditional maintenance ordering process at the yards in Germany was digitised. Therefore, the evaluation and commissioning process was digitised and changed to a new process. Due to the change in the job profile of the employees of maintenance commissioning, the designation in Digital Diagnosticians has also changed.

The maintenance process is now followed by six steps that are shown in Figure 9.1. For this purpose, IVGs were installed on the hump of marshalling yards. With the help of this, the freight wagons are visually recorded as they pass through. That results in high-resolution images of the wagons passing through from several sides. Each freight wagon that passes over the hump and thus through the IVG is automatically photographed and the recorded images are then uploaded directly into the diagnostic software of DB. In order to identify damage in the best possible way, the Digital Diagnosticians have the option of making various image settings, such as adjusting the brightness. The damage recording can then be started, for example, by marking the damage. This means that the Digital Diagnosticians both see and evaluate the freight wagon images in digital form and thus, they carry out the inspection of the freight wagons at an office workstation with at least one monitor. After the digital diagnosis, the findings are then transferred automatically to the worklist of the workshop – without any paperwork. According to the usual commissioning process, the work orders are transferred to the workshop so that they can quickly start with the repairs. As soon as the maintenance work is completed and the wagon has been repaired, the Digital Diagnosticians initiate the recommissioning process, and the wagon can be used again for freight transport.

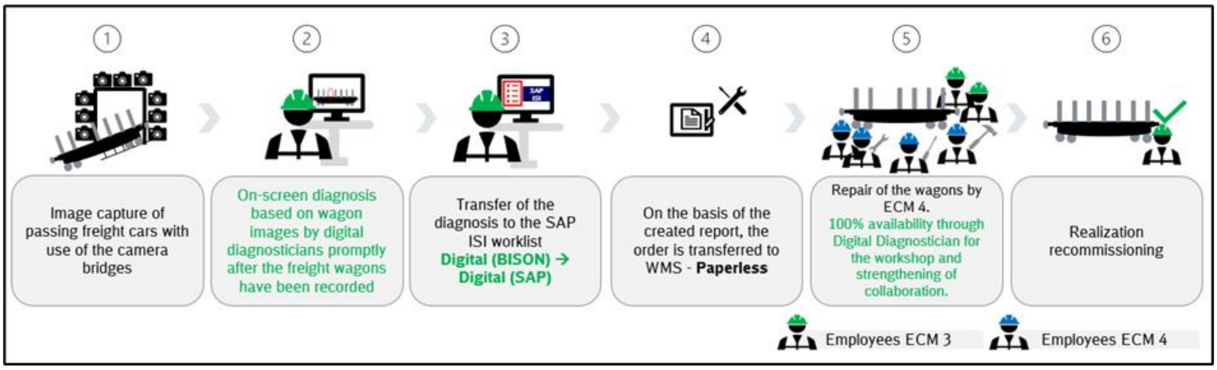


Figure 9.1 Transformed maintenance ordering process at DB Cargo (Fr8Rail IV D2.3, 2022)

Methodologies for harmonization

The process of maintenance ordering (ECM 3) is strongly influenced by the GCU (2024) Appendix 10 (General Contract of Use for Freight Wagons). It is therefore essential that the GCU can be carried out at least in part using digital tools such as cameras or sensors.

The sensor and image data must be assigned to the freight wagons, for which the UIC number is suitable. In addition, a minimum standard of image data per IVG must be met. For the views, the minimum is the view from the left and right, then from the top, front, rear and bottom.

The quality or resolution of the image data (or sensors) limits the different types of damage that can be recognised. It is therefore relevant to coordinate the minimum characteristics of relevant damage to be recognised.

Furthermore, the exchange of data is essential for cross-border traffic. This involves not only optimizing operational processes but also improving data quality and consistency within national systems. In addition, both images and analysis results can be integrated into various process steps, such as wagon inspections and diagnostics in the maintenance process. Moreover, condition information helps optimize the route planning of vehicles (locomotives, wagons) at an early stage. Another important aspect is the enhancement of traffic safety. Continuous data collection and exchange enable earlier diagnosis of vehicle damage, allowing for preventive measures to be planned. This, in turn, can accelerate the current transportation process and reduce delays within the overall system.

