D25.3

Report on the basic functional and technical specifications regarding CMS as relevant input for FP3

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1. Executive Summary

The present document constitutes the basic functional and technical specifications regarding CMS as relevant input for Flagship Project FP3 – IAM4RAIL. The term Condition monitoring systems (CMS) here refers to wayside monitoring systems and in particular the Intelligent Video Gate (IVG) concept developed within the Shift2Rail programme and the projects FR8HUB and FR8RAIL III. The concept is now further developed in a concept called "Standardised European Checkpoints" within Flagship Project FP5 – TRANS4M-R. As these checkpoints will also be developed within FP3 WP7, the main purpose of this deliverable is to provide FP3 basic functional and technical specifications developed previously for the concept within Shift2Rail as well as the vision for the further development of the concept within FP5. Moreover, as CMS also includes other wayside monitoring systems (WMS) than the IVG concept, previous work within Shift2Rail regarding these technologies will also be addressed in this deliverable.

The IVG concept was first described and showcased on a model train within Shift2Rail and the project FR8HUB and the full scale demonstrated within FR8RAIL III, including installation of gate in Gothenburg, Sweden for terminal purposes, while for yard purposes the gate in Nurnberg yard in Germany was used. The work will now continue within FP5 with extending the concept with further functionalities for terminals, yards and borders and to further European countries, both on a local/national and a European level.

Challenges experienced during the Shift2Rail projects regard first of all installation challenges; one should consider all the required steps i.e. finding a suitable location, contracting sub provider, obtaining all permissions for installation, purchasing components, transportation of equipment, construction, fine tuning while estimating costs and effort for each step. As for the technical challenges and the image processing, hit rates over 95% for character recognition (codes) are required i.e. ability to recognize more code types e.g. domestic ILU codes differs and are hard to recognize, as well as improved damage detection abilities. Regarding the technical challenges with data exchange, it is particularly worth considering that handling information of dangerous goods is strictly regulated.

Regarding Wayside monitoring systems based on other detection technologies, the industry is already providing sensors to monitor a large number of freight wagon conditions. However, there are still areas of freight wagons that are difficult or impossible to monitor with stationary or on-board sensors. However, it will not be possible to deploy a comprehensive condition detection solution at one time but step by step. The gradual integration of domestic and international data will also present economic, technical and legal challenges.

Keywords: Condition monitoring systems (CMS), Intelligent Video Gate (IVG); Wayside monitoring systems (WMS)

2. Abbreviations & Acronyms

Abbreviation / Acronym	Description
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
CBM	Condition Based Maintenance
CMS	Condition Monitoring Systems
DTS	Cloud system that Indra uses
ECM	Entity in Charge of Maintenance
EMC	Electromagnetic Compatibility
FP3	Flagship Project 3 (previous *Destination 3*)
FP5	Flagship Project 5
FTP	File Transfer Protocol
HBD	Hot Bearing Detector
HMI	Human- Machine Interface
ILU	Intermodal Loading Units
IMO	International Maritime Organization
IVG	Intelligent Video Gate
MAWP	Multi Annual Working Plan
OCR	Optical Character Recognition
POC	Proof of Concept
PU	Public
RCMF	Railway Coordination Messaging Format
RFID	Radio Frequency Identification
RMG	Rail mounted gantry crane
RU	Railway Undertaking
UIC	International Union of Railways
TOS	Terminal Operating System
TRL	Technology Readiness Level
VPN	Virtual Private Network
WAN	Wide Area Network
WILD	Wheel Impact Load Detectors
WP	Work Package
WPMS	Wheel profile Monitoring Systems
WMS	Wayside Monitoring Systems

3. Background

The present document constitutes the Deliverable D25.3 “Report on the basic functional and technical specifications regarding CMS as relevant input for FP3” in the framework of the Flagship Project FP5 – TRANS4M-R as described in the EU-RAIL MAWP and contributes as well to the Flagship Project FP3 – IAM4RAIL.

The term *Condition monitoring systems (CMS)* here refers to wayside monitoring systems and in particular the *Intelligent Video Gate (IVG)* concept developed within the Shift2Rail programme and the projects FR8RAIL III and FR8HUB. The concept is now further developed in a concept called “Standardised European Checkpoints” within FP5 – TRANS4M-R.

As these checkpoints will also be developed within FP3 and WP7, the main purpose of this deliverable is to provide FP3 basic functional and technical specifications developed previously for the concept within Shift2Rail as well as the vision for the further development of the concept within FP5. Moreover, as CMS also includes other wayside monitoring technologies than the IVG concept, previous work within Shit2Rail regarding these technologies will also be addressed in this deliverable.

4. Objective/Aim

This document has been prepared to reach alignment with FP3 regarding Enabler 12, thus providing a knowledge transfer of previously work carried out in Shift2Rail regarding CMS which will now continue both in FP3 and FP5. Moreover specifically, the aim of this deliverable has been to fulfil Task 25.8 within WP25 of FP5:

"Task 25.8: Specifications and requirements for FP3"

Lead: TRV; Participants: KTH, LSP, RISE, DBC, ADIF, CD, CDCARGO, OLTIS, INDRA, HACON, THA, PROSTEL, CEIT; Start: M06; End: M12

Enabler 12 will be addressed in this task. To reach complete alignment with Destination 3 a first early Deliverable (D25.3) will be produced, where all the automation needs and integration with physical layer will be detailed."

"Enabler 12: Specify and develop Railway Checkpoints that will automate Freight Train Transfer Inspections at borders or other operational stop points, digitalising and automating processes through innovative sensors, specialised adapted video gates and handheld devices, in combination with harmonized procedures and regulation across European rail network and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions

The main outcome of Railway Checkpoints is a specification and demonstration that will partially automate freight train transfer inspections at borders or other operational stop points.

To ensure an interoperable EU-harmonized development the approach is to specify the functional and non-functional requirements from a Logistics-, Inspection-, Condition- and Cross boarder perspective. This includes digitalising and automating processes through the use of emerging technologies in specialised adapted "Intelligent video gates" (IVG), using OCR, sensors and other detection and identification technologies. The demonstration is combined with evaluation of data sharing and exploitation possibilities as well as harmonized procedures and regulation across the European rail network. Apart from enabling improved operations these checkpoints can also contribute to improved maintenance processes and safety performance e.g., in freight train preparation phase and monitoring safe attachments on wagons."

5. Basic functional requirements and technical specifications for Intelligent Video Gate (IVG)

5.1. Previous work within Shift2Rail

5.1.1. FR8HUB

The concept of IVG was first addressed within Shift2Rail in FR8HUB WP4 Intelligent Video Gate of IP5, 2017-2019. Within that framework, two deliverables were produced; D4.1 (2018) and D4.2 (2019).

As a technical system, the IVG consists of structural components (gate components for keeping/ housing devices, electrical supply, etc.), technical components (image recording, illumination, RFID-reader, user interfaces) as well as logical components (image processing, RFID-processing, memory, visual data evaluation, etc.). The main technical components composing the Intelligent Video Gate are:

- Cameras
- Illuminators
- RFID antennas and tags
- Wheel sensors

The concept of Intelligent Video Gate (IVG) consists of a gate system installed at relevant railway nodes equipped with high-frequency cameras for automatic identification of wagons and intermodal loading units (ILU; for example, containers, swap bodies, and semi-trailers). Image recognition techniques are used to identify wagon numbers, loading unit codes and placards also allowing automatic data information merging with corresponding Rolling Stock RFID tags.

5.1.2. FR8RAIL III

Within the WP3 in FR8RAIL III three deliverables have been produced containing requirements definition and IVG preliminary installation report D3.1 (2020) and description and preparations for a demonstrator of the IVG D3.2 (2021) and Demonstration and Evaluation D3.3 (2022).

The aim of D3.1 “Requirements Definition and IVG Preliminary Installation Report” was to define requirements for installations of Intelligent Video Gates together with a preliminary installation report for a single-track installation at a terminal or yard. The deliverable presents characteristics, similarities and differences of two types of possible facilities: shunting yards, mainly in Germany, and intermodal terminals, mainly in Sweden. A preliminary installation report is presented for an IVG placed in connection to the Port of

Gothenburg, in Sweden. Moreover, D3.1 also contributed in finding possible synergies with other WPs within FR8RAIL II and FR8RAIL III. One example is FR8RAIL II WP 5 Freight Automation, task 5.1, where it was investigated how the IVG concept can contribute to the automation of the train preparation process considering e.g. brake tests and inspections.

The aim of D3.2 “Description of demonstrator - Intelligent Video Gate” was to describe and prepare for a demonstrator of the IVG. The aim was achieved though installing intelligent video gates at two pilot sites, Gothenburg, Sweden and Nuremberg, Germany, see Figure 1 and Figure 2. The final deliverable of this WP, D3.3, was a demonstrator of the installed gates, including an evaluation of identified use cases, described in section 3.2.4 of this document.

