Deliverable D 7.1
Demonstrators Vision & Global Architecture for Checkpoints

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Table of Contents

List of Figures

List of Tables

1. Executive Summary

The present document is focused mainly on the description of the vision of the future European Railway Checkpoints (ERC) from a holistic point of view.

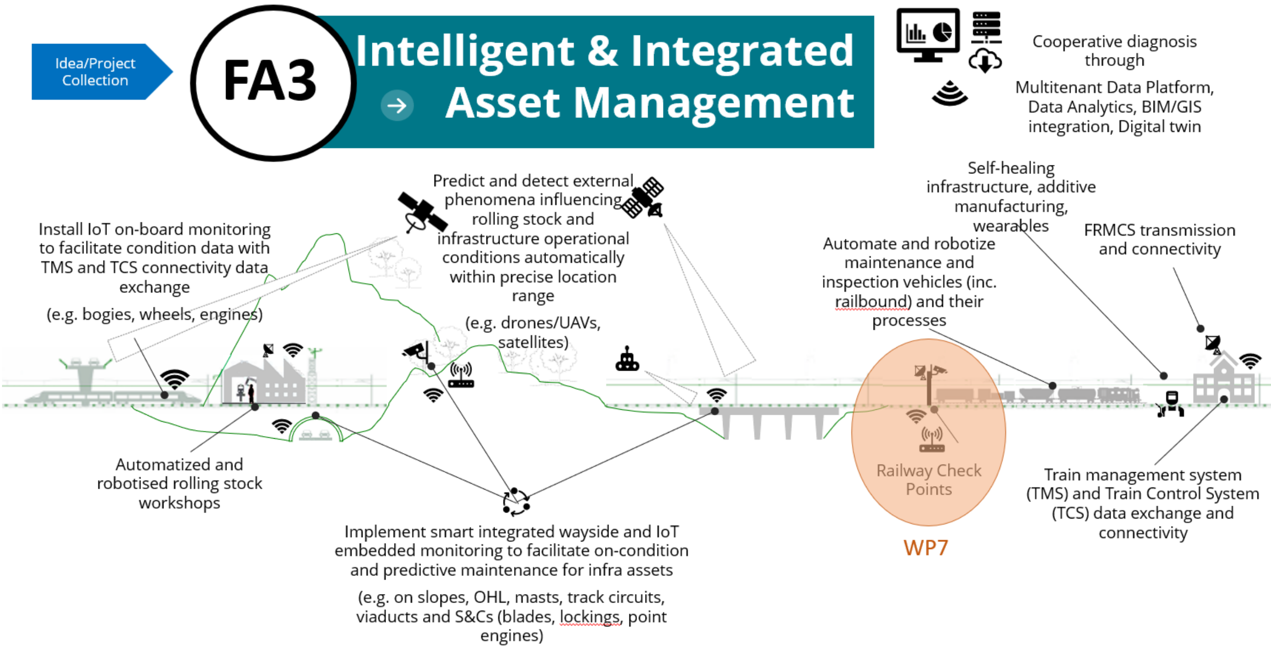

Figure 1 FP3-IAM4RAIL project schematic scope

This means that a complex system like ERC, with its multiple parts and its different functionalities, as well as the several aspects that are part of it, are analysed, in a global and integrated way. From this point of view, its operation can only be understood globally and not simple sum of its parts. It is therefore necessary to make minimal or basic connections between these parts and obtain an overall vision of this complex system.

One part of this complex system is the technology that can be used to monitor and check the rolling stock from the railway infrastructure. So, part of this vision could be based on the concept of Intelligent Video Gate (IVG) defined on previous European projects for freight trains, as FR8RAIL III and FR8HUB. IVG consists of a gate at the railway equipped with cameras and Radio Frequency Identification (RFID) readers for automatic identification of wagons and intermodal loading units, as well as damages, through image recognition and detection of wagon numbers, loading unit codes, placards and RFID units. For this WP7, the IVG concept is extended to mixed traffic, including not only freight trains, but also passengers' trains.

To have a holistic vision of ERC, it is needed to describe its architecture, including the requirements that can be relevant for the usage of the ERC (e.g. local measuring, storage in the cloud and analysis in a central location, involving data from different ERC as a data network) and the mapping of significant technologies currently in use, but expandable in the early future for infrastructure assets and on-board systems that would also allow to extend the concept of IVG (at this point in time focused only on images analysis).

From the whole map of technologies, some of them could be developed in WP7 “European Railway Checkpoint for mixed traffic”, for example, wayside technologies with laser, scan and ultrasound, which could provide essential rolling stock information for different applications, such as condition-based parameters, predictive analysis and safety elements diagnosis.

The use of these technologies with its advantages and disadvantages will be analysed to show the alternatives and best achievable solution, that can support the description of the holistic vision for the ERC.

As part of the ERC concept the different possible locations (the more suitable for these technologies) are included, considering the results of previous projects and the proposed locations to be used during the development of the FP3-IAM4RAIL project.

Other main aspects to be defined as part of the holistic vision are the functional and operational objectives of ERC. To name one as an example, the daily automatic inspection and its automatic diagnosis on the passenger’s fleet, focusing on condition-based elements and safety elements (related to train elements such as brake system or wheel status), where a collected database is used to define further maintenance tasks, estimation of end of life, or non-scheduled entry of the train to Maintenance Workshop.

The evaluation of these different functional and operational objectives of the European Railway Checkpoints, as part of the holistic vision, will be described in this document.

Several aspects of the ERC, that should also be part of the concept, are the standardisation of the communication protocols for the data flow, the operational procedures for the ERC, the need to make a Cost-Benefit Analysis (CBA) for the deployment, the identification of main stakeholders involved in the use of this ERC, the study of the Intellectual property rights for the obtained data, and other legal terms that can affect the holistic vision of the ERC.
All these aspects cannot be addressed in depth during the development of the WP7 but they will be part of the holistic vision described in the “conclusions” of this deliverable D7.1.

The content of this deliverable (drafted as the main outcome of task 7.1 “WP7 demonstrators Vision & Global Architecture for checkpoints”) will be used as input for the task 7.2 “Wayside inspection technology including Railway Checkpoints” and task 7.3 “Design & Deployment strategy for Railway Checkpoints and other Demonstrators”.

This deliverable is aligned to FP5-TRANS4M-R project and its deliverable D25.3 “Report on the basic functional and technical specifications regarding CMS as relevant input for FP3” delivered in June 2023.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
CBM	Condition Based Maintenance
CMS	Condition Monitory System
ERC	European Railway Checkpoints
FOS	Fiber Optic Sensors
HVAC	Heating, Ventilation and Air Conditioning
IM	Infrastructure Manager
IR	Infrared
IVG	Intelligent Video Gate
OCR	Optical Character Recognition
RFID	Radio Frequency Identification
WP7	Work Package 7

Table 1 List of Acronyms

3. Background

The present document, deliverable **D7.1 "*Demonstrators Vision & Global Architecture for Checkpoints*"** of Flagship Project FP3–IAM4RAIL, is aligned to deliverable **D25.3 "*Report on the Basic Functional and Technical Specifications Regarding CMS as relevant input for FP3*"** of Flagship Project FP5–TRANS4M-R.

The term *Condition monitoring systems* (CMS) here refers to wayside monitoring systems and to the IVG concept developed within the Shift2Rail programme and the projects FR8RAIL III and FR8HUB specifically focused on freight trains, where originally, lot of manual activities were managed, physical checks of outgoing trains before the departure were carried out purely manually, and where thanks to Intelligent Video Gates (IVG) defined in FR8HUB project has been initiated the next logical step to a higher automation of terminals and to reduce the lead time needed for the identification/verification process of train-sets by implementation of IVG.
The IVG overall process is to support the general functions of the terminal operator to identify, verify and document the main steps within the transport chain due to the upcoming change of responsibility and liability for the freight, such as automatic identification of vehicles and load units as well as image documentation of quality and damages.

The scope is now further developed in a concept called "Standardised European Checkpoints" within FP3–IAM4RAIL and FP5–TRANS4M-R.

The Standardised European Checkpoints are focused on CBM based in analytics with different wayside capture technologies (image processing, RFID-processing, visual data evaluation, etc.) over freight trains in the FP5-TRANS4M-R project and over passengers and freight trains in the FP3– IAM4RAIL project.

As these checkpoints will be developed within FP3-WP7, one important purpose of this deliverable D7.1 is to take into consideration the basic functional and technical specifications developed previously for the concept within Shift2Rail (summarised in D25.3 of FP5). Moreover, as CMS also includes other wayside monitoring technologies than the IVG concept, previous work within Shit2Rail regarding these technologies will also be used in FP3. Another main purpose is to further develop the concept aligned to the one developed in FP5.