9.1.2. Wagon inspection and confirm wagon set

Current operational procedure described by ProRail:

Current: The Wagon Inspection procedure for Pantograph monitoring and wheel brake monitoring takes place on set points along the tracks. In the current test phase, the monitoring is actively checking damages to the pantographs and brakes of freight trains in the Rotterdam area. The reason for testing in a low-speed area is making sure the accuracy and effectivity can be proven. When a defect is detected the train operator is contacted trough an e-mail alert. Detected damages must be fixed by the train operators.

Future: Pantograph damages can take down/break powerlines; however, they are easily detected by placing smart cameras at gates on a set number of points. By removing and repairing pantographs in an early stage the damage to the powerlines will be minimal. The same process is applicable for the brakes. By detecting problems early, the damages done to the tracks by flat wheels and or fire damage from a stuck brake system can be detected early. With a warning going out to the train operator damages can be mitigated.

Installing both the pantograph and brake detection system on the gates will mitigate future damages to the rail infrastructure. Cameras can be mounted on the same base or multiple use cameras can be chosen for the gates.

Current operational procedure for conformation of wagon sets is done by comparing the detected UIC codes with the Wlis (Dutch interpretation of the TCM) based on the Train Composition Message (TCM). By comparing the results from the UIC codes with the composition list (Wlis), errors are detected. Currently there is no active process for sharing the result of the wagon sets with all exploiters.

Methodologies for harmonization

Specifically for the confirmation of wagon sets, it is important to have the (placing of) UIC codes on the wagons harmonized. Ideally, this includes the font and size of UIC codes. Also, the image quality of the camera's should conform to a certain minimum resolution and can be harmonized for all gates, so image recognition will be possible in all different countries.

9.1.3. Dangerous goods by rail

Current operational procedure described by Trafikverket

The most widely applied regulatory scheme is that for the transportation of dangerous goods. The United Nations Economic and Social Council issues the UN Recommendations on the Transport of Dangerous Goods, which form the basis for most regional, national, and international regulatory schemes. For instance, the International Civil Aviation Organization has developed dangerous goods regulations for air transport of hazardous materials that are based upon the UN model but modified to accommodate unique aspects of air transport. Individual airline and governmental requirements are incorporated with this by the International Air Transport Association to produce the widely used International Air Transport Association (IATA) Dangerous Goods Regulations (DGR). Similarly, the International Maritime Organization (IMO) has developed the International Maritime Dangerous Goods Code ("IMDG Code", part of the International Convention for the Safety of Life at Sea) for transportation of dangerous goods by sea. IMO member countries have also developed the Hazardous and Noxious Substances (HNS) Convention to provide compensation in case of dangerous goods spills in the sea.

The Intergovernmental Organisation for International Carriage by Rail has developed the regulations concerning the International Carriage of Dangerous Goods by Rail ("RID", part of the Convention concerning International Carriage by Rail). RID is an abbreviation of the French Règlement Concernant le Transport International Ferroviaire Marchandises Dangereuses. The road equivalent is called ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road) and is basically the same as RID but with road-specific sections. Many individual nations have also structured their dangerous goods transportation regulations to harmonize with the UN model in organization as well as in specific requirements. See figure 9.2.