Figure 1. Physical installation in Gothenburg, Sweden

Figure 2. Physical installation in Nuremberg, Germany

5.2. Functional requirements

5.2.1. IVG at intermodal terminals

Establishing IVG in intermodal terminals and freight yards can have several positive effects. From the perspective of the terminal operator, the IVG concept would imply an improvement in operational efficiency, mainly due to:

1. Faster arrival process. Handling deviation and identification of wagons and cargo carriers with higher degree of automation during arrival processes, e.g. check-in (document handling) / damage claims / handling of dangerous goods.
2. Faster departure process. Higher degree of automation at departure e.g. departure control, improved safety and handling of dangerous goods.
3. Improved and faster operational management when sequence of wagons and intermodal loading units (ILU) (and any deviations from pre-arranged sequence) are known in advance, which enables optimized transshipment plans and a more seamless interface toward road transporters.

Obviously improved services at terminals imply an improved and more attractive range of services, which in the long perspective should lead to a higher degree of customer satisfaction and contribute to modal shift ambitions of the European green deal and sustainable transport goals.

Figure 3 illustrates the main information that can be automatically and digitally retrieved from the IVG and the main operational benefits that this could lead to. When studying the benefits and added value that the two different technologies; image processing and RFID will imply, they appear to be a good complement to each other. The image processing can read codes and placards of dangerous goods without extra equipment on the wagon or ILU, unlike other technologies, where RFID requires that the units are pre-installed with tags. The camera can also be used for other purposes than purely detecting and identifying devices, such as damage inspection and departure control. RFID technology can identify vehicles at the Swedish Transport Administration's detector stations and sites as well as at some operators' and shippers' own facilities. In particular, RFID adds increased reliability to the IVG concept as the technology provides a reliable complement to the camera, which does not achieve the same level of reading capability, especially in unfavourable operational situations such as dirty devices and in difficult winter conditions.

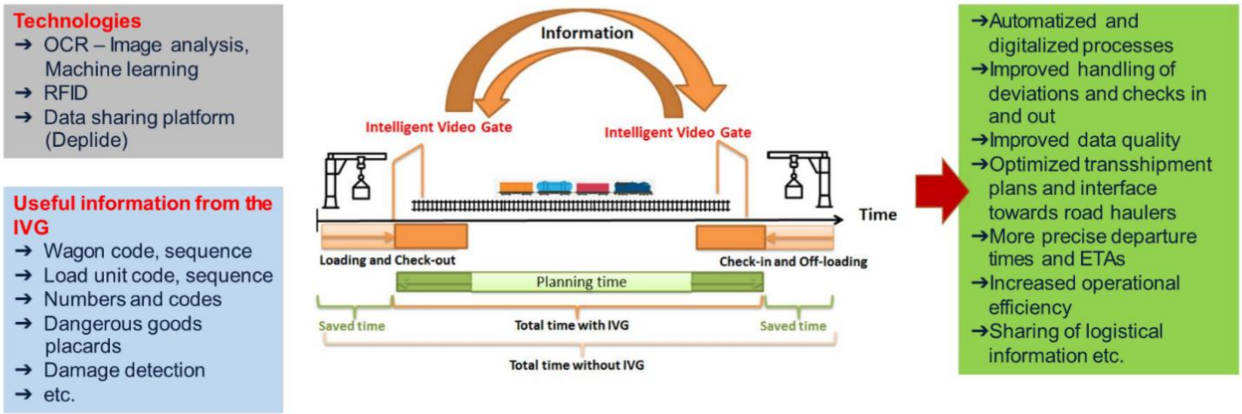

Figure 3. The main identified benefits of the IVG concept. Information (blue box) that can be identified and benefits (green box) that it can lead to. (D3.1, 2020)

Thus the IVG concept aims at automating and digitalising the processes of an intermodal terminal. In an intermodal terminal, for the transshipment operation at least two terminal staff members are required; one driver in the crane cabin and one staff member on the ground, assisting the crane driver. They communicate between each other by radio. The duty of the ground staff is to check that the crane spreader straddled ILU in a proper way, that semi-trailer kingpin is positioned well on the wagon and to read the ILU number to a crane driver if it's not visible from the top etc.

Figure 4. Cameras and software inside the RMG crane cabin in Jernhusen's intermodal terminals.

Figure 4 shows cameras and software installed inside of the crane cabin. The first task of the crane operator for incoming trains is to check for deviations from the list of pre-advised ILU's and their sequence on the train. This check is done manually by observing the registration numbers of the ILUs. If this deviation control could be done automatically with an IVG, this would facilitate the crane operator's task immensely, as it sometimes is difficult to spot the placards and numbers manually due to e.g. weather, dirt and misplaced placards. Moreover, it would save time per transshipment as the crane operators do not have to carry out the deviation control.

Expected influences on terminal operations are in the first stage connected to the replacement of the manual control and data collections along arriving trains, in favour of automatized process with automatic identification of ILU and wagon through optical and RFID recognition, as described in the project FR8HUB (D4.2, 2019). Benefits for railway companies are better information about what is in the train in every moment while loading/ unloading, and possibilities to plan train- and shunting activities based to IVG info since IVG enables more time for planning. Easily accessible data from the gate without manual handlings also enables safer and reliable information on dangerous goods and safer control of train composition upon departure and arrival, potentially even under way. It is possible to use operational data from IVG to plan and maintain infrastructure, which is beneficial for infrastructure managers. Detection of handling or shunting mistakes (e. g. wrong load unit on the wagon, wrong wagon in the train composition) can be done with the help of the gate.

Expected benefits for the terminal are faster registration of incoming units, automatically updated register of load units (and wagons), and increased security due to fewer persons needed along the trains and tracks. The duties of the staff will change from walking and manually checking the incoming trains, to handling the register and facilitate better planning of terminal activities. The video equipment and picture recognition can also be used for identification of critical damages, losses, open doors or manhole covers on load units and other security risks. The number of complaints is expected to be reduced significantly and thus also the number of working hours related to that.

5.2.2. IVG at Yards

Shunting yards are train formation stations of single wagons or wagon group in railway freight traffic. The transportation of single wagons or wagon groups are performed in mixed trains. These operations differ significantly from block trains. After their arrival, the individual wagons or wagon groups are disassembled, shunted and finally reassembled into new mixed trains leaving for different destinations all over Europe (DB Cargo, 2020).

Once a train arrives at the shunting yard "arrival zone" (see Figure 5 for overview of the yard in Nuremberg in Bavaria, Germany), a shunting locomotive pushes the entire train slowly over a hump. An employee separates the wagons from each other by releasing the coupling. From this moment, the separated wagons or wagon groups move on a track without human action and only by gravity (DB Cargo, 2020).

After passing the IVG on this track, the wagons enter the directional tracks, where the wagons are reassembled in a different order. The track switch is triggered by the automatic shunting system of the yard (DB Cargo 2020).

According to their weight, the wagons accelerate differently. That is why automatic brakes are located in the tracks which regulate the wagons' speed. At a flat yard when the wagons are not linked to each other completely in the classification track, a small shunting device which is also triggered by the shunting system pushes the wagons together (Figure 6). Afterwards the train is coupled together and ready for the next transportation (DB Cargo, 2020).