4. Objective/Aim

The Transport Industry is requesting daily a safer, more available, more effective and more punctual service. Therefore, it is necessary to be focused on all different sectors, as digital telecommunication sector and adjacent technology fields to maintain the rate of development in terms of train design, communications, infrastructure, etc…

A high priority objective in this project is related to standardization and centralization in a unique ERC concept, in which, through a global view, with different technologies installed on the train (on-board) or in the infrastructure, allows any fleet to be run through the whole European Rail network, capturing analytic and status conditions over different train-infrastructure elements, affecting and improving critical factors such as traffic regulation, passenger safety and maintenance stays.

The objective of the project is related to the design and development of a global digital predictive maintenance platform using automatic diagnostic systems based on digital inspection technologies, such as an artificial vision using laser cameras and sensors, which will allow intelligent maintenance to be carried out which optimises cycles, increases availability and safety and reduces environmental impact of this process.

To this end, the new automatic diagnostic system will enable the possibility of real-time monitoring of rolling stock whether in main track, or maintenance facilities, without the need to reduce operating speed, and available for any type of rolling stock.
Thanks to this scalable and versatile design, great flexibility will be possible to adapt it to every need of each type of train and maximise its impact on fleet maintenance.

To manage these data captured over the system, the development will have an intelligent system capable of proposing a maintenance plan for different types of railway rolling stocks.
This intelligent system will be based on the observation of the state of integrity of the components of different equipment (brake system, wheel parameters, status of pantograph, bearings defects, visual inspection on different train elements on roof, side and underframe) that are reflected through multiple variables thar will be measured and analysed. The knowledge of this, once analysed and compared with a reference state of integrity considered as optimal, as a continuous evolution, will allow the system to observe if there is any latent or detected problem, carry out an analysis of possible causes of the problem and, finally, propose a predictive maintenance plan according to health status observed in the equipment.

This way, in addition to the safety provided to the rolling stock, the automatic inspection system will provide added value to the safety in infrastructure, considering that it allows the inspection of any external element of the rolling stock that could be a potential danger to the infrastructure due to loss of gauge of deterioration.

Subsequently, the system will be able to use and control the entire enormous volume of data generated in a train of this type, which has a high degree of automation (including sensors) to allow failures and anomalies to be detected through the use of deep learning algorithms and to determine the health status of systems, being able to apply predictive rules that have the overall objective of improving the safety, reliability and operational availability of the fleet.

This standardised architecture should be based on market knowledge, considering only those available technologies that have proven to efficiently support the automatic detection of deviations from nominal conditions. Amongst the different technologies on the market, we could name:

- **Thermography technology**: Infrared thermography is a passive imaging method for non-contact temperature measurement. It makes use of the quality that bodies must emit electromagnetic radiation, the so-called infrared radiation. This subsystem performs accurate thermal scan thanks to its cutting-edge photovoltaic sensors. The system creates a thermal map of the train surface identifying temperature anomalies. The thermal map is not affected by thermal emissivity of the materials.

- **Image module technology:** This technology takes a colour picture of each element stored with the information coming from the other modules. It uses a standard colour area scan camera together with a proper infrared illuminating system. IR illumination is safe because it is invisible to the human eye. Infrared illumination is automatically activated at night-time. Images during night-time operation will be black and white (gray scale).

- **Line Scan Technology:** The LineScan module acquires at high speed, high resolution, the upper surface of the contact shoe. The system is able to automatically recognize contact shoe material and detect cracks.

- **3D Technology:** The acquisition of the three-dimensional profile of the element, carried out by means of laser triangulation with high resolution cameras, can take up to 3.000 profiles per second. Collected data is processed by a dedicated algorithm that is able to compare the acquired profile with pre-determined thresholds, identifying irregular train shapes exceeding the allowed clearance.

- **Laser-camera triangulation technology:** to determine the actual wear status and distribution. The processing system performs the analysis of the measured parameters and a comparison to defined tolerance thresholds. The analysis and reporting software provide performance trending and predictive identification of intervention dates.

- **Acoustic technology:** to detect defects, via acoustic signal of each element. The main technology consists of the analysis of sound radiation captured by microphone arrays which isolate the sound of individual elements as the train goes through. Then indicative patterns of a running surface or roller defect can establish.

- **Vibration technology:** based on load bars and accelerometers to detect lack of roundness on wheelsets and determine damages on wheel or infrastructure. Current technology is also used to check train gauge or rail straightness status.

- **Train gauge technology:** By using this technology**,** the vehicle running gear condition and vehicle running behaviour - important inputs for vehicle maintenance - can be also monitored by measuring 3-dimensional wheel forces.

- **Fiber optic sensors (FOS):** Used for monitoring train integrity or derailing, etc.

- **Radiofrequency Identification Technology:** Equipped with RFID TAGS and reader to link and control each specific element such as train, fleet bogie or any other independent element.

After identifying the variety of technologies that may be utilized in each piece of equipment, the primary objectives would be linked to functional and operational targets.

- **Functional Targets:**

    - ***Increase in fleet safety***: continuous inspection and diagnosis of the trainset, especially on train systems related to Safety, such as brake system or wheel status, has a direct impact on safety status of the trainset, keeping a daily diagnosis and control of its parameters (wear, defects...).

    - ***Decrease in fleet maintenance tasks:*** a continuous diagnosis over the fleet can be performed, analysing its damaged/worn elements. With it, over scheduled or no-scheduled entries to workshop, maintenance team will know, in advance, whether a system needs to be inspected/replaced or not, being focused directly to its specific railway inspection point.

    - ***Increase in the life of train components & Decrease in stock level for spare parts:*** as a continuous wear status and graphics are evaluated and diagnosed, control of wear elements will guarantee maximum life of weal elements (brake pads, wheels...), managing its trainset entry to the workshop for as long as the life or wear elements can provide.

- *Decrease in dust:* same as previous justification, extension of life of wear components affects directly to dust amount. The longer an element is extended, the less dust is produced.

- **Operational Targets:**
  - ***Centralise and regularise Railway traffic***: wayside located on any part on commercial service guarantees a continuous and remote diagnosis of any fleet covered by its inspection equipment. This way, different fleet operator or fleet design will be provided with continuous diagnosis and status, in real time, of its main maintenance checkpoints, permitting railway traffic to be more versatile and centralised.

  - ***Increase in fleet punctuality & reliability:*** as a continuous fleet diagnosis and status, maintenance life of the fleet will be extended. This way, reliability of the fleet will be increased affecting directly to its punctuality.

  - ***Increase in fleet availability***: there will be an increase in workshop entries, and any maintenance tasks performed will be directly focused on the Diagnostic system previously indicated by the Wayside. There will therefore be a reduction of fleet time in the workshop, increasing availability of operation in commercial service.

5. Scope

Based on the goals and objectives outlined in the previous chapter, various criteria and scenarios can be used to define best wayside design considering 3 different factors:

- location of measurement equipment
- train checkpoints
- mapping of different technologies

In the following chapter, synergies between these 3 factors (train checkpoints, location and technology) will determine specific designed and configutated wayside equipments, considering advantages and disadvantages over each scenario.

The combination of these different factors will contribute to the definition of a Communication SW Architecture that ensures the collection of data and the availability for the required analysis.