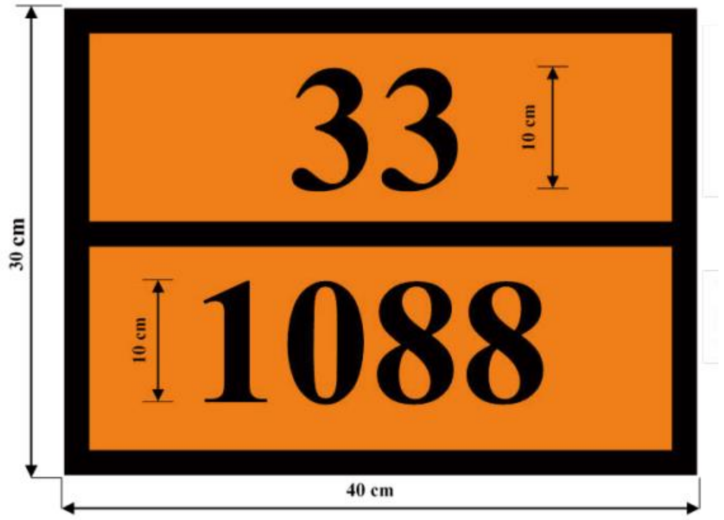


Figure 9.2 Example of orange-coloured plate with ADR/RID Hazard Identification Numbers (2-3 digits) and UN number (4 digits), complemented with specific plate measurements (MSB, 2023)

In Sweden, dangerous goods on rail are regulated in RID-S issued by The Swedish Civil Contingencies Agency (MSB). The Swedish Transport Agency reviews compliance. MSB has market control. Today, Trafikverket receives the UN number and the carriage's position from the railway companies via data transfer, which according to RID-S is what is required. RID an international set of regulations with the same meaning throughout Europe and within the UN. RID-S is a Swedish translation where there is room for Swedish special rules, however not of a significant nature. Similar exists for all countries, with the possibility of local editions for each country.

Methodologies for harmonization

For containers and swap bodies, the placards (see Figure 9.3) do not need to be read as equivalent information can be gathered from UN codes. However, Semi-trailers cannot be read in the same manner as there is the UN number are not located on the side of the unit but on the front and rear side, then the camera must be aimed at the front and rear trunk which implies a higher cost.

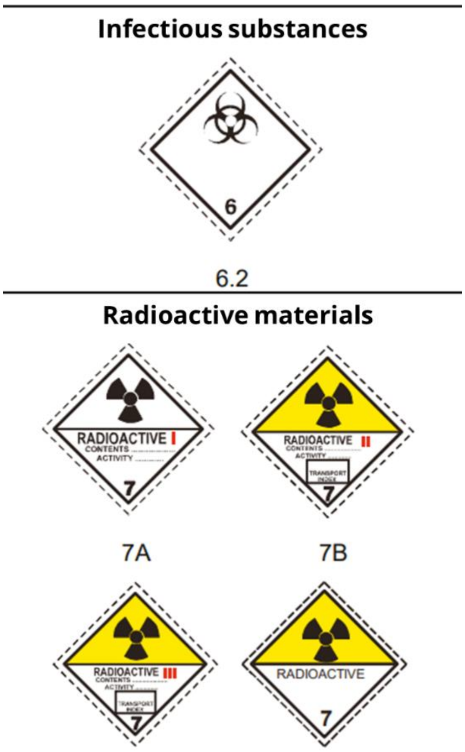


Figure 9.3 Examples of placards for dangerous goods (MSB, 2023)

9.1.4. Data exchange

Current operational procedure described by ProRail and Trafikverket

As the procedures for and harmonisation of data exchange are addressed in subtask 29.1.3 in chapter 7 as well as in the alignment with System Pillar project HERD, see section '9.2 Alignments', brief description of the operational procedures for data exchange is presented in this section for two of the existing systems; ProRail and Trafikverket, as well as how Adif handles data exchange and cybersecurity. Finally, reference to WP32 related to seamless data-exchange is identified.

ProRail: Data exchange is currently done on an internal level with an alarm e-mail going out to the freight train operators when we detect a problem.

Trafikverket: The flow of data from the demonstration gate in Gothenburg that was installed within Shift2Rail project FR8RAIL III, is illustrated by Figure 9.4. T The data is first stored sent on site on a Hitachi FTP server of and Indra collect the data to a DTS platform for image analysis. In the next step, a data sharing system called *Deplide* has been used for distributing the data from the gate in Gothenburg.