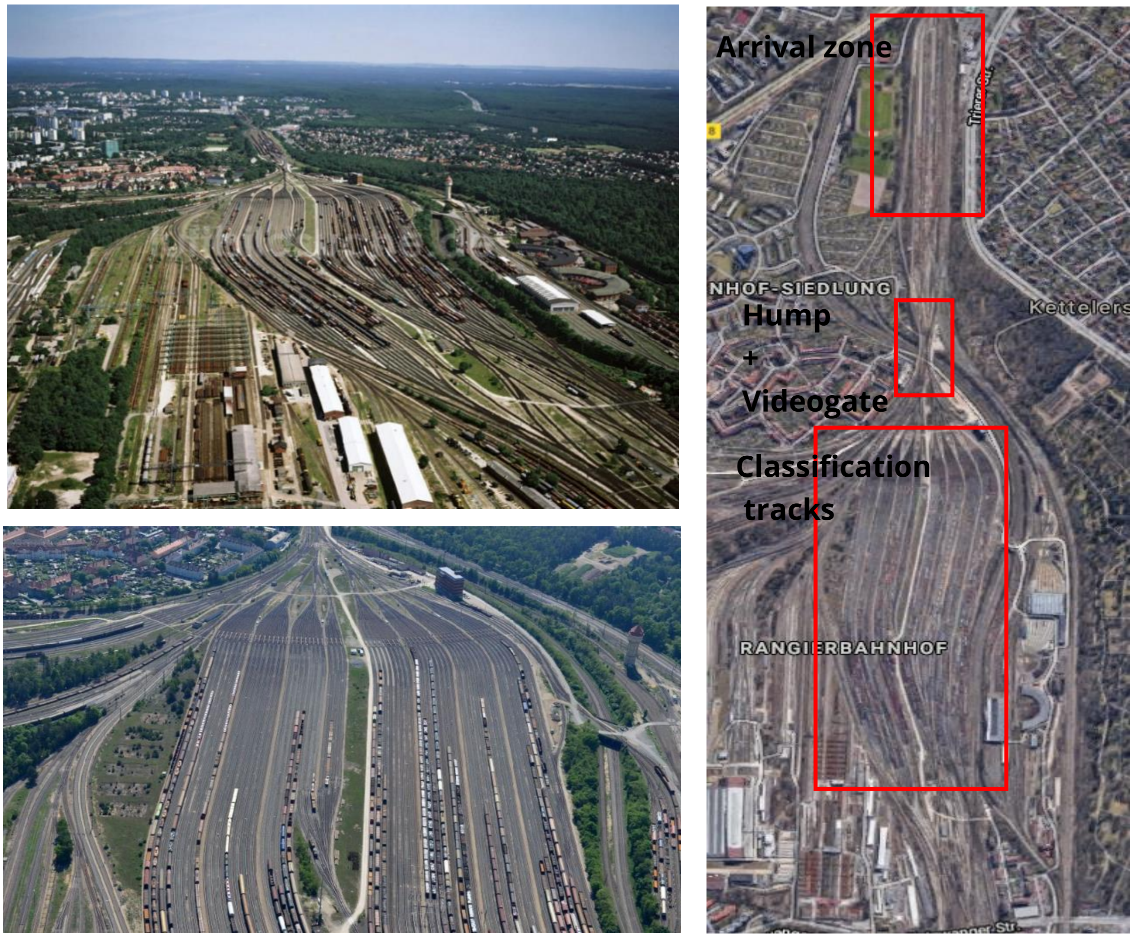

Figure 5. Shunting yard in Nuremberg, Bavaria, Germany. (Top left: DB Cargo, 2000; bottom left: DB Cargo, 2015; right: Screenshot Google Maps, 2020)

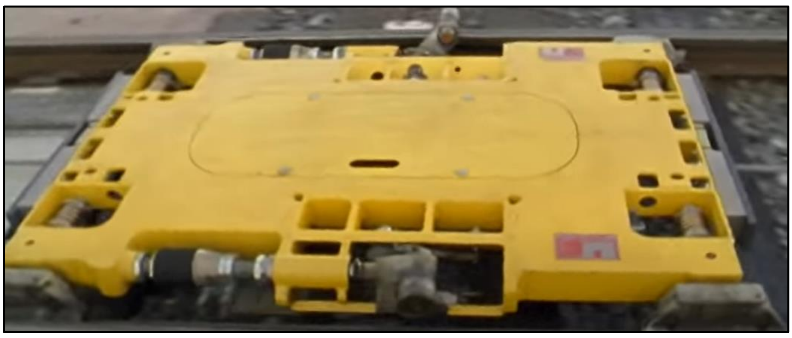

Figure 6. Shunting device for pushing wagons together. (DB Cargo, 2020)

5.2.3. Functionality of IVG at terminals vs yards

5.2.3.1. Similarities

The main similarity between shunting yards and intermodal terminals is their purpose of reordering freight on tracks for railways. To have a better overview of the wagons' current position and condition and, therefore, to safe time in handling and maintenance, visual information is needed. This information can be provided by the IVG. The two different types of IVGs also have some similarities. Both IVGs:

- Are equipped with Linear cameras
- Are equipped with RFID-sensors
- Can provide images from different perspectives
  - The Line-Scan images are merged, so that the entire wagon is shown. This process takes place on a local unit (edge-computing)
- Can identify different information on the wagons. (For example the Wagon number (UIC))
  - Therefore the IVGs focus on the image processing and the RFID reading method of the UIC wagon number. The combination of both techniques leads to better results when it comes to the quality of the wagons pictures and the assignment of these pictures to wagon numbers (DB Cargo, 2020).
  - This process takes place on a local unit (edge-computing)

5.2.3.2. Differences

The following section deals with the differences between yards and terminals.

Nuremberg shunting yard is constructed as an inclined yard, which means that wagons are pushed over a hump by a shunting locomotive in order to be reassembled to a new train.

Intermodal terminals are constructed as flat yards, the wagon itself doesn't vary whereas the freight is loaded/unloaded. Therefore, the entire train enters the transshipment area where cranes reorganize the freight either to other trains or to trucks. Wagons are lined up while passing the IVG and to enable transshipment to and from trucks cranes are used in the system. To analyse each ILU correctly, the cabin of the Rail mounted gantry crane (RMG) is equipped with a separate software. (DB Cargo, 2020). While the yard in Nuremberg mainly uses the IVG to monitor and focus on the condition of the freight wagons for claim and maintenance purposes, TRV and Port of Gothenburg primarily analyse ILUs and dangerous goods placards. It also could be possible to use the IVG as an automatic trigger for notifying customers that their freight is leaving the yards. In Table 1, the differences between the IVGs at the shunting yards in Germany and intermodal terminals in Sweden are listed.

Table 1. Differences between shunting yards in Germany and intermodal terminals in Sweden

Shunting yards Germany	Intermodal Terminal Sweden
Inclined yard: Wagons are pushed down a hump for an automatic shunting into the directional group	Flat yard: Wagons are pulled by a shunting locomotive to the track, where they are loaded/unloaded by a gantry crane or reach-stackers
Shunting deploying the gravity method by making use of the incline formed by the hump. Only single wagons or small wagon groups are passing the hump and IVG located on the hump while accelerating.	Wagons are attached to a whole train while passing the IVG at constant or variable speed.
Marshalling on tracks for trains	Marshalling on tracks for trains and on truck lanes for freight transported on vehicles (trucks). Therefore, semi-trailer parking is necessary
No cranes used on the shunting yard	Due to the different transportation modes, cranes or reach-stackers are in use for transhipment (loading/unloading) of loading units and the respective flexible integration of trains or trucks. Separate software inside of an RMG crane cabin.
Operated by governmental organization (e.g. DB Netz)	Private or public terminals
IVG construction: The IVG in Germany is a gate with three bars mounted together.	IVG construction: The IVG in Sweden is a gate with two separate bars on each side of the track
Speed measuring: To identify the speed of a wagon a laser scanner is mounted on the top of the IVG.	Speed measuring: To identify the speed of the wagons different wheel sensors are mounted to the track.
Minimum speed requirement for IVGs at marshalling yards: 0-5 km/h Reason: The wagons are accelerating while passing the IVG. The wagons start accelerating at the top of the hump with a speed between 0-5 km/h Maximum speed: 40 km/h	Minimum speed requirement for IVGs at terminals: 10 km/h Trains will pass the system with a speed higher than 10 km/h – so the requirement for lower speeds is not necessary Maximum speed: 360 km/h or more

RFID-sensors: Each IVG is equipped with two RFID-sensors to detect both sides of the wagon. (Detect both RFID-chips to clearly identify the wagon – main reason for the use of two RFID-sensors are the trains passing on parallel tracks). The identification of the wagon side is necessary for the maintenance ordering and maintenance workshop to clearly identify the damages.	RFID-sensors: The IVG in Sweden is equipped with only one RFID-sensor to identify the wagon number because this is a single track installation.. However, there are another RFID reader close by.

5.2.4. Evaluated use cases

As part of the tasks of suggesting paths for data exploitation and the final evaluation of the IVG concept, a set of use cases were identified and evaluated within FR8RAIL III (D3.3, 2022). See Table 2 for short descriptions of these use cases.

Table 2. Identified and evaluated Use case for the IVG concept within FR8RAIL III (D3.3, 2022)

Use case	Description
Information to customers	An **information system gives customers** of railway undertakings and terminal operators the possibility to access **timestamped information about ILUs, wagons and trains** gathered by IVGs, along with **estimated deviations** from their planned time of arrival.
Planning	IVGs located at sending terminals or along railway lines can provide useful information for **the transshipment planning** at intermodal terminals.
Damages	Detection of damages, initially graffiti.
Dangerous goods	Information collected by IVGs can help infrastructure managers with more **accurate status of dangerous goods**.
Dangerous goods and TMS	Use of IVGs to improve and **optimize the scheduling** of transits with dangerous goods for reducing **the exposure risk**.
Use cases for the IVG at yards	IVG is currently used to speed up and digitalize the reporting process of the **maintenance** ordering unit. By identify the damages on the high-resolution images, risks for the employees' health and the amount of unnecessary paperwork can be reduce.