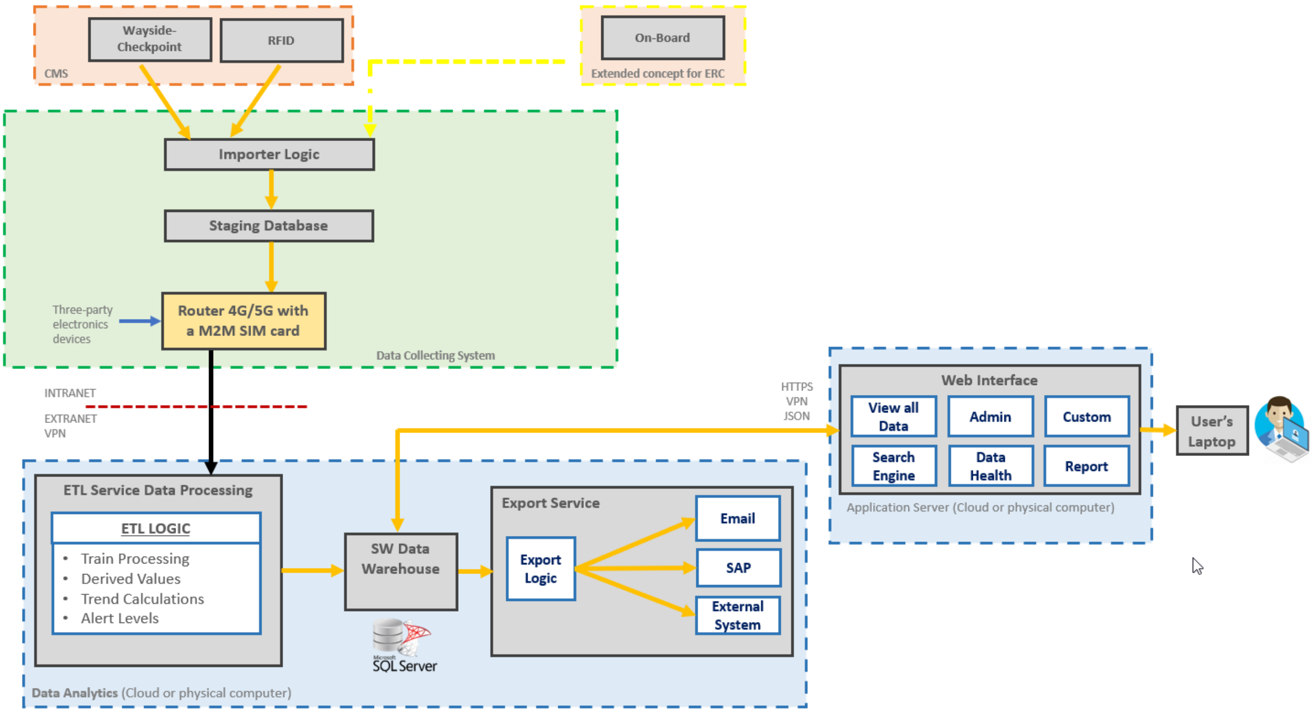

Figure 2:2 Communication architecture

5.1. Different locations of installation

One objective of this task is to develop automatic measurement equipment that allows the reduction of human error rolling stock maintenance times increasing the availability of rolling stock in commercial service, reducing maintenance costs by automating part of the tasks, improving safety in the circulation of rolling stock and in the future with AI software tools and the CBM to be able to estimate when it is necessary to carry out preventive maintenance of those train components that are monitored.

Another parallel goal of this task is to select the best installation to demonstrate the capabilities of this technologies to transport the goods faster and to reduce the time spent inside the terminal. We would like to demo the advantages of IVG to manage not only safety and maintenance functions but also to reduce the time slot in the terminal or in the maintenance depot. This way we could increase productivity and reduce cost.

As is well known, one of the most delicate and key tasks of IM infrastructure managers is to ensure the security of the material that circulates on the network. Currently, because of the liberalization of the railway business, the number of trains and therefore the volume of passengers carried is increasing and the forecasts estimate that in the coming years it will be even greater due to Paris agreement[1] through the decarbonization of transport. This increase in trains circulating on the network should not diminish the security of the traffic, so periodic reviews of those elements that intervene in the safety of the material (and therefore the safety of the passengers and the rolling stock) must be carried out to guarantee the secure handling of them.

Automatic inspection systems are well known items of equipment, but they must gain even more importance in the performance of this surveillance task. Also, any increase in their use must be such that the costs associated with this implementation will drop significantly.

Another issue, which is not minor, is the optimization of the time of use of the maintenance workshops, since they are currently saturated with the amount of available rolling stock, for which another task that these teams can perform is to reduce the time that they are inside the workshops and therefore increase the availability of commercial rolling stock.

[1] The Paris Agreement is a **legally binding international treaty on climate change**. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."4 November 2016. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."

On the other hand, and although it does not directly affect the safety of the railway network, reliability can be affected by, for example, accidents related to pantograph hitches in the catenary that cause significant damage to the network in terms of economy and reliability. These verification and control tasks can be carried out externally using OCR cameras that allow the status of the pantographs to be identified, faults determined in them, through image analysis and identify when it will be necessary to carry out the next preventive maintenance through AI.

The verification and control tasks must be carried out at the most relevant points or locations within the network. It must be highlighted that the best location is the one making possible to regularly monitor the state of the rolling stock and decide whether is suitable for circulation afterwards. Some locations where the verification may take place and some remarks about them:

Suitable physical locations:

- **Maintenance workshops**: this location is a natural periodic access point for rolling stock maintenance. In maintenance workshops a great deal of digital information can be gathered and then transferred to the cloud to later decide whether a train can be considered fit for commercial service again. (maintenance data must be compared against safety and reliability pre-determined data).

- **Terminal**: some maintenance tasks can take place in freight terminals. However, in such places the fleet may incur high extra-costs. Therefore, quick maintenance response must be sought to reduce costs and ensure material is delivered on-time.

- **Cross border points**: the liberalisation and opening of the circulation of rolling stock throughout Europe may imply that maintenance works can be done anywhere in Europe. So, to improve safety in the circulation of this material, the installation of an inspection point on the general road is already planned.

- **Main line location**: if feasible, train diagnosis should be eased without the need to take the train to the maintenance workshop. Once a critical maintenance issue is diagnosed, the corrective action is planned, and the train is taken to the workshop for fixing it, but not for diagnosing.

Locations in the Netherlands:

In the following table, a list of different locations in The Netherlands are included. These locations provide a set of cameras to monitor parts of the systems of the rolling stock with at a maximum speed of 160 Km/h. These are main line locations:

Location Netherlands	Measurement	Type	Sensor
Hekendorp	Pantograph status	SLT, ICM,DDZ,FLiRT, ViRM	Camera
Hekendorp	carbon strip thickness	SLT, ICM,DDZ,FLiRT, ViRM	Camera 3d
Hekendorp	Bogie condition	SLT, ICM,DDZ,FLiRT, ViRM	Line Camera
Hekendorp	Train	All NS	RFID
Hekendorp	Bogie health condition		Analytics
Near Schipholtunnel	Pantograph status	SLT, ICM,DDZ,FLiRT, ViRM	Camera
Near Schipholtunnel	carbon strip thickness	SLT, ICM,DDZ,FLiRT, ViRM	Camera 3d
Near Schipholtunnel	Bogie condition	SLT, ICM,DDZ,FLiRT, ViRM	Line camera
Near Schipholtunnel	Train	All NS	RFID
Near Schipholtunnel	Bogie health condition	SLT, ICM,DDZ,FLiRT, ViRM	Analytics

Table 2: Measurement point in The Netherlands

Locations in Spain:

In Spain we decided to install it in two different locations. The first one will be in a maintenance workshop in Madrid. In this depot the speed will be less than 30km/h and we should measure wheel defects, pantograph status and train number. This depot was selected because there is a lot of trains, therefore, we can get a lot of data, needed for this project. The second IVG will be in the main line to France from the west side of Spain and the maximum speed will be less than 80km/h. In these locations we should measure the wheel profile, the wheel bearings and the train number. These second locations were selected because there are different types of trains, freight trains and commuters' trains. We selected these locations to try to have enough data from a high number of trains. However, these locations could be changed in the future because it depends on the train traffic and operational points of view from the rail undertaking company.

Location Spain	Measurement	Type	Sensor
Atocha	Pantograph status	Serie Civia	Camera
Atocha	Wheel profile	Serie Civia	Camera 3d
Atocha	Wheel defects	Serie Civia	Line Camera
Atocha	Train	Serie Civia	RFID
Beasain	Wheel profile	Serie 120, 121,449, 440	Camera 3D
Beasain	Bearings status	Serie 120, 121,449, 440	Sound measurement
Beasain	Train	Serie 120, 121,449, 440	Camera 3d

Table 3: Measurement point in Spain

Cloud Architecture:

As digitisation is one of the priorities in the industry and the third leg. All these processes will be done through the cloud, where all this data will be processed and analysed with the aim of simplifying the process and having a data history that allows determining the behaviour of defects to anticipate failures.

Data on the state of measurement technology using different technologies and companies cannot be exchanged or shared between different stakeholders across Europe in a simple and standardized way. The HERD project will allow to link data providers and consumers and that way create a market for data communication that improves processes.

The outcome of the project will enable authorised entities to easily access quality-assured data for unimpeded implementation of business cases. With this project we will try to incorporate the results of HERD or, at least, take them into account in a second phase.

This digitisation will require both key hardware and software elements to accompany this track-mounted equipment:

- **Data storage cloud:** all data belonging to Infrastructure managers will be stored on an infrastructure manager server and specific access will be given to maintenance companies to verify that their rolling stock is in perfect condition. As this is sensitive information, Infrastructure manager will ensure that this information is not distributed to third parties.

  <u>Access to the data cloud could be done from an API (Application Programmable Interface)</u>:

  Understanding API as a set of programming rules to tell the counterparty (in this case, the maintenance company) how you want to communicate with the cloud database system.

  The API would handle the data transfer, in a specific and predefined way. The API would be the gateway that the maintenance company can use to receive special access to the data. With this API, automated data requests can be made and therefore integrated into the maintenance company's software.

  As an example, instead of logging into the infrastructure manager's database and requesting data, this data request could be made from the maintenance company's system. This would give entities flexibility.

  - ✓ For one hand, the infrastructure manager would predefine rules on how to access data.
  - ✓ For the other hand, the maintenance company would have flexibility to integrate its asset data more efficiently.