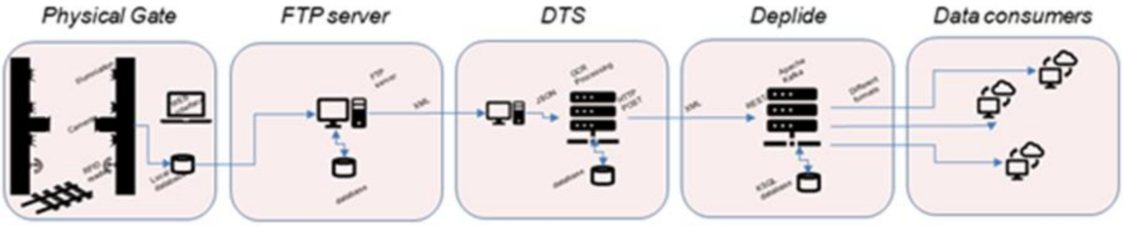


Figure 9.4 Data flow chart for the demonstration gate in Sweden

For each train registered by the IVG, a Deplide topic receives the output of the image processing system as a message in XML format. A specially developed software component, a so-called *stream processor*, transforms the message into one message per wagon in the train. These wagon messages, which are published on another Deplide topic, mainly follow a general format called *Railway Coordination Messaging Format* (RCMF), which is also used in other railway-related RISE projects. However, to fulfil the needs of this project, the messages also contain some data that are not part of basic RCMF. Examples of such data are RFID readings and ILU information.

Today there are various data formats in place. RNE (Rail Net Europe) has some system running such as TIS (Train Information System). That one is using Technical Specification for Interoperability relating to Telematics Applications for Freight Services (TAF/TSI) protocols and the TIS show freight train movements in real-time all-over Europe. For RFID readings there are a EPCIS standard in place for many IM's in Europe, RFID for Rail, which was launched some ten years ago. EPCIS Standard enables disparate applications to create and share visibility event data, both within and across enterprises. It is a ratified standard developed by GS1 and its contributors from various industries and regions.

Moreover, as for sharing of images and data retrieved from the gates this process must adhere to GDPR (General Data Protection Regulation) Regulation (EU) 2016/679.

Related to Cybersecurity topic, ADIF, as a public entity, is obliged to comply with the National Security Scheme (NSS), established in article 42 of Law 11/2007, of June 22, on electronic access by citizens to Public Services and regulated by Royal Decree 3/2010, of January 8, updated by Royal Decree 311/2022, of May 3.

The legal mandate of the NSS is essentially the protection of the information processed, and the services provided and must be technically applied to all elements that, in relation to such information or services, may be directly or indirectly attacked in their confidentiality, availability, integrity, traceability and authenticity.

The elements to be preserved are: hardware, software, information media, communications, facilities, personnel and services provided by third parties.

Therefore, ADIF has obligations regarding the information/documentation that it manages itself or shares with third parties, to protect the services, information and systems against possible threats that negatively impact the operation of ADIF's business.

The degree of sensitivity of the information owned by ADIF is defined in the internal document “ADIF-PG-108-007-N08-01 Classification of Information and Labelling of Documents.” and is classified based on the impact that its loss or inappropriate use would have on the business. The person responsible for the information/service has identified the degree of classification of the information/application/service that is the subject of this declaration.

Within the framework of the development of innovation projects, ADIF applies this Cybersecurity procedure, with the establishment of a specific procedure that includes the signing of an agreement with any entity that needs ADIF data.

This entity undertakes to comply with and respect, in relation to confidential information, the applicable legislation on Industrial Property, Intellectual Property, Trade Secrets and, in particular, with regard to the protection of personal data contained in Regulation (EU) 2016/679 of the European Parliament and of the Council of April 27, 2016 ("GDPR") and the Organic Law on Data Protection and Guarantee of Digital Rights 3/2018 of December 5 (LOPDGDD), with regard to the processing of personal data and the free circulation of these data (or regulations that develop and/or replace them), and the rest of the applicable regulations in force.

Finally, related to data-exchange there is the need to align with the work that is being done in WP32, mainly related to the topics of the use of Conceptual Data Model (CDM) for the data to be exchanged, and also the Data Spaces (by following International Data Space Association RAM – Reference Architecture Model) as the enabler for trustful and secure data exchange.

Methodologies for harmonization

ProRail: With the use of universal gates a system of alarms and communication would be mandatory. Identification of the train and operator can be done by using a smart camera system to read the UIC train number and directly contact the operator (real time) when a problem is detected.