5.2.4.1 Digital process transformation in the wagon maintenance - (Fr8Rail IV)

The main reason for the implementation of IVGs at yards in Germany was the digital process transformation of the wagon maintenance process. Until the implementation of the IVGs into the process the employees of the ECM 3 (Entity in Charge of Maintenance) had to go to on the tracks to investigate all the wagons running into the workshop regarding damages. This leads to a big amount of time the employees spend on the way to the wagon and back to the workshop. Sometimes with bad working conditions due to weather circumstances. Additionally, they had to document all the identified damages on paper and then back in the workshop they have to implement them in SAP to order the maintenance work of the workshop. This leads to a big loss of time which they can spend in the workshop to support the ECM 4 (maintenance operation).

With the implementation of the IVGs into the working process the employees of the ECM 3 spend more time in the workshop than before. Additionally the investigation of the wagons could start earlier and be faster than before. All these process optimizations lead to an increase of the maintenance quality of the wagon maintenance. The following chart shows the difference between the old and new ordering process of the wagon maintenance.

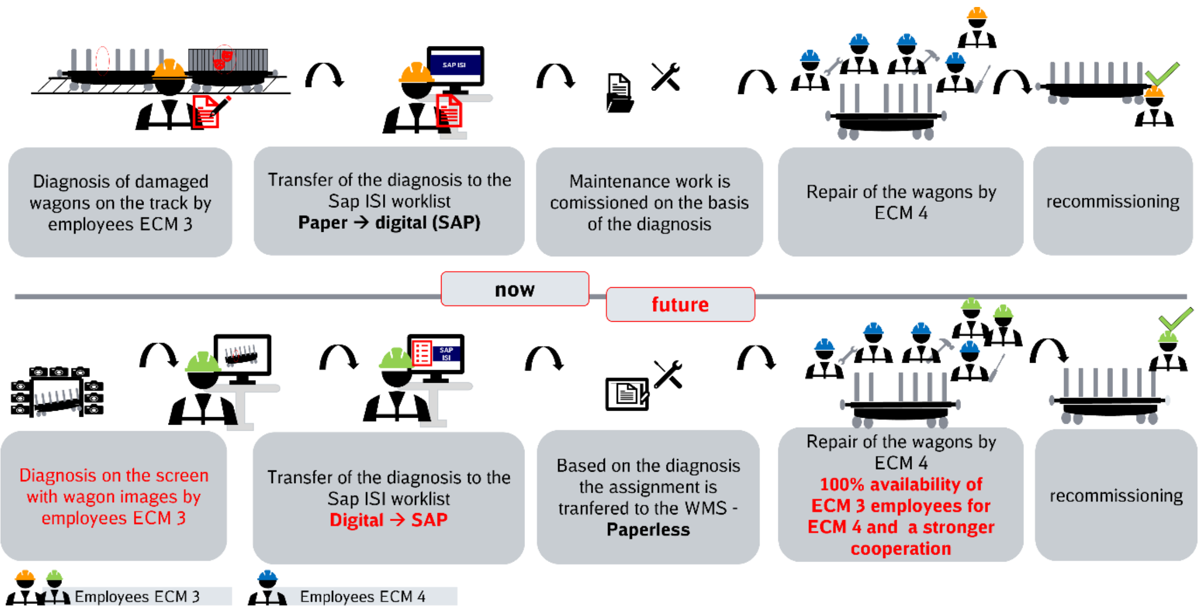

Figure 7. Transformation of the wagon maintenance ordering process.

Additionally to the process transformation, the implementation of the IVGs change the possibilities of damage detection as a new angle ordering process is visible. During the old process it was not possible to view the wagon roof or the interior of the wagon from the top. With the IVGs a special camera positioned at the top provides this view and leads also to a better view of the wagon especially from above.

5.2.5. Further functionalities

Synergies have been sought with other work packages and projects within Shift2Rail. Apart from work packages in FR8RAIL III and FR8HUB, also in the framework of the FR8RAIL II WP5 Freight Automation Deliverable 5.1 (2020) synergies were investigated, in particular regarding track side inspection through IVG and the train preparation process including the brake test process. The synergies are elaborated in FR8RAIL II D5.1, in this report a short reference is made regarding the main outcome. The train preparation phase including the brake test, include a number of visual inspection assignments, which could in theory be carried out by the IVG. However, innovative solutions are required for handling alarm detection on outgoing trains on non-dedicated lines with mixed traffic, further elaborated in D5.1. The visual inspection for external control of the rolling stock could for this purpose inspect the following:

- First and last wagon number, complete train, brakes off
- Cables, hoses, pipes
- Wagon body and bogies
- Pantograph
- Brake pads (where visible)
- Position of various air taps

If a microphone is attached to the IVG system, also acoustic control could be carried in order to detect air leakages.

5.3. Technical Specifications

As a technical system, the IVG consists of structural components (gate components for keeping/ housing devices, electrical supply, etc.), technical components (image recording, illumination, RFID-reader, user interfaces) as well as logical components (image processing, RFID-processing, memory, visual data evaluation, etc.).

5.3.1. Selection of components

The main technical components composing the Intelligent Video Gate are:

- Cameras
- Illuminators
- RFID antennas and tags
- Wheel sensors

For each of these components a detailed description is provided in (D4.1, 2018), together with its main technical characteristics, necessary for component evaluation during the selection process.

5.3.2. Installation of IVG

The IVG-system described in this section is installed on the entrance/exit tracks of the terminal. Ideally, all rail movements in the terminal run over one track or a double track. This can however not be achieved in all terminals (for example terminals with several routes into the terminal) and several IVG-systems could be needed. Generic construction requirements for IVG at intermodal terminals were presented in (D4.2, 2019).

The installation of the IVG needs about 20 meters for the measurement zone along the track. The installation also requires sensors, preferably wheel sensors, to trigger the IVG for a start-up procedure of cameras and illuminators. The distance of these triggering sensors in relation to the gate is depending on the actual train speed at the site.

The wayside IVG components, such as cameras and illuminators, should be placed on a wayside pole approximately 3 meters from the rail, mainly due to Electromagnetic Compatibility (EMC) regulations as well as optical characteristics and local regulations in each country. For the physical site installation, it is important for the pole to be stable and robust to avoid that mechanical vibrations produced by the running trains are transferred to cameras producing blurred images.

Regarding the construction requirements, different scenarios of local conditions need to be considered. The draft illustrated in Figure 8 corresponds to general minimum distances in construction works near/at railways including gauge guidelines, electromagnetic impact guidelines etc. in order to avoid heavy tests for homologation and interference with other infrastructures or rolling stock. Trains in this site transit at approximately 40-50 km/h.

One single camera can get a high-definition picture of the entire side of a wagon. The image definition is enough to detect loading unit code as well as UIC-wagon code, the UIC code will also be detected by the RFID reader, complementing each other. Illuminators are installed as well in order to have clear wagon photos also during night.

If damages detection is required, a dedicated camera for the bogie side check or a 3D system could be good alternatives. As described in (D4.1, 2018) this function should be carried out using laser scanners (or calibrated cameras for 3D pictures).

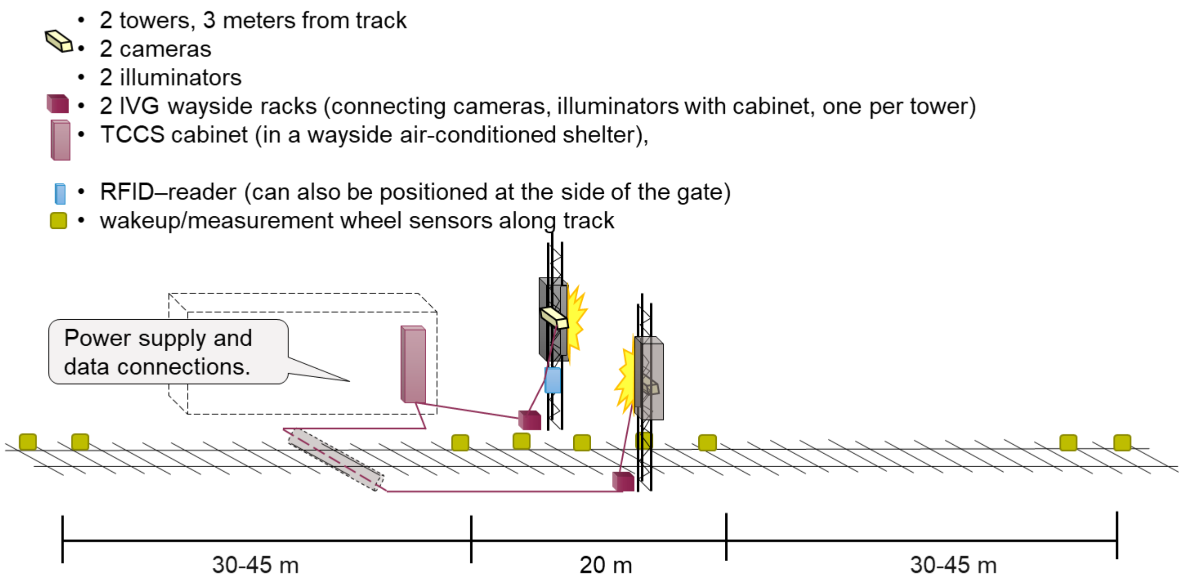

Figure 8. General minimum distances in construction works. (D4.2, 2019)

Full data collection on both sides of the train surely leads to more precise results and higher reliability of data. If one side of the train is of such poor condition (e.g. graffiti, dirt, exposure problems, etc.) that almost none of the numbers could be identified, this lack of information would lead to higher manual effort later, after the train has arrived.