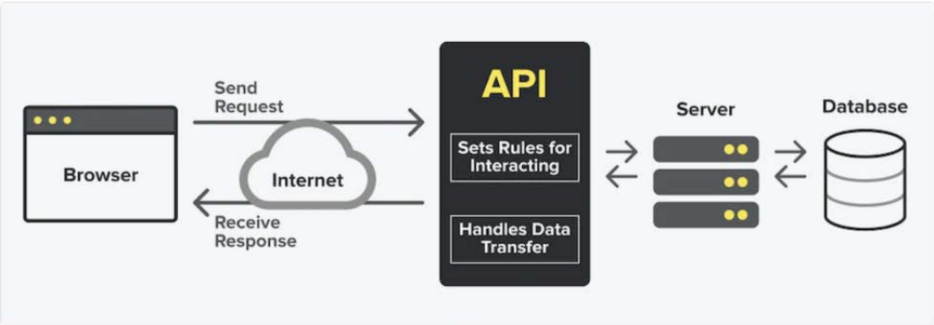

Figure 3 Application Programmable Interface

- **Processing of this data through a cloud-based artificial intelligence application**, which allows with this data:
    - ✓ Extend the maintenance periods: through the data of each train, the AI must be able to establish when it will be necessary to re-turn the wheel, change the carbon bands or checking the state of the axle bearings.
    - ✓ Carry out condition-based maintenance this way, so that static maintenance will be stopped by kilometres and will be changed to another one based on its condition.

5.2. Train checkpoints achievable over its different locations

5.2.1. Wheel profile parameters

In order to ensure rolling stock safety, the wheel profile and parameters such as the flange height, the flange width, the diameter, the Back-to-Back distance or the rim thickness, among many others, are measurements to be complied with specific tolerances on a regular basis (established in the maintenance plan of each vehicle). Being out of range in any of the mentioned parameters will forbid the rolling stock circulation on commercial railway service mode.

With the aim to improve these maintenance checks (making them more reliable, frequent and efficient), one of the checkpoints that will be developed within the scope if this project will be a wheel profile and a diameter monitoring system. This automatic tool will be able to perform, with no human intervention and thanks to vision technology techniques, all these checks in a very accurate way without the need for stopping the train or, if desired, sending it to the depot (the system will be able to be installed in the mainline and will be able to monitor the vehicles during their normal operation).

The system will use lasers and cameras to extract the profile of each of the wheels passing through it, and RFID technology to identify each of the vehicles. It will be able to work with speeds of over 100km/h and will ensure that the precision of the measurements comply with the requirements of the rolling stock maintenance plans. Its design will be modular to minimise the impact in the infrastructure, allowing a quick installation and minor interference with commercial services or depot operations, depending on the area in which it will be installed.

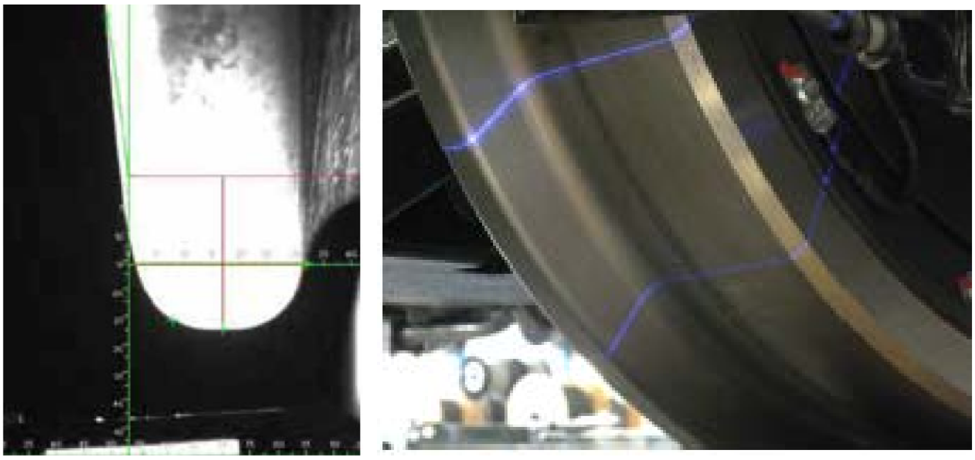

Figure 4:4 Example of Wheel profile parameters

5.2.2. Wheel defects

In a similar way, wheel condition or wheel surface defects are critical aspects all bogies or rolling assemblies need to control, such as flats, bubbles or cracks. The presence of these defects may affect the safety of the rolling stock and the comfort of the passengers. An early detection will not only improve those two aspects, but also minimise the costs that those damages may imply (small defects will be easier to repair and will not damage the infrastructure, for example, unlike the big ones).

This is why a checkpoint will be included in the scope of this project capable of detecting these types of failures in an automated manner. The system will use vibration sensors installed under the rails to measure the impact of each wheel and detect abnormalities on its contact surface with the rail. It will also make use of RFID technology to identify the specific vehicles being monitored. The design and installation of the system are aimed to be very simple, implying no civil works or track modifications (unless it is an embedded track configuration).

The state of the art of these systems requires medium-high speeds of operation of the vehicles (over 40km/h approximately), since the impact/vibrations of the wheels when passing over the system are high and, thus, the failure detectability easier. This means that these types of systems usually need to be installed in the mainline, aspect that not always is the most convenient (the owner of the infrastructure may be different from the maintainer, the access to the mainline is usually quite restricted…). So, one of the key benefits of the checkpoint developed within this project will be the capability of working at low speeds (below 20km/h), which will help to install the system in depot areas.

Figure 5:5 Example of Wheel condition

5.2.3. Pantograph status and wear condition

On electric fleets, where Pantographs are a critical element on trains, to control the pantograph status can result in avoiding future damages on infrastructure (catenary) or in the train health.
That way, a continuous wear control on carbon strip and damage analysis is needed on the maintenance operations.

The aim of this checkpoint will be very similar to the wheel profile and diameter monitoring system: improve these maintenance checks (making them more reliable, frequent and efficient) by performing them with no human intervention and without the need for stopping the rolling stock. It will also use vision technology techniques to generate a 3D model of the carbon strip or to measure specific parameters over the pantograph.

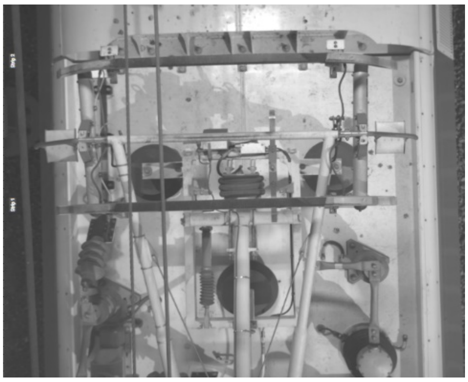

Figure 6:6 Example of Pantograph status

5.2.4. Train shape and fairings analysis

A continuous control on the train shape and its fairings status can be required to diagnose if any opened fairing affects directly to critical train gauge or it is out of tolerance.
The Train Profile Measurements System is defined to guarantee a complete monitoring of trains in critical points of the network (i.e. tunnels, bridges, country borders and junctions between different networks).

The system allows the acquisition of a 3D profile of the train. State-of-the-art components, specifically designed to guarantee high performance of the system, allow accurate inspections of every part of the train and to promptly detect any safety issues reducing risks of major accidents and increasing network availability. The acquisition of the three-dimensional profile of the train, is carried out by means of laser triangulation with high resolution cameras. Collected data is processed, identifying irregular train shapes exceeding the allowed clearance. A light version with laser pointers to monitor just a fixed clearance infringement is available.

5.2.5. Bogie condition monitoring

Due to their complexity and operating conditions, bogies are elements subject of suffering many different types of anomalies. The aim of this checkpoint will be to automatically monitor the status of different bogie elements, such as dampers, rockets or bolts.

It will use linear scan cameras to acquire high resolution images that, after being processed by the algorithms developed within this project, shall be able to identify some of these problems. This shall decrease the effort needed to perform visual inspections during maintenance and improve the safety of the rolling stock thanks to an early detection of issues.

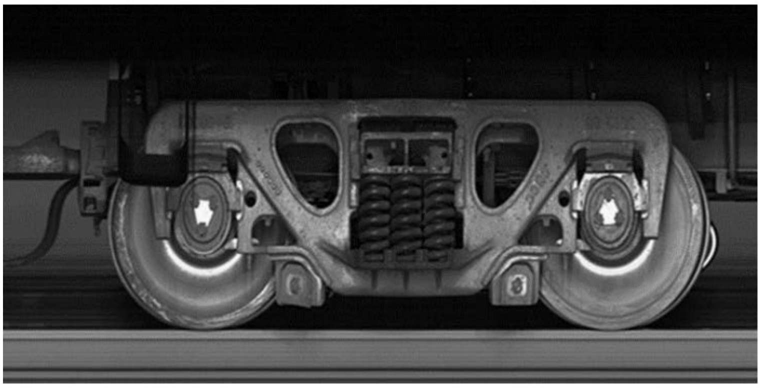

Figure 7:7 Example of Boggie condition

5.2.6. Brake system monitoring

The brake system and its perfect status represent a decisive factor in the safety and quality fields of railway transport. There is a need to systematically check the decisive risk factors and especially the brake status. The measurement system acts as the depot's check gate.