TRV: If the checkpoints should be able to communicate with each other, some kind of common data format is needed. As described above, there are various formats in place today.

9.1.5. Border inspection

Current operational procedure described by ÖBB and Trafikverket

Trafikverket: Today rail operators and IM's share data according to *TAF/TSI* regulation. The data is solely data of the overhanded train to another IM or rail operator. It contains data needed for the incoming operator and allows them to plan and check the composition of trains including length, gross weight and, if applicable, where dangerous goods are in the trains.

There are also at least as important checks of technical and safe running procedures when handover train between IM's at borders. There are some agreements made between the main actors like the *General Contract of Use for Wagons (GCU)* and *Agreement on freight Train Transfer Inspection (ATTI).* GCU (2024) is a multilateral contract based on the international convention COTIF 1999 and Annex CUV. The GCU specifies the mutual rights and obligations of Wagon Keepers (K) and Railway Undertakings (RU) with regard to the use of rail freight wagons as a means of transport throughout Europe and beyond. ATTI (UIC, 2017) points at ATTI members' responsibilities compliance with the terms of the Internal Regulations and the ATTI Agreement.

The operational procedures described by ÖBB has been presented in D25.1 why here we only summarise the main elements and the identified regulations.

Every railway undertaking must make a technical inspection of the wagons at the border when taking over a train in order to guarantee its technical reliability. This obligation is governed by TAF TSI.

The basis for this technical wagon inspection is the GCU which specifies the mutual rights and obligations of Wagon Keepers (K) and Railway Undertakings (RU) regarding the use of rail freight wagons as a means of transport throughout Europe and beyond. All technical conditions for wagon transfers and inspections between railway undertakings are defined in Appendix 9 to the GCU (2024).

To minimize the inspection effort on the borders, the International union of railways (UIC) established ATTI. The ATTI Special Group (ATTI SG) sets the rules governing the transfer of wagons between participating RUs, based on the GCU (UIC, 2017). To facilitate international freight transport, the participating RUs undertake to comply with the current internal regulations, including appendices. The objective of the ATTI SG is to enhance cooperation between RUs, harmonizing and developing the relevant rules accordingly. It aims to allow better forward planning as well as to increase the quality and safety of trains subject to the agreement.

To main goal of ATTI is that the acceptance sampling and transfer inspection at the handover location is replaced by quality spot-checks. This means that between two ATTI participants the inspections at the borders can be omitted. There are 174 members of the ATTI (UIC, 2023).

Moreover, if there is no change of the train driver and the train starts within 1 hour and there is no switch of locomotive – there is no need of a short brake test. If there is a change of train driver, a short brake test is going to be needed or a complete brake test if the last brake test is older than 24 hours. A short brake test can be done by one worker, while a complete brake test requires two.

Methodologies for harmonization

To summarise, the main opportunities concerning Checkpoints on borders are:

- Support the train inspection on borders with defined checks of wagons and load for non-ATTI trains to minimize train stopping time
- Check the train composition
- Check that wagons do not cause damage to the infrastructure

By increasing the automation level of inspections and wagon set confirmation, the checkpoints can enable higher level of efficiency and harmonisation of the procedures at borders. Furthermore, this can also be achieved by promoting and extending ATTI as the detailed inspections according GCU appendix 9 can be reduced.

9.1.6. Procedures for installation and procurement

Current procedure described by Trafikverket and Adif

Trafikverket are planning to deploy two Checkpoints beyond the first already commissioned in Gothenburg, close to the port. This one operates since 2,5 year ago and is considered as a test bed.

The functionality for our gates originates mainly from to capture of logistic data. As a test we will, together with Hitachi, place a lower camera to inspect the wheel area of the wagons, including springs, brakes etc.

The installation plan for the second gate is set to 2025, the aim is that it should be commissioned in Q2 or Q3. For gate three the date is not set yet. The already existing gate is on a single-track area and for gate two it is on a double track which has different prerequisites and adaptations must be done accordingly.