If shunting is done through the gate, i.e. wagons passes several times in random pace, the solution might not work properly. This also applies when the train goes very slowly, stops or restarts. Minimum speed should be above 10 km/h. In case of uneven speed, it will be handled by the system as long as the train remains above 10 km/h or 15 km/h which will be even better. At the DB gates at yards other types of sensors are used, adapted for lower speeds. The vibration sensitivity of the cameras is different depending on the train velocity when passing through the gate. At low speed < 25 km/h a stable enough pole/installation should be sufficient but at higher speed there is need for more stable construction.

The RFID-tag reading will work at any speed of the train, low or high. The following drafts assume bidirectional vehicle movements on the track(s) and should give an overview of the most expectable variants for implementation.

Figure 9 shows a single-track with a full gate construction that collects data and images just from one long-side of the train including images from the roof. Depending on the situation (with or without electrified track) the position of the roof cameras could be changed. For example, just one roof camera in the middle section could be enough when having no electrified track. The cameras are for image acquisition and for later number checks and damage documentation. The RFID-antenna unit is responsible for the collection of RFID-tag-data of the wagon.

Optical fibre is recommended for communication cabling between the IVG and other external systems such as TOS or a radio link if more convenient for installation purpose. When feasible also 5G can be tested as communication link. Fibre connection or radio link is recommended but even 5G might be sufficient but is not clarified yet. Both bandwidth and EMC requirements have to be further investigated.

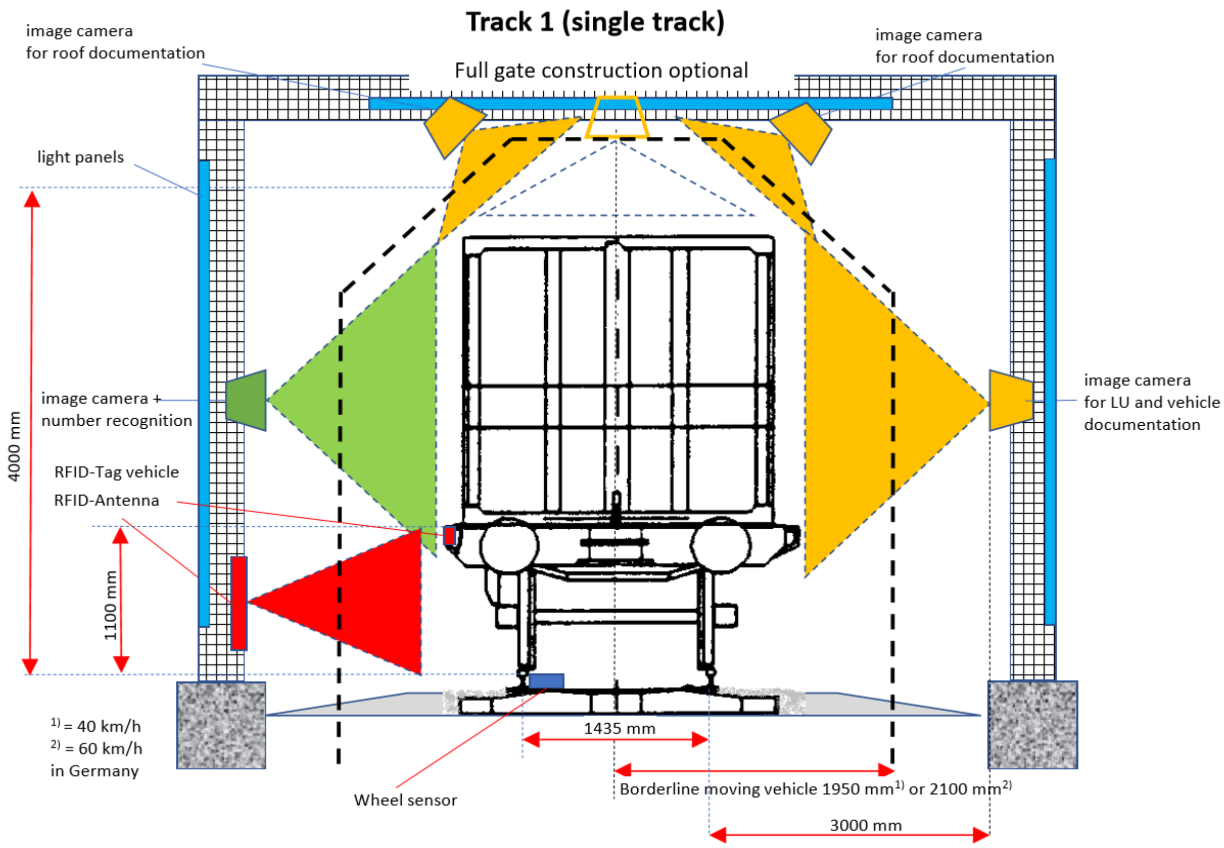

Figure 9. Single track gate with train operation. (D4.2, 2019)

5.3.2.1. Basic Requirements and Time plan for the Demonstration

The following basic requirements should apply in the installation site in order to allow correct IVG setup and functionality as elaborated in section 5.3.2:

1. 60-80 meters of rail for installation purposes
2. Train speed above 15 km/h
3. 4-5 meters of free lateral space for the installation of wayside poles holding cameras, illuminators, RFID and other equipment
4. Power supply for wayside equipment
5. Free space and power supply for the cabinet in a nearby conditioned shelter. Cabinet dimensions 600x800 mm base and 2100 mm high. Possibility to open doors on both sides of cabinet. Each door is 600mm wide (mounted on the narrower sides of the cabinet).
6. Ducts for passing electric and optical fibers from the wayside installation zone to the cabinet inside the shelter.

Preliminary work on the installation of the gate started from the beginning of the project FR8RAIL III with discussions on site selection and basic installation requirements stated above. Activities intensified during begin of summer 2020 according to the general planning provided in Figure 10.

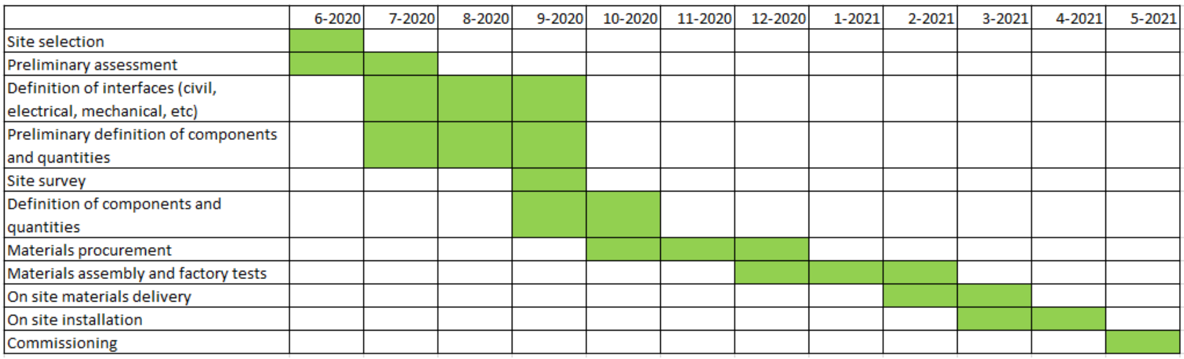

Figure 10. Installation plan for the IVG in Gothenburg.

Gothenburg being the chosen installation site, a preliminary assessment of the installation site has been performed based on information and photos provided by Trafikverket. An experienced project manager was involved from Trafikverket side to take care of local permissions and all necessary site works.

The definition of responsibilities between Trafikverket, Hitachi and an Italian supporting company provider called TEA have been done as well as follows:

- Trafikverket will take care of all installation permissions and local works, including provision of wheel sensors, wayside poles, power supply and cables.

- TEA will provide cameras, illuminators and wayside racks providing IO (input/output) logic for wayside equipment, together with detailed design of wayside poles.
- Hitachi will provide all know how for IVG installation and the TCCS cabinet containing all basic IVG functionality up to high definition image creation at a wagon bases.
- Trafikverket will solely fund the gate in Gothenburg.
- Hitachi will provide some items and provide with deep installation knowledge.