In one way, the system measures the brake pad wear of both outgoing and incoming trains and provides the base information to run an appropriate maintenance plan, keeping brake pads within the quality standards. The processing system performs the analysis of the measured parameters and comparison to defined tolerance.

The complementary parameter to the brake wear is the brake disk wear which is monitored by a dedicated system. The measurement system acquires the brake disks profile by means of high-speed laser-camera triangulation technology determining the actual wear status and distribution.

The processing system performs the analysis of the measured parameters and comparison to defined tolerance. System's analysis and reporting software provides performance trending and predictive identification of intervention dates.

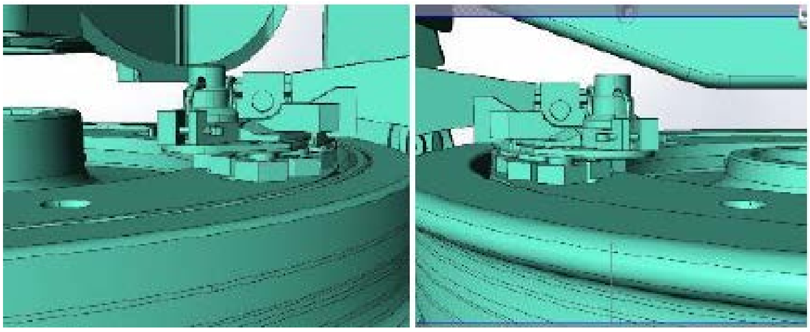

Figure 8:8 Example of Brake system

5.2.7. Temperature monitoring via High Voltage cabling systems

High Voltage cabling system performs accurate thermal scan thanks to its cutting-edge photovoltaic sensors, specifically designed to reduce false positives. The system creates a thermal map of the train surface identifying temperature anomalies. The thermal map is not affected by thermal emissivity of the materials.

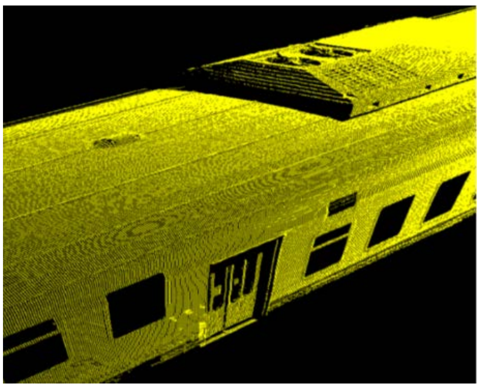

Figure 9:9 Example of thermography capture

5.2.8. Bearings and gearbox status

Thanks to the acoustic technology continuous analysis on bogie bearings or gearbox, a prior damage detection can be found avoiding future damages on wheels, axles or gears.

This proposed technology uses advanced acoustic beam forming technology to detect early and advanced bearings defects on rolling stock wheels during fleet are over commercial service. There will be arrays of microphones on each side of the track, which isolates the sound from individual bearing while passing the system.

The principle of operation is based on detecting features in the acoustic signal of each bearing that are indicative of a running surface or a roller defect. A bearing fault excites the structural response of bearing components which then radiate sound that is measured by the microphone.

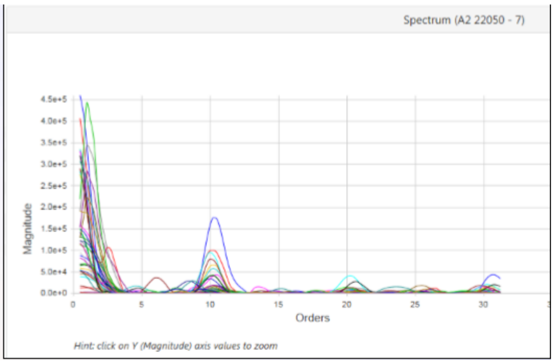

Figure 10:10 Example of sounds patterns

5.2.9. Gauge exchanger analysis

To avoid delays or safety issues during gauge exchanging operations, a monitoring system based in sensors and photovoltaic cells, can provide an on-time diagnosis on the exchanging operation.

Figure 11:11 Example of gauge exchanger from standard to Iberian gauge

5.2.10. Catenary monitoring (extended concept for ERC)

An on-board inspection system can be installed on any train roof to monitor and analyse status of the catenary. This way, a possible wire damage or interface can be detected before any bigger damage causes important delays or extra costs for infrastructure.

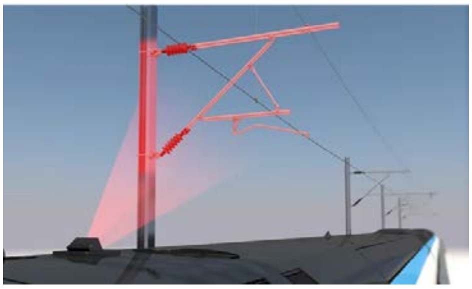

Figure 12:12 Example of technology to monitor the catenary.

5.2.11. Rail monitoring (extended concept for ERC)

An on-board inspection system can be installed on underframe part of the train to monitor and analyse status of the rails and its gauge. This way, a possible derailment damage or interface can be detected before any bigger damage causes important delays or extra costs for the infrastructure.

Figure 13:13 Example of technology to monitor the track.

5.3. Mapping of different technologies of each railway checkpoint

Railway checkpoints are critical for ensuring the safety, reliability, and efficiency of train operations. These checkpoints are used to inspect different components of the train, such as wheels, axles, brakes, bogies, pantographs, structure, undercarriage, HVAC, doors, etc., and to detect any defects or abnormalities that may require maintenance.

Over the years, manufacturers and maintainers have changed focus from manual inspection to optimisation and automatisation of processes and maintenance plans. As a result, different types of technologies for train inspections have been developed, based on basic principles of image reconstruction, sound, temperature, electromagnetism, and mechanical systems. These technologies are used to optimise and automate the processes of inspection and maintenance, and to reduce downtime and maintenance costs.

This chapter focuses on mapping the different types of technologies used in railway checkpoints, including asset detection systems, radio frequency, strain-gauged load bars, accelerometers, image processing systems, acoustic, vibration, thermal and ultrasonic. The basic principles, applications, advantages, and limitations of this technology will be thoroughly examined.

Additionally, the ways in which this technology can be integrated with other techniques such as Machine Learning, Big Data Analytics, Predictive Maintenance, Remote Monitoring, and Integration with Enterprise Systems to enhance the overall efficiency and effectiveness of train operations will be explored. By understanding the different types of technologies used in railway checkpoints, railway operators can make informed decisions about the best approaches to inspect and maintain their trains and components and enhance the overall safety, reliability and efficiency of their operations.

5.3.1. Asset Detection system

The detection of rolling stock in motion is a key aspect to allow a dynamic analysis of the rolling stock, which reduces maintenance time. This detection not only involves knowing whether the train has been detected or not; other parameters of interest to the system, such as train speed, track and direction, must also be determined. Various technologies can be applied for this:

- **Axle counters** are a type of asset detection system that is used to count the number of axles that pass through a specific point in a railway checkpoint. These systems are usually installed between rails, and they can detect the number of axles that pass through a specific point. Axle counters use sensors that are placed between the rails to detect the passage of each axle. These sensors send signals to a central processor, which counts the number of axles and calculates the speed and direction of the train.

- **Wheel detectors** are another type of asset detection system that is used in railway checkpoints to detect the presence of wheels passing over them. These systems are usually installed on the rail, and they use sensors to detect the passage of each wheel. The sensors send signals to a central processor, which counts the number of wheels and determines the spacing between them.

- **LiDAR/RADAR** systems are advanced asset detection systems that use lasers or radio waves to detect the presence of objects and to measure their distance and speed. These systems are commonly used in high-speed applications and can provide accurate data even in adverse weather conditions. LiDAR/RADAR systems are particularly useful in railway checkpoints because they can detect the presence of trains and other objects from a distance, allowing operators to take appropriate action before the train arrives.

- **Video analysis**, by making use of image processing techniques. These techniques can be used to detect and calculate rolling stock parameters, such as speed. They usually combine object detection algorithms with feature extraction algorithms, which allow to track the detected object and estimate its displacement and speed.

5.3.2. Radio Frequency

RFID technology is a low-cost tracking method. It is widely used in railway checkpoints because of its accuracy, speed, and ease of use. RFID-Sensor is maybe 3x3cm, so relatively small. RFID reader is very quick, so more sensors can be read in a short period of time. RFID systems use radio waves to communicate between an RFID reader and an RFID tag, which is attached to the asset being inspected. The RFID reader sends a signal to the RFID tag, which responds with a unique identifier. This identifier is then used to retrieve relevant data from a database, such as the maintenance history of the asset or its current location.