In order to get the gate running smoothly there is also need for maintenance. As this is a research project the procurements procedures will be different than the standard ones. Normally when Trafikverket procures, we buy a finished product with special requirements that must be met. In the normal case the requirements are made in advance but in this project, we will do it a little bit backwards, do the technical approved procedure after to be able to bring it into Trafikverket's eco system as an owned asset.

In the Spanish railway network, managed by *Adif,* there is a regulatory barrier due to the risk analysis procedure regulation 402/2013, a mandatory procedure before installing any installation or equipment on the track, including control points, in the General Interest Railway Network (RFIG). This regulation is a transposition of the directive 2004/49/CE of the European Parliament, which in the Spanish case is called: "Implementing Regulation, Number 402/2013, of the commission of April 30, 2013 regarding the adoption of a common safety method for the evaluation and assessment of risk".

Methodologies for harmonization

Trafikverket:

Many lessons are learned and the performance isregularly improved. At the moment, the gate works close to the requirements and expectations that were set in Shift2Rail (FR8HUB WP4, FR8RAIL3 WP3). We are taking all these experiences into account when gates number two and three are planned.

Very close cooperation with our technical partners in Europe's Rail is a key factor when planning and procure functionality. As equal importance is to convince and prove for the stakeholders that the checkpoints and gates will enhance the information flow.

Adif:

The use of regulation 402/2013 involves a series of steps and prior evaluation work, which must conclude by considering whether the risk of setting up this control point is significant or not significant. If it is not significant, the control point can be installed without any obstacle, within the procedure. However, if it is concluded that the risk is significant, it must be mitigated with a risk analysis, which must be carried out by an assessment body (AsBo) external to Adif. All these steps lengthen the acceptance processes for the installation of the equipment to several months and even, in our own experience, to a little over a year.

On the other hand, it is necessary to establish who is civilly responsible in the event of an accident, incident or delay on the track, as a result of the installation of this control point on the track, and it is necessary to have a policy that ensures compensation in any of the above cases. Currently, it is the Spanish infrastructure manager, Adif, that covers the costs of material or personal damages that may occur as a result of an accident. In the next innovative projects that are developed, Adif will sign an agreement with companies that wish to install innovative equipment on the track, so that these companies take out a civil liability policy that will cover them in the event of an accident.

Within these evaluation works is the study of Electromagnetic Compatibility, according to Railway applications - Electromagnetic compatibility EN 50121, since one of the risks that must be covered is the potential effect of these fields generated on the safety equipment on the track or even on the rolling stock that may alter its normal operation.

9.2. Summary of results

Table 9.1 presents a summary of identified procedures (step 1), identified regulatory framework and barriers (step 2) and suggested mitigation measures for harmonized procedures (step 3).

Table 9.1 Summary of identified procedures, regulatory framework and barriers and Suggested mitigation measures for harmonized procedures.

	Step 1	**Step 2**	**Step 3**
Identified procedures:	**Current description provided by:**	**Identified regulatory framework / barriers:**	**Suggested mitigation measures for harmonized procedures:**
Maintenance ordering	DB	GCU Appendix 10 (General Contract of Use for Freight Wagons).	It is essential that GCU Appendix 10 can be carried out at least in parts using digital tools such as cameras or sensors.
Wagon inspection	ProRail	UIC codes	Placing of UIC codes on the wagons could be harmonized. Ideally, this includes the font and size of UIC codes
Confirm wagon set	ProRail	UIC codes	Placing of UIC codes on the wagons could be harmonized. Ideally, this includes the font and size of UIC codes