A physical site survey from Hitachi was planned in mid-September for final confirmation and definition of last installation details, such as cables length, ducts availability, wheel sensors installation positions, poles positions, cabinet position inside shelter, etc., see Figure 11, Figure 12 and Figure 13.

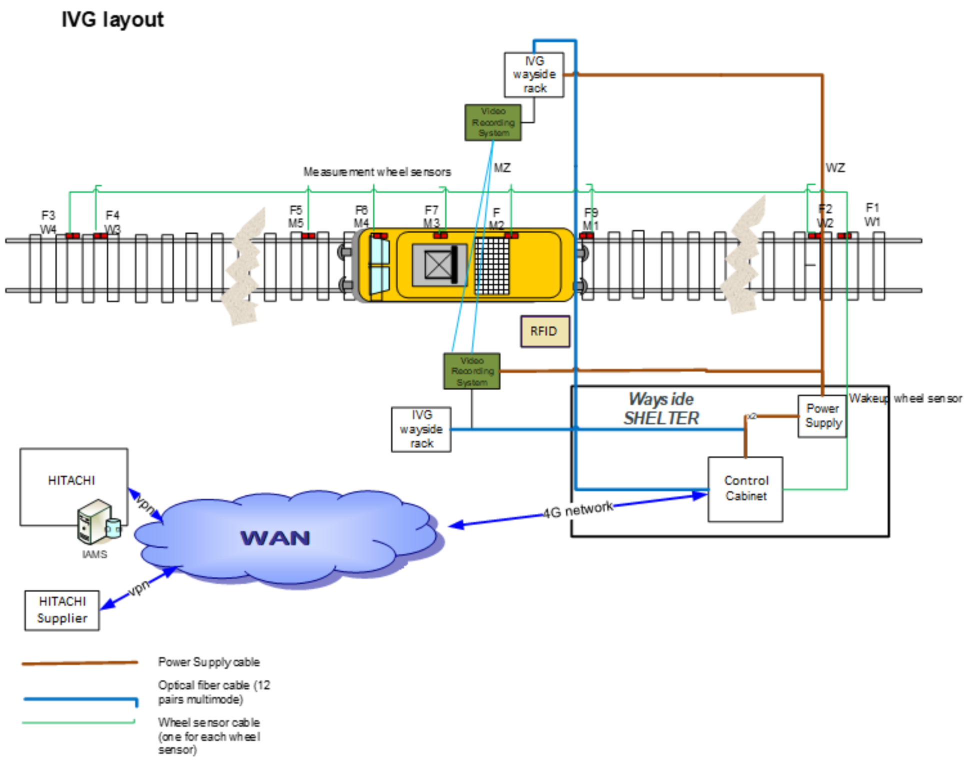

Figure 11. IVG layout in Gothenburg.

Figure 12. Positioning of poles in Gothenburg.

Figure 13. Positioning of poles, cabling and technical cabinet in Gothenburg.

Starting from the site survey the definition of materials and quantities was finalized and procurement started. It took take a few months for the materials to arrive in order to start with assembly at factory site and factory preliminary tests.

After this, all materials was delivered at Gothenburg premises for Trafikverket to perform installations according to Hitachi instructions. At installation site, the finalization of the commissioning of the gate could be performed allowing the acquisition of high definition train images.

Once the images have been obtained by the acquisition system on site, they are sent to the image processing system (which can be also on-site or remotely located at the terminal or other facilities, in this case being sent over the fibre/5G communication infrastructure already described). This system consists of a database, a processing engine running the artificial vision and Deep Learning algorithms over the images captured and a HMI/Web interface.

5.3.4. Image Analysis

The final system for image processing has a modular design which uses Artificial Intelligence models to solve some of the problems that the railway and freight industry face in order to automate processes, such as automatic codes detection and readings (OCR), dangerous cargo signs and placards detection, classification of different types of containers and the detection of damages that could affect the reading or the detection of codes, illustrated by Figure 14.

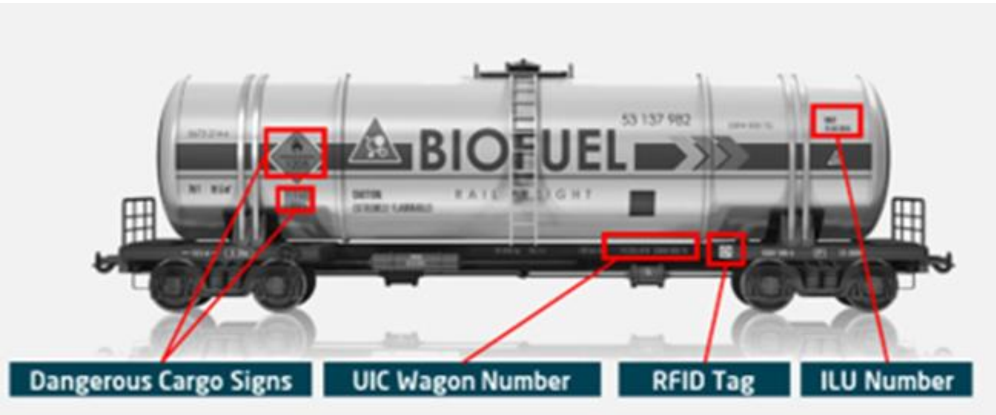

Figure 14. Detection and readings of codes (OCR), dangerous placards and RFID tags.

In the initial design for IVG, traditional Computer Vision (CV) for understanding image data based on feature detection and simplistic CV algorithm was considered. These methods were enough at the time since the requirements of the test environment were not as high as a real-life scenario. In this final version of the system, where it needs to work regardless of the variability in the conditions (light, weather, background, reflections, defects etc.), it is required to take a step further into Artificial Intelligence methods. After evaluating the reliability of different Artificial Intelligence methods, the most promising one is using Supervised Learning methods, such as Deep Learning, to build a model that can automatically detect and recognise the points of interest in the image (features) and interpret them correctly. These models can then be used by a robust and reliable system that is able to work under real-life conditions such as the mentioned above, being resilient to changes in the environment as well as scalable and reproducible.

Furthermore, the Artificial Intelligence models are integrated in a modular cloud service able to integrate any source of input data. This provides facilities to incorporate new detection models and also to face the challenges of the future, such as real time processing. On the other, an on-site solution would avoid network delays when transferring high definition images.

5.3.4.1. System Architecture

The system architecture for this project was designed to be easily integrated with partners and to be highly adaptable to changes. For this purpose, the system is organized into different modules that adapt to the input and output of the system according to the project requirements. The system architecture is detailed in Figure 15.

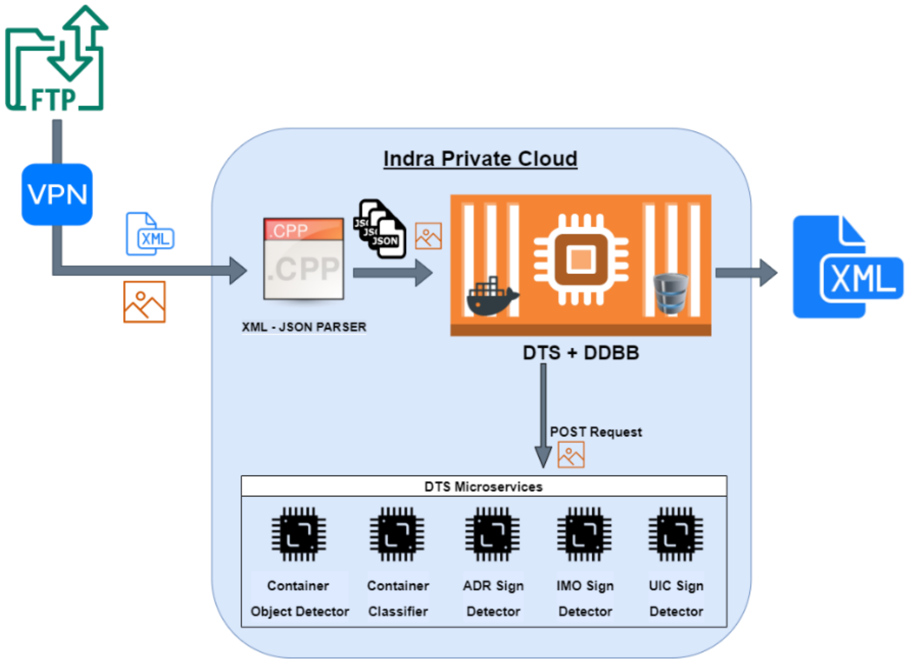

Figure 15. System Architecture

The first step is creating a VPN connection to Hitachi's FTP. This connection is kept alive during all the process and is checking constantly for new updates in the data. When a new transit comes, all the wagon's images from that train and the XML with the completed transit information is copied to the Indra Private Cloud.

Indra's cloud stores the AI models, and it is in charge of performing the inference in the images received. This way, the models are always available, and the system only needs to make a request to get the desired results. This unit will be explained more in details in the next section.