RFID systems are particularly useful in railway checkpoints because they can be used to identify assets quickly and accurately without the need for manual input. This can save time and reduce the risk of errors, as well as improving the overall efficiency of the inspection process.

5.3.3. Strain gauged load bar

Strain gauged load bar technology is used to measure the weight of a component in motion and to detect overloads and imbalance conditions between wheels, axles, or bogies. Strain gauges are installed on load bars or other load-bearing components, and they measure the deformation caused by the weight of the asset. The data collected by the strain gauges is used to calculate the weight of the asset and to identify any imbalances or overloads that may cause damage or safety issues.

This technology is widely used in railway checkpoints to ensure that trains are operating within safe weight limits and to detect any abnormalities that may require maintenance. Strain gauged load bar technology is particularly useful in detecting overloads and imbalances, which can cause damage to the wheels, axles or bogies of the train.

5.3.4. Accelerometers

Accelerometers are used to detect certain types of defects in wheels, such as flats or out-of-roundness, by measuring the linear and angular acceleration with mechanical and/or piezoelectric sensors. Accelerometers are installed on the axle box or other components of the wheelset, and they measure the vibrations caused by the wheel. The data collected by the accelerometers is used to identify any abnormalities in the wheel profile and to detect any defects that may require maintenance.

This technology is widely used in railway checkpoints to ensure that the wheels are operating within safe limits and to detect any abnormalities that may cause damage or safety issues. Accelerometers are particularly useful in detecting defects in wheels that cannot be seen by visual inspection, such as flats or out-of-roundness.

5.3.5. Image processing systems

Image processing systems are used to inspect different components of the train, such as wheels, axles, brakes, bogies, pantographs, structure, undercarriage, HVAC, doors, etc., and to detect any defects or abnormalities that may require maintenance. These systems use cameras or other sensors to capture images of the components, which are then analysed by software to identify any abnormalities.

Image processing systems are particularly useful in detecting defects that cannot be seen by visual inspection, such as cracks or corrosion. These systems can also be used to inspect components in hard-to-reach areas, such as the undercarriage of the train. By using image processing systems in conjunction with other techniques, such as Machine Learning, Big Data Analytics, Predictive Maintenance, Remote Monitoring, and Integration with Enterprise Systems, railway operators can improve the overall efficiency and effectiveness of their train operations.

There are multiple techniques associated with image processing that can be used for asset analysis in the railway environment. Depending on the use case and the applicable technology, these techniques can be more or less feasible, enabling valuable information to be obtained for end users and automating certain processes that imply cost reductions.

Image processing systems usually involves a series of steps to obtain the information mentioned before. Those steps can be summarised as follows:

1. **Image acquisition**: the process begins with the acquisition of digital images, using digital cameras, laser scanners or other imaging devices. Using the proper configuration of imaging sensors, lights and other elements are fundamental for the further processing and analysis.
2. **Preprocessing**: for automating the information extraction in images, images obtained in the previous step should be prepared. This tasks commonly include the adjustment of image size, scale, and colour.
3. **Processing**: once the image is prepared, multiple processing techniques can be applied in order to obtain features. Depending on the application, these tasks can include Image Segmentation, Optical Character Recognition, Object Detection, Image Enhancement, among others.
4. **Analysis**: the features obtained usually have no meaning by themselves. For instance, a segmented image, where every object is represented by a certain colour, cannot be used for automating a process or making a certain decision. Instead, this image can be used, for example, to compute the area of a certain object.

5.3.5.1. Image or video acquisition

The first step in every computer vision application is to obtain appropriate source images for their later processing. Image acquisition consist of a series of
High-resolution, Infrared (IR) and thermal cameras, or 3D imaging systems can be used to obtain images of the asset's parts. Choosing an appropriate camera technology, alongside an appropriate illumination system, is essential to obtain a high-resolution image that highlights the key features used later in maintenance tasks.

5.3.5.2. Optical Character Recognition (OCR)

Optical Character Recognition (OCR) is a technology that converts images of text into machine-encoded text, therefore making it accessible to editing or for further categorisation. An intuitive use case is the recognition of the UIC-number of every wagon. OCR systems usually face a series of challenges that difficult their implementation:

- Firstly, OCR systems expect **high quality or high-resolution images** with some basic structural properties. In most cases, those properties refer to high difference between the text to be read and the background. The images generated through computer vision cameras usually do not meet these quality requirements. From the point of view of an application in railway environments, these problems are exacerbated due to the variability of environmental conditions.

- **Scene complexity** is another challenge hard to address with conventional OCR techniques. Focusing on the identification of text in rolling stock, the existence of other marks on the generated images makes it difficult to extract the text of interest by using OCR techniques themselves.
- **Uneven lighting** is a common condition found in external environments. This problem can be reduced using external light sources. However, it continues to be a challenge for character recognition.

5.3.5.3. Deep Learning for computer vision

The variability of wagons and container types makes it impracticable to use traditional OCR algorithms. Variability in character types, colour and background colour hinders the parametrisation of certain characters. These drawbacks make the use of advanced artificial intelligence techniques applicable in these cases.

Artificial Intelligence, particularly Deep Learning methods go beyond the traditional point of view, were features need to be parametrised in some way in the algorithm. Deep Learning algorithms are presumably capable of understanding what the image contains and automatically recognise these features as well as the patterns that shape the objects of interest in the image.

This knowledge is generated through a cyclic algorithm, called iterative learning. In this cycle, labelled data is fed to the learning algorithm, which automatically extracts those patterns and features of interest. These techniques make it possible to include images of different conditions or scenarios, making the trained models more robust to changes in the environment and with the capacity of adapting to new conditions and to iterative learn from new information.

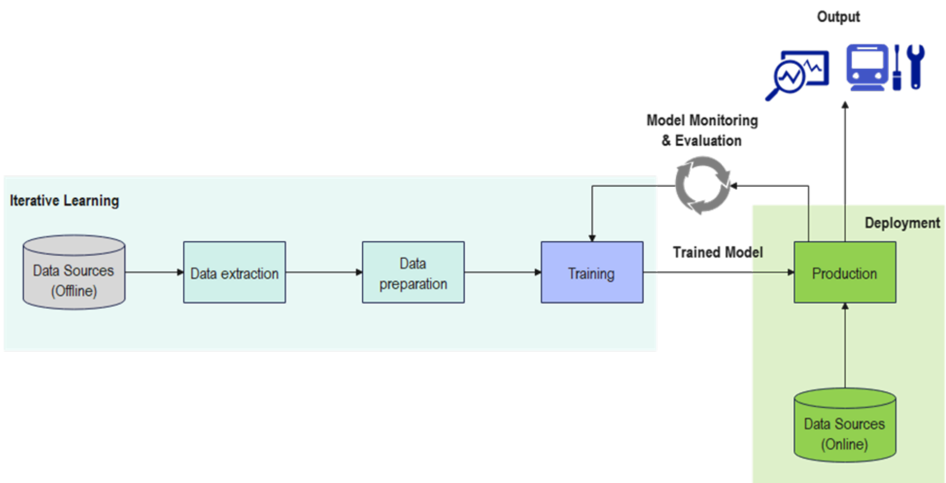

Figure 14:14 Deep learning algorithms process

Based on the previous explanation, it can be assumed that supervised Deep Learning algorithms relies on having as much labelled data as possible. Some of the main applications of Deep Learning for image processing are the following:

1. **Image Classification:** deep learning models, especially Convolutional Neural Networks (CNNs), are extensively used for image classification tasks.
2. **Object Detection**: used to detect and locate objects within images.
3. **Image Segmentation**: deep learning models can segment images into regions or objects of interest, allowing for more precise analysis.

5.3.5.4. Benchmark

A benchmark refers to a standardised and commonly accepted set of data and evaluation criteria, used to compare the performance of different systems or algorithms. For image processing technologies, the usage of benchmarks is necessary for several reasons. They provide a way to implement standardised comparisons, in such way that different solutions' performance can be compared under the same conditions. Benchmarks are also commonly used to establish the metrics which will later define the objective of the systems.

In terms of the Standardised Railway Checkpoints, the number of checkpoints installed during demonstrators and the variety of images and data acquired by them brings of the need to define a common framework for testing solutions. The importance of this framework lies in making it feasible to compare solutions developed under certain conditions or checkpoints. For instance, it is recommended to avoid evaluating different models with different datasets, each one compiling the features of a certain checkpoint.