Dangerous goods	TRV	● UN Recommendations on the Transport of Dangerous Goods ● International Carriage of Dangerous Goods by Rail ("RID") (Règlement Concernant le Transport International Ferroviaire Marchandises Dangereuses). ● Road equivalent is called ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road	For containers and swap bodies, the placards do not need to be read as the equivalent information can be gathered from UN codes. However, Semi-trailers cannot be read in the same manner as there is the UN number are not located on the side of the unit but on the front and rear side, then the camera must be aimed at the front and rear trunk which implies a higher cost.
Data transfer and Cybersecurity	Task 25.4, Task 29.1.3, ProRail, TRV, Adif	● Sharing of images and data retrieved from the gates this process must adhere to GDPR (General Data Protection Regulation) Regulation (EU) 2016/679. ● Ru's and IM's share data according to TAF/TSI regulation ● Regarding RFID readings there is a EPCIS standard ot adhere to. ● The eFTI Regulation which is set to transform freight transport within the EU by replacing paper-based documentation with electronic data in all transport mode ● Within the framework of the development of innovation projects, ADIF applies a Cybersecurity procedure that includes the signing of an agreement with any entity that needs data from Adif. This entity undertakes to comply with and respect, in relation to confidential information, the applicable legislation on Industrial Property, Intellectual Property, Trade Secrets and, in particular regarding the protection of personal data contained in Regulation (EU) 2016/679 of the European Parliament and of the	A system of alarms and communication would be mandatory. If the checkpoints should be able to communicate with each other, a common data format is needed

		Council of April 27, 2016 ("GDPR") and the Organic Law on Data Protection and Guarantee of Digital Rights 3/2018 of December 5 (LOPDGDD)	
Border inspection	Task 25.4, ÖBB, TRV	ATTI or GCU Appendix 9. GCU Appendix 9 implies time consuming manual inspections.	● Increase automation level of inspections and wagon set confirmation (EP10 and EP11). Checkpoints could be used to check the train composition and that wagons do not cause damage to the infrastructure. ● Promote ATTI. Support the train inspection on borders with defined checks of wagons and load for non-ATTI trains to minimize train stopping time
Procedures for installation and procurement	TRV, Adif	● Risk analysis procedure regulation 402/2013, directive 2004/49/CE of the European Parliament. ● Within these evaluation works, the study of Electromagnetic Compatibility is addressed, according to Railway applications - Electromagnetic compatibility EN 50121, since one of the risks that must be covered is the potential effect of these fields generated on the safety equipment on the track or on the rolling stock that may alter its normal operation.	The use of regulation 402/2013 involves a series of steps and prior evaluation work, which must conclude by considering whether the risk of setting up a checkpoint is significant or not.

9.3. Alignments

As the topic of operational procedures and their harmonization are addressed in WP2, in particular in *D2.1 Preliminary Operational Procedures* and the upcoming deliverable *D2.4 Final Harmonized Operational Procedures,* an alignment has been intended with this subtask. Thus, the main operational procedures defined in D2.1 which will be influenced by TE12 and WP29, "Wagon inspection" and "Confirm wagon set" have been addressed in this subtask. Furthermore, these procedures are two of the main KPI measurements for WP29.

Moreover, alignments have been sought with FP3 WP7 where checkpoints on main lines are being developed, elaborated in D25.3, as well as with System pillar project Harmonised Railway diagnostics (HERD), where harmonisation of the railway diagnostic data shared in Europe is being addressed.

HERD is a special project within the System Pillar of the European Railway Joint Undertaking (https://rail-research.europa.eu/). The project aims at harmonising the railway diagnostic data shared in Europe. This includes diagnostic data of trains recorded by wayside sensors as well as diagnostic data of railway infrastructure recorded by sensors on-board of a railway vehicle.

Some of the information recorded by Railway Checkpoints, would classify as diagnostic data of trains measured by wayside sensors and therefore would be within the scope of the HERD project.

In order to align FP5-TRANS4M-R WP29 with HERD, the responsible of the project was contacted and the alignment process was initiated.

The experts of the HERD project sent the document they are currently working on, which is the second document they have produced corresponding to the second phase of the project's progress. The document received is in draft form at the time of writing this document. The deliverable is cantered on developing two use cases, one for wayside vehicle monitoring and one for on-board track monitoring. Additionally, the system for submitting new use cases is described.

Reading the draft sent by HERD, it can be deduced that, although the scope of the project would encompass the diagnostic information collected by the Railway Checkpoints, the state of progress is not enough to extract a concrete format or even indications on how to share the information collected by the sensors.