Once the whole transit has been processed, the main output of the system is the XML file that is sent to be exploited. Furthermore, in the latest updates, two other outputs were included. One of them is the keeping of the results in an easy-to-read format. It saves a compound image that includes both sides of the wagon, one on top of another, with all the detected readings and the final results that are stored in the database, an example of a result image can be seen in Figure 16. This final result image simplifies the validation process since the validator can check all the results in one same spot and get a glance of the performance of the system for each detected wagon. The other output that is saved by the system is the history of the database which, alongside the original images from the gate, are stored for 30 days.

Figure 16. Result image capturing both sides of the wagon

Even though the basic functionalities of the type of intelligent video gate installed in Gothenburg work well, there is room for improvements of the information extraction from the images produced by the gate.

The areas that will be improved within this project are described below.

The accuracy of the readings of UIC and ILU codes needs to be improved. The accuracy must be at least 95 %, but according to the evaluation included in deliverable D3.3 of the FR8RAIL III project, the system can currently correctly read only 78.30 % of the UIC codes and 85.39 % of the ILU codes. Note that this evaluation only includes codes that a human evaluator can read, while there might be additional UIC and ILU codes on the wagons and

ILUs that are not (fully) visible. Some of these cases might be solved through improvements of the image quality, while others are, for example, caused by the codes being damaged. Also, it sometimes happens that the system misinterprets other characters that are visible in the images as codes.

The system sometimes reports wagons without UIC codes. One reason for this is that two physical wagons may be "short-coupled". This means that they are permanently attached to each other and are administratively considered to be one wagon with one UIC code. In such cases, the UIC code may be painted on only one of the wagons in each pair. The image processing system will then report two wagons, one of which has no UIC code. This is a correct interpretation considering only what is visible in the image, but an incorrect one from an administrative perspective. One way of solving this is to post-process the readings by looking up in a database whether or not each UIC code registered by the gate belongs to a short-coupled wagon. This would work because different UIC code series are used for wagons of different types. Physical wagons that are part of the same short-coupled wagon can then be grouped together.

It is common that semi-trailers and swap bodies do not have ILU codes, but that they have other codes decided by their owners. These codes are currently not detected by the system, but the addition of this functionality is desirable. Also, it sometimes happens that ILUs are not detected at all (that is, that the system does not report the existence of an ILU which is actually present on a wagon).

The system can distinguish between five different types of wagons. However, this does not include an ability to distinguish between intermodal wagons that carry ILUs and similarly looking wagons with integrated goods compartments. Achieving this would require additional development. A model might be trained to directly make this distinction based only on visual cues in images, but the results might also be improved with the use of detected UIC codes (again since these indicate type of wagon) and ILU codes (since these are carried by intermodal wagons).

Like the readings of UIC and ILU codes need to be improved, so do the readings of ADR and IMO signs (indicating dangerous goods). Here, too, the accuracy should be at least 95 %, but according to deliverable D3.3 of the FR8RAIL III project, only 84.00 % of the ADR and IMO signs are currently correctly detected. Note, however, that while ADR signs are considered correctly detected if they completely agree with what a human can see in the image, IMO signs only have to be *found* by the system to be considered correctly detected. The reason for the lower evaluation requirements for IMO signs is that since the camera produces black and white images, it is not possible to reliably distinguish between different IMO signs for which the colour affects the interpretation. To make it possible for both the gate and human validators to distinguish between different IMO signs, the current camera must be replaced by a colour camera.

Currently, the system does match the readings of RFID tags on wagons and is thus not able to use them to check the UIC codes that have been extracted from the images or to fill in missing UIC codes. Adding this functionality would be very useful. Also, the RFID readings should preferably be delivered to Deplide not only through the image processing system, but also directly from the gate. This would allow the RFID readings to be used even in case the image processing system is temporarily unavailable.

5.3.5. Data sharing

A data sharing system called *Deplide* has been used for distributing the data from the gate in Gothenburg. The system, which has the event streaming platform *Apache Kafka* as one of its core components, has been developed at RISE and is used in several logistics projects. Deplide receives and distributes data over channels called *topics*. The system also provides reliable storage of the received data and may process the data in different ways. The location and role of Deplide in the overall data flow are presented in Figure 17.

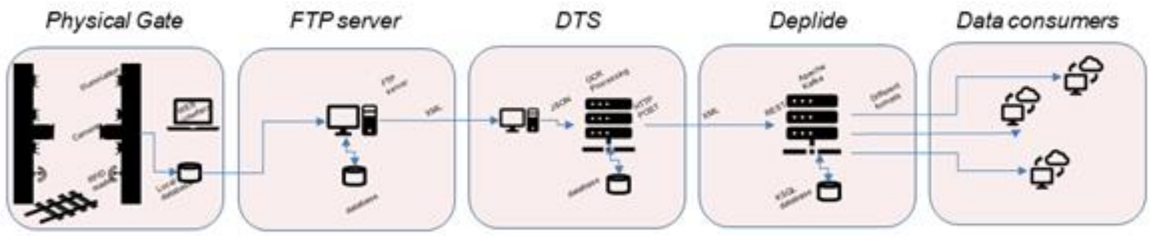

Figure 17. Data flow chart for the project

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. One should note that there are other aspects apart from technical aspects that also need be addressed in full scale systems, such as the varying willingness to share the data with others outside of the organisation.

5.3.6. Artificial Intelligence in FR8RAIL IV

During the Fr8Rail IV project phase of Shift2Rail first approaches for specified AI-cases based on the images of the Intelligent Video Gates were made. The most useful and promising case was the detection of Brake-Pads and the diagnostic of the thickness of the

Brake-Pads. Therefore a first development approach was made to identify the opportunities and challenges of the use of AI for the generated data. (D2.1, 2022)

The development was based on a set of example data with several thousand images. These images were manually labelled and use for the training of the specific AI model. To verify the learning success of the AI-model a validation with a “foreign” data set of around 700 images was made.

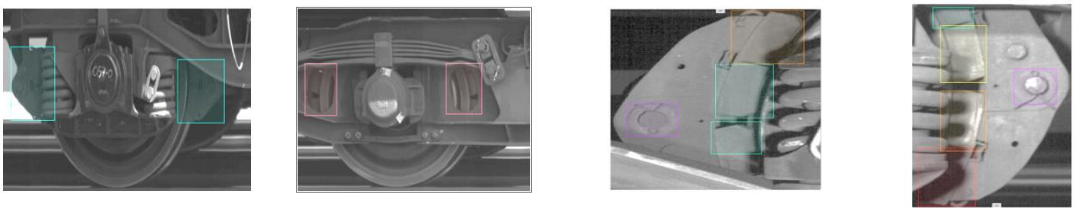

Figure 18. AI-Labelling Process

Regarding the results of the test different challenges occurred. As the quality of the measurements didn`t reach the target value new learning periods for the Ai-model were necessary. These is an intense work that is partially shifted to fulfil during the period of Europe’s Rail.

Additional to the quality test a business process evaluation was made. This evaluation was made to proof the use of the generated data in the current business process and to identify the opportunities for wagon owners and train operators. The operation was made with colleagues who are responsible for the quality of the maintenance of the wagons. After a test run of 3 weeks the feedback from the users were collected and analysed. The following table shows the three most important opportunities and challenges for this case. (D2.3, 2022)

Table 3. Most important opportunities and challenges of the Brake-Pad detection based on user feedback

Postive Feedback	Open points
Good comprehensibility of the suggestions	The camera angle could be improved
No additional time is needed when the AI suggestions are displayed.	There is a lack of information about the number of detected brake pads
Data is available in time	Detected brake pads do not help to evaluate undetected brake pads.

Additional to the start of the development of a first case data for the training of AI-models for different Use-Cases were labelled. Therefore a new process was implemented and all the colleagues who were part of the digital transformation of the maintenance ordering process produce labelled data during their daily work by assigning damage codes to different damages on the images. These information are used in the workshop and as well for the development of new AI-models. To create new Use-Cases and possible AI-models a way for the development and implementation was invented. (D2.4, 2022) The process can be seen in the picture below.