This solution can be approached in two ways: by defining common benchmarks against which solutions will be evaluated or establishing minimum requirements for the implemented benchmarks. These criteria should include, at least, the following aspects:

- **Dataset of images**: every development should be tested against a previously defined set of images. Those images should meet some minimum requirements, which should be defined and validated including:
  - Resolution.
  - Image format.
  - Camera – object distance.
  - Camera angle.
  - Climate conditions.
  - Minimum number of images.

- **Ground truth**: the images to evaluate should be labelled. That is, if the performance of a certain detector is going to be evaluated, the correct or expected output of the system should be known beforehand. This way, every developed module will have a different ground truth, depending on the target of the module.
- **Use case which will be evaluated**: every use case should be evaluated using a specific benchmark. This way, a model developed for detecting certain codes in the wagons cannot be evaluated under the same conditions, dataset and metrics than a model developed for detecting defects.
- **Metrics**: which can provide an objective and quantifiable way to evaluate the performance of a solution. They also allow a direct comparison between different systems. One of the most common metrics used for evaluating is the Accuracy, which measures the proportion of correctly classified features, out of the total features of the dataset. For the use case of recognising UIC codes, the Accuracy of a solution will be the percentage of UIC codes correctly detected, against the total number of UIC codes in the dataset. For computing the Accuracy in this case, the following metrics should be considered:
    - True Positive: a code "AAAA" correctly detected as "AAAA".
    - False Positive: the system detected a code which was not in the image.
    - True Negative: the system detected no code in the image, and there was none.
    - False Negative: a code in the image which was not detected.

5.3.5.5. Damage detection

By processing the assets' images, it is possible to detect damages of different parts of the asset, such as wheel profile, wheel defects, pantograph, brake system, or general defects such as graffiti, gauge inference, absence of elements in the enclosure and asset's integrity.

Deep Learning techniques, like the ones explained in the previous section, can be applied to this specific use case. In particular, it is common to use segmentation models to determine which area of the image comprises a defect. In turn, these models allow the type of segmented defect to be classified. These models are usually based on deep neural networks, with specific architectures such as U-Nets.

U-Nets are an adaptation of typical Convolutional Neural Networks (CNN). The typical use of convolutional networks is on the classification tasks, where the output to an image is a single class label. However, in many visual tasks, as the case of damages detection in critical areas, the desired output should include localisation, i.e., a class label is supposed to be assigned to each pixel.

5.3.6. Acoustic

Acoustic technology is used in railway checkpoints to detect defects in wheels, bearings and other components that produce sound or vibration. This technology works by using microphones or other sensors to capture sound or vibration data, which is then analysed by software to identify any abnormalities.

Acoustic technology is particularly useful in detecting defects that cannot be seen by visual inspection. For example, it can be used to detect defects in bearings or other components that produce noise or vibration. This technology can also be used to detect defects in wheels that cannot be detected by accelerometers or other sensors.

5.3.7. Vibration

Vibration technology is used in railway checkpoints to detect defects in wheels, bearings and other components that produce vibration. This technology works by using sensors to measure the vibration of the component, which is then analysed by software to identify any abnormalities.

Vibration technology is particularly useful in detecting defects in bearings or other components that produce vibration. For example, it can be used to detect defects in bearings that may lead to increased vibration levels. This technology can also be used to detect defects in wheels that cannot be detected by accelerometers or other sensors.

5.3.8. Thermal

Thermal technology is used in railway checkpoints to detect defects in the train components by measuring their temperature. This technology works by using infrared cameras or other sensors to measure the temperature of the component, which is then analysed by software to identify any abnormalities.

Thermal technology is particularly useful in detecting defects that cannot be seen by visual inspection, such as hot spots caused by friction or overheating. This technology can also be used to detect defects in electrical components, such as pantographs or HVAC systems, that may produce abnormal heat signatures.

5.3.9. Ultrasonic

Ultrasonic technology is used in railway checkpoints to detect defects in the train components by using high-frequency sound waves. This technology works by using sensors to emit sound waves that penetrate the component, and then measuring the reflections of these waves to identify any abnormalities.

Ultrasonic technology is particularly useful in detecting defects in components that cannot be seen by visual inspection or other techniques. For example, it can be used to detect defects in the structure of the train, such as cracks or corrosion, that may not be visible to the naked eye. This technology can also be used to detect defects in the welds of the train components, which may be prone to fatigue or cracking over time.

In conclusion, the different types of technologies used in railway checkpoints play a critical role in ensuring the safety, reliability and efficiency of train operations. By understanding the basic principles, applications, advantages and limitations of each technology, railway operators can make informed decisions about the best approaches to inspect and maintain their trains and components. By using these technologies in conjunction with other techniques, such as Machine Learning, Big Data Analytics, Predictive Maintenance, Remote Monitoring and Integration with Enterprise Systems, railway operators can improve the overall efficiency and effectiveness of their train operations.

5.4. Main variables to support the location selection for each wayside technology

Depending on where the wayside equipment is installed, some issues need to be considered to achieve the best equipment behaviour:

5.4.1. Fleet to be monitored

Location of the installation is critical to define which fleet or fleets are able to be inspected through its specific wayside. And the design of the wayside systems is partially dependant on the fleets to be inspected (the systems need to be designed/configured for the specific fleets).

5.4.2. Run Speed

In relation to maximum/minimum train speeds available in each installation point, different technologies can/cannot be suitable to be installed. As an example, acoustic technology or running stability monitoring cannot be applied at low-speed train passes. The speed plays also an important role with regard to the accuracy or quality of the information. For example, image caption systems need to be specified and configured to be able to work at specific speeds (a camera configured to work at a specific speed will work properly at lower speeds but not higher). This is then an important factor to consider during the technology selection and system design process.

5.4.3. Geometry of the track

To achieve a proper measurement and avoid false positives on its measurements, pictures or diagnosis, wayside needs to be installed in a flat and straight track where no curves or levels could modify the train envelope or the train speed. For instance, in Wheel Defect Detection the proximity of track junctions could cause some noise in measurements and also false positives. In linear images compositions also, having the equipment close or within a curve could cause image deformations.

5.4.4. Lateral minimum distances

Like some other inspection equipment, gantry legs or cameras could be installed in lateral sides of the track. In this case, sufficient space should be envisaged between track and foundation so that the installed equipment does not conflict with the gauge on adjacent tracks.
In addition to this, a greater distance could be needed from the centre of the trail in order to build a pole to support cameras for pantograph monitoring.

5.4.5. Climate Conditions

The location of wayside equipment can be directly affected by external weather conditions (rain, snow, minimum/maximum temperatures) .
In case the equipment is installed in a critical climate conditions area, it may be needed to design and install some extra protection elements e to such as heaters, hatches, covers…

5.4.6. Machinery accessibility

Boom truck, excavation truck, manlift or any machinery needed to prepare civil works and equipment installation, need to be provided with normal accessibility to facilitate maintenance or installations works.

5.4.7. Interface with track infrastructure

Defined location needs to be chosen in any area where wayside equipment and its diagnosis technology are not affected with any element on infrastructure.

Figure 1515: Example of a catenary arm blocking a pantograph analysis

5.4.8. Location

- **Workshop location:**
  - Advantages:
    - Accessibility to maintain the equipment.
    - Accessibility to install the equipment.
    - Increase in workshop availability (trains with no corrective actions will return directly to commercial service without blocking any workshop track).
    - Higher control of safety elements condition.
  - Disadvantages:
    - Reduction in fleet availability.
    - Lack of previous planning in maintenance team on corrective actions of the diagnosis.
    - Reduced life of consumables; as a train is already in the workshop, elements close to end of lifespan will be replaced.
    - Not suitable for technologies related to high-speed inspection, such as acoustic technology.

- **Cross-border location:**
  - Advantages:
    - Increase in workshop availability (trains with no corrective actions will return directly to commercial service without block any workshop track).
    - Higher control of safety elements condition.
    - Increase in fleet availability.
    - Ontime planning team for corrective actions.
    - Increased life of consumables; planning team can extend as much as possible trains going to workshops thanks to daily automatic inspection on consumables.
    - All kind of technologies can be applied.
  - Disadvantages:
    - Accessibility to maintain the equipment; as the equipment is installed in a commercial track, equipment is needed to be maintained when no commercial services are activated, normally at night shifts.
    - Accessibility to install the equipment: same as for maintenance tasks, equipment is needed to be maintained when no commercial services are activated, normally at night shifts.

- **Main line location:**
  - Advantages:
    - Increasement of workshop availability (trains with no corrective actions will return directly to commercial service without block any workshop track).
    - Higher control of safety elements condition.
    - Increase in fleet availability.
    - Ontime planning team for corrective actions.
    - Increased life of consumables; planning team can extend as much as possible trains going to workshops thanks to daily automatic inspection on consumables.
    - All kind of technologies can be applied.
  - Disadvantages:
    - Accessibility to maintain the equipment; as the equipment is installed in a commercial track, equipment is needed to be maintained when no commercial services are activated, normally at night shifts.
    - Accessibility to install the equipment: same as for maintenance tasks, equipment is needed to be maintained when no commercial services are activated, normally at night shifts.