Having established communication with the HERD project, there must be a follow-up of their developments and a continuous alignment of both projects. In this manner, as the Railway Checkpoints are developed, and the harmonization of the diagnostic data continues the efforts made by HERD can be leveraged to improve the shared information taken by the Railway Checkpoints.

9.4. Conclusion

As described in Chapter 5 of this deliverable, different demonstrators are ongoing and planned in different countries and locations in Europe, with varying emphasis on different operational procedures and use cases and hence different functionalities and technologies are incorporated. In order to achieve as high degree of standardisation as possible for the development of the Checkpoints, a minimal viable product was specified in Task 25.4, and harmonization of main operational procedures have been investigated within this sub-task. As the topic of harmonization is addressed also in other parts of EU Rail, alignment activities are deemed essential. Hence alignments have been sought and will be further worked on, in particular with WP2, WP32, FP3 and System Pillar project HERD.

10. Conclusions

This document has been prepared to provide the output of *Task 29.1: Demonstrator definition and start of development* and the related sub-tasks. The main aim of the task was to develop checkpoint demonstrators for digitalisation and automation of rail freight processes and suggest potential sites for demonstrators.

The planned objectives of the deliverable have been achieved and TRL 7 has been achieved for both the technical components of the ERC concept as well as the data exchange. As ERCs have been installed and will be further installed as elaborated in chapter 5 and 6, system prototype demonstrations in operational environment have been and will be carried out.

The demonstrator definitions elaborated in chapter 5 and the deployment strategies presented in chapter 6 of this report, constitute the basis for future developments of the demonstrators. The necessary information on locations, modes of operation and characteristics were provided. Based on the locations and possible uses, the results of the initial analyses for a Europe-wide showcase were presented. Various implementation options were considered and opportunities and risks derived. Based on these analyses, it was shown that a showcase consisting of several parallel demonstrators is theoretically feasible. This concept serves as the basis for the further development of the demonstrators and the showcase in conjunction with WP24 and WP33.

Use case definitions and approaches for the automatic detection of information and damage have been elaborated in chapter 7. The necessary technical implementation of the algorithms and approaches was discussed and the necessary information described. Relevant aspects of the chapter primarily describe the requirements to be achieved and the current development progress.

In regard to the exchange and exploitation of data, chapter 8 has presented an operational analysis identifying the data from checkpoints that are needed in different use cases. Based on this analysis, a data requirements specification for parts of the conceptual data model has been produced. The specification includes information about trains, vehicles, ILUs, irregularities and cargo. A requirements specification for parts of a Conceptual Data Model (CDM) for railway data has been developed. This model will make it easier to exchange data between systems and organisations. Chapter 8 highlights the fundamental role of the development of a Conceptual Data Model (CDM) and its implication in the functionalities of the European Railway Checkpoint (ERC) system for the improvement of operational processes in the rail freight environment, the digitalisation of these processes and the improvement of interoperability and harmonisation in the sector.

Regarding harmonized procedures and regulations, the main conclusion derived from chapter 9 concerns the different demonstrators (as described in chapter 5), with varying emphasis on different operational procedures and use cases, hence different functionalities and technologies are incorporated, and harmonization of them could be a limiting factor. In order to achieve as high degree of standardisation as possible for the development of the checkpoints, a minimal viable product was specified in Task 25.4 - D25.1, and harmonization of main operational procedures has been investigated in this deliverable. As the topic of harmonization is addressed also in other parts of EU Rail, alignment activities are deemed essential. Hence alignments have been sought and will be further worked on. For WP29 the main alignment activities carried out thus far have been; with WP2 regarding harmonized operational procedures, with WP5 regarding yard automation, with WP32 and FP1 regarding seamless data exchange, with FP3 WP7 regarding ERC development and with System Pillar project HERD regarding diagnostics data.

In the next step, the demonstrator definitions and deployment strategies presented in this report will be implemented and evaluated within *Task 29.2: Demonstration and evaluation of the installed checkpoints.* The demonstrators shall consider the activities listed in the subtasks of task 29.1. Moreover, the definitions will also be an input for WP33*, Task 33.5: Showcase of Standardised European Railway Checkpoints*.

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