5.5. Evaluation of functional and operational objectives

5.5.1. Functional objectives

The European Railway Checkpoint (ERC) developed within the framework of the FP3-IAM4RAIL project outlines a set of functional objectives aimed at solving the challenges inherent in the use cases defined within the broader scope of the project, particularly those addressed in WP7 (European Railway Checkpoint for mixed traffic). These objectives, detailed below, are designed to improve fleet safety, streamline maintenance procedures, optimise spare parts management, minimise dust generation and extend the overall life of train components.

- **Increase in Fleet Safety:** the ERC focuses on increasing fleet safety by taking advantage of advanced technologies outlined in Chapter 5.3, "Mapping of different technologies of each train checkpoint." By meticulously inspecting the rolling stock and thoroughly analysing the data collected in various scenarios and locations, the ERC enhances the detection of critical points of failure. Early identification and resolution of anomalies prevent potential safety compromises. Moreover, automated inspection technologies replace manual tasks, mitigating human-induced errors and ensuring consistent, repeatable and standardised inspections.

- **Decrease in Fleet Maintenance Tasks**: real-time monitoring of condition-based parameters facilitates the early identification of issues, reducing the reliance on physical inspections and minimising the need for extensive repairs or component replacements. The data collected helps to recognise trends and patterns, enabling the development of predictive maintenance models. These models optimise the timing of maintenance tasks, ensuring interventions are carried out only, when necessary, ultimately reducing the overall number of maintenance tasks.

- **Decrease in Spare Parts List**: monitoring critical components in real time, as detailed in Chapter 5.2, "Train checkpoints achievable over its different locations," provides accurate data on their condition and performance. Condition-based maintenance, guided by this monitoring, reduces routine replacements and the need for an extensive inventory of spare parts. Efficient predictive maintenance further identifies patterns in component performance, allowing for a more judicious utilisation of inventory and a decrease in the overall number of spare parts required.

- **Decrease in Dust**: the ERC contributes to environmental sustainability by extending the life of train elements susceptible to wear. Wayside equipment facilitates continuous checking and accurate diagnosis, leading to longer replacement intervals. This proactive approach not only reduces the need for routine replacements but also diminishes the generation of dust elements associated with wear and tear.

- **Increase in Life of Train Components**: by enabling predictive maintenance interventions based on real-time data from checkpoints, European Railway Checkpoints extend the life of train components. This preventative strategy minimises unexpected failures, optimises maintenance schedules and contributes to the overall longevity and reliability of the railway infrastructure.

In essence, the ERC not only addresses immediate safety concerns but also strategically transforms maintenance practices, spare parts management and the environmental impact of railway operations. Through the pursuit of these objectives, the FP3-IAM4RAIL project pioneers´ advancements in railway technology that promise a safer, more efficient and sustainable future for European rail networks.

5.5.2. Operational Objectives

Train maintenance inspections are undeniably essential to prevent service disruptions resulting from various failures across different types of trains. The overarching goal of WP7, titled "European Railway Checkpoint for mixed traffic," focuses on the automation of maintenance inspection tasks. Currently, many maintenance inspections are carried out manually, leading to delays in the overall process and, in certain instances, human-induced errors. Building upon the functional objectives delineated earlier, the operational objectives within WP7 can be articulated as follows:

- **Centralise and Regularize Railway Traffic**: real-time data, covering assets' status and operational aspects, is obtained from checkpoints strategically installed in various locations, as detailed in Chapter 5.1, "Different locations of installation." By centralising the monitoring of this data, railway operators can make informed, data-driven decisions. This centralised approach optimises the efficiency of traffic flow, facilitating the real-time management of assets and streamlining the response to potential issues. The result is a more harmonised and organised railway traffic system.

- **Increase in Fleet Punctuality**: the precise reporting of assets' operational aspects enables the development of efficient maintenance scheduling. Predicting the optimal timing for maintenance tasks minimises disruptions in train schedules and plans. Moreover, the implementation of predictive maintenance interventions helps to reduce the occurrence of sudden emergency repairs and extended downtimes. This concerted effort not only enhances operational reliability but also significantly improves the punctuality of the entire railway fleet. Passengers and stakeholders can rely on a consistently on-time and dependable rail service.

- **Increase in Fleet Reliability**: building on the notion of predictive and optimised maintenance strategies, along with early fault detection, the objective is to elevate the overall reliability of the railway fleet. By mitigating the risk of unexpected failures and emergency repairs, the implementation of maintenance tasks at the appropriate times reduces disruptions. The strategic management of maintenance, combined with early intervention measures, contributes to an increased level of reliability across the entire railway fleet. This proactive approach fosters a dependable and resilient railway infrastructure.

In essence, the operational objectives outlined in WP7 transcend the mere automation of maintenance inspections. They represent a paradigm shift towards a more efficient, reliable and punctual railway system. Through the integration of advanced technologies and data-driven decision-making, WP7 strives to revolutionise the landscape of railway operations, ensuring a seamless and dependable service for both operators and passengers alike. The pursuit of these objectives within the broader context of the FP3-IAM4RAIL project reflects a commitment to advancing the efficiency and reliability of European rail networks.

6. Conclusions

As already presented in previous chapters, it is paramount to address the continuous evolution of the transport realm and particularly the specific needs of the railway sector in terms of maintenance. The potential improvement in automatic train inspection on track covered by a wayside equipment, is a topic that deserves in depth study and detailed demonstrations.

As a summary, customised wayside can be defined and designed considering different high-level criteria:

- the location where it will be installed,
- the technology applied and
- the inspection points to particularly focused on:

Location	*Type of Train*	*Technologies*	*Inspection Points*
• Workshop • Terminal • Cross-border • Main line	• Passenger • Freight	• Thermography • Image module • Line Scan • 3D • Laser Camara triangulation • Acoustic • Vibration • Radiofrequency	• Wheel Parameters • Wheel status • Coach fairings • Coach gauge • Brake status • High voltage cabling • Bearings • Train integrity • Running stability • Wheel forces

Table 4: Criteria to customise effective wayside.

Wayside described in previous points is mostly required by EU regulation. However, there is still room for improvement in the maintenance field.

FP3-IAM4RAIL project aims at identifying standard, centralised and unique European Railway maintenance processes/systems/activities which may allow to run any fleet through the whole European Rail network and positively impact the following critical aspects: increasing availability and reliability of fleet, reducing maintenance costs while maintaining safety of operations.

As an impact resume, described technology and system guarantees a very high environmental, economic and social impact.

Economic impact: implementation of this new technology will mean economic savings by providing greater operational availability in terms of the fleet, which will be able to extend basic maintenance inspections, so that trains can extend their passage through the workshop, ensuring the current high levels of safety. In addition, it will also mean a release of overload of existing rolling stock in the current maintenance workshops, potentially giving them greater operational availability.

The task of physical maintenance inspections in the workshop will be reduced, because as soon as the train arrives in the workshop, failure diagnostics are already known, allowing advance preparation of maintenance. Maintenance staff will be focused exactly on diagnosed tasks.

Social impact: execution of this project will generate a series of synergies in society and the national economy, such as:

- Generation of direct and indirect jobs.
- Promotion of new technologies in the industrial railway market.
- Knowledge development in companies in a specific sector.
- Generation of wealth in companies in the sector and associated companies.
- Reduction of environmental impact.

Part of the technical team assigned to maintenance in the workshop will be restructured into office positions for management and handling and diagnosis of the information received by the track teams.

In general terms, an improvement in working conditions and an enhancement of technological knowledge in maintenance personnel will be generated. As well as an upgrading in the safety conditions of operators, due to will be maintenance operations that currently have risk of being carried out on train (roof inspections, high voltage inspections...).

Environmental impact: due to increase of operational availability of the fleet, there will be a decrease in workshops entries, which implies a decrease of building needs, and a decrease of warehouse stock as the useful life of wear components is extended.

On the other hand, digitalisation of maintenance will result in the optimisation of equipment consumption and energy in workshops.

In terms of **civil works**, as the design and manufacturing of this technology can be compressed in a no-massive structure, it doesn't have a major impact on civil works.

Current technology has achieved a high protection against climate conditions reducing as much as possible protection hatches or casings, reducing the equipment installation over minimum needs.

As shown in the following image, defined technology and Wayside don´t need any “important” civil works.

Unique installation requirements are 4G connectivity area and a flat track whether in ballast or in concrete.

Figure 16:16 Automatic Train Inspection

7. References

D25.3, (2023) Deliverable 25.3 “Report on the Basic Functional and Technical Specifications Regarding CMS as relevant input for FP3”, FP5-TRANS4M-R WP25: Seamless use case definitions/preparations, Functional and Basic Technical Specifications, 2023, ERJU.

8. Appendices

Non applicable.