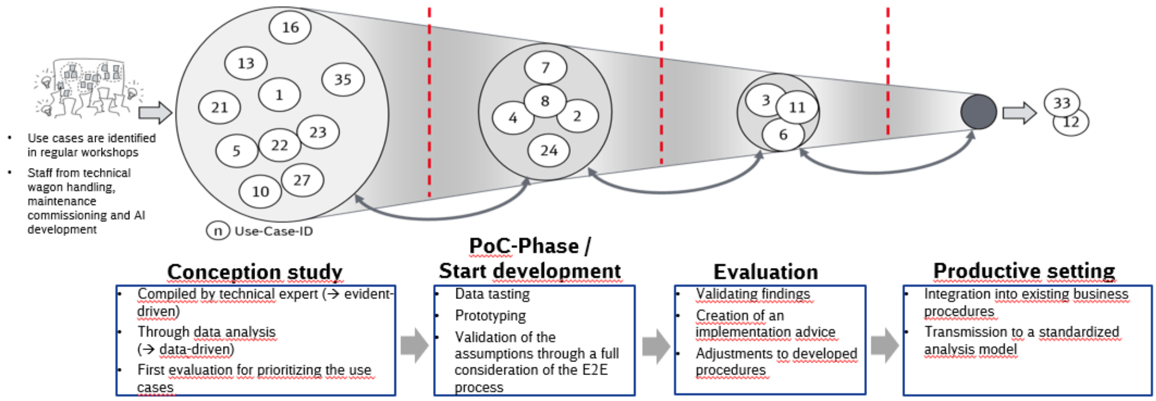

Figure 19. Process for use case and AI model development and implementation.

The process starts with different studies of the current process behaviour or damages that occur more often. A concept study is made to get an overview for each idea of a new case and to identify the needs and opportunities such as cost reduction or increasing maintenance quality. If there is a positive result for such a case the development starts within a Proof of Concept (POC) phase to create a Minimum Viable Product which shows the necessary information and data. A test and quality gate is reached if this POC shows that there is the possibility to identify all needed data and information. Afterwards the development goes on to develop the real AI-model that can be implemented into the business process. If the needed quality is reached this productive implementation is the last step of the initial development of an AI-case. During the productive work several re-trainings of the AI-model are necessary to keep the quality of the results high and to adopt new issues.

6. Other wayside monitoring systems (WMS)

The IVG is one relevant system for condition analysis. However, in order to get a comprehensive impression of the condition of the freight wagons, further data collection is necessary. Traditionally, track-based sensors can be split in several categories (Ngigi, 2012). The most common subdivision of track-based sensors is:

- Hot-axle bearings (Hot-Box detectors): a classical system used for measuring the temperature of journal bearings of a train by measuring the radiation of every journal that passes in front of the detector
- Hot and cold wheel detectors (Hot-Wheel Detectors): usually based on infrared detectors to assess if a wheel has locked up and is sliding along the track, or if the brakes lock up and causes the entire wheel to heat up.
- Acoustic bearing detectors: microphones are used to record the characteristic of the sounds made by bearings as the train passes. This type of detector is more advanced than the hot axle bearing due to its high sensitivity and ability to predict the failure of bearings in an early stage.
- Wheel profile Monitoring Systems (WPMS): extract data from the actual wheel profile which is compared to the new wheel profile to obtain key wheel parameters such as flange height, width, or tread hollow. Most of the available WPMS employs non-contact technique (laser line or high-intensity strobe light illumination) to monitor the wear on the wheel as the train passes.
- Wheel Impact Load Detectors (WILD): detects the presence of wheel defects by measuring the magnitude of the load exerted by the wheel on the rail and compare with predefined thresholds. Diverse types of sensor technology can be deployed, such as accelerometers, load cells, strain gauges or fibre optic. Flat-spots, shelling or out-of roundness characteristics on the wheels will induce excessive impact on the rail and can contribute to wear of the tracks and vehicles
- Tread Condition Detectors: generally use ultrasonic sensor technology to detect any discontinuity on the tread surface of the wheel caused by cracks or breakings
- Brake pad inspection system uses machine vision technology to identify pad thickness, wear rate, uneven wear and detect missing brake pads using digital images captured by the inspection system
- Bogie Performance Detectors: are wayside systems implemented to identify the level of performance for railway vehicles, and usually employ different measurements strategies, for instance to identify vehicles that show excessive hunting (hunting index), or to assess the bogie wheelset angle of attack
- Intelligent video gate (IVG): takes pictures from freight wagons from the sides and from above with different kinds of cameras to detect various damages – described above.

In Shift2Rail some systems where deeper analysed, for example the Hot-box/Hot-Wheel Detectors (HBDs). One of the major concerns regarding bearing condition monitoring is that HBDs are mainly used as a reactive system by detecting faults on vehicles as they occur to prevent any further damage. Actually, HBD technology for Wayside Monitoring Systems can also be used in a more predictive way.

Rolling Stock Providers should be involved in the process of threshold definition in order to set warning threshold levels to prevent faults / failure by means of early maintenance action. Of course continuous monitoring is the best option but even discrete monitoring at key checkpoints may improve bearings failure prevention. A continuous transmission of the measured temperatures (independent of the exceeding of limit values) would allow to combine it with speed, load etc. to get a more detailed condition analysis and prediction of the wheel bearings.

Similarly, to hot box/hot wheels systems, the WILD systems can be considered as a reactive system by default. Using a method of crib mapping could help categorize the wheel defects by differentiating single defect wheels, wheels with multiple defects or patterns that could indicate wheels with out-of-roundness (ovality or higher order shape deviation). Moreover, it may be possible that additional information about the condition of the bogies may be extracted from the same signals, even if further studies would need to be examined.

6.1. Functional requirements

There are different kind of functional requirements for these Wayside Monitoring systems. Based on earlier studies in the Shift2Rail project FR8RAIL IV the following have been addressed:

- The data must be collected constantly in a stable quality, regardless of external influences (rain, snow, day/night, sunshine, temperature, etc.). Data processing should be completed within 2 hours, or faster depending on the specific use case. The wagons spend about 2 h minimum in marshalling yards, similarly in terminals. To prevent action being taken before the wagon/train goes back on the track. Trackside systems must provide the data much faster, but here other regulations and requirements apply to the systems, also the costs are too high for an economic use in the area of condition monitoring. Thus, the raw data must be forwarded to the operator or analysing service provider with only a minimum of delay.
- The data must be pre-analysed and submitted to the production systems. In case of anomalies and especially in case of operational danger, an alarm has to be triggered in order to be able to take corrective actions.
- Maintenance of the sensor systems should be minimal. If maintenance is required, it must be possible to carry it out quickly and easily, ideally without or only a very short stay in the track area.

- Autonomous systems in terms of power supply offer advantages when placed in the track network (however, power connections are also sporadically present in the track network).
- The system should be useful at operating conditions of the railway undertakings. So it should meet the functional requirements for every type of potential operating conditions (e.g. shunting with forward and backward moving)

Specific requirements regarding the quality of the measured data are different for any kind of system. Therefore, a specific analysis of the system is necessary to take in account which measured data are relevant and how accurate they should be.

6.2. Technical Specifications

All system should provide their information independent of the operating mode of the train. Therefore the system should work at least for passing trains with a speed between 0 and 120 km/h, depending on specific use cases. Moreover, the following technical specifications are necessary based on earlier studies in the Shift2Rail project FR8RAIL IV:

- The optical data must fulfil damage-specific requirements, especially the resolution and brightness are relevant, as well as the undistorted state of the images.
    - E.g. At least 2 pixel per mm to identify scratches or holes in tarpaulins
- Systems that provide numerical data must fulfil the requirements of a measurement system, otherwise the data cannot be used in internal processes. The benchmark here is the required measuring systems in the workshop.
    - Every measuring system has to be officially validated with a measuring system that is currently state of the art and validated for measuring. This is a need to fulfil safety requirements.
    - E.g.: Even the wagon inspector checking the train at the starting point is only using certified measuring gauge, because it is necessary for the process.

More precise specifications depend on individual damages. Each damage type has another requirement to be detected. The necessary damages are explained in AVV Annex 9 and 10. If the damage detection should be used as an assistance system (final decision lies with the human), the presence of a damage should be detected during operation with a certainty of at least 95.45% (2 Sigma), ideally above 99%.

7. Vision for future work

7.1. From IVG to Standardised European Checkpoints

Within FP5 the vision is to extend the concept of IVG developed in Shift2Rail and to specify further new functional requirements leading to digitalisation and automation of manual processes through the use of emerging technologies in specialised adapted "Intelligent video gates" (IVG), using OCR, RFID, sensors and other advanced detection and identification technologies. The new functional requirements will be based on process analysis on three types of operational stops; borders, yards and intermodal terminals. The next logical step is to specify technical requirements (within WP25) and develop and demonstrate them (within WP29) in order to achieve these functional requirements as well as the suggested the standardisation aspects of the concept.

As described in chapter 3, within Shift2Rail, gates were installed for terminal purposes in Sweden and for yard purposes in Germany. However further countries are now in included in FP5 who plan to install their own gates or have an interest in contributing to this work including Netherlands, Spain, Austria, Czech Republic and France. Hence it is essential that this work is carried out in a harmonized manner on a European level, leading to standardised implementation of the concept, as the concept goes from the name "Intelligent video gates" to "Standardised European Checkpoints".

7.2. Wayside monitoring systems (WMS) – other detection technologies

An overall condition monitoring is only possible by using a multitude of data acquisition and measurement systems. Due to hidden areas such as components that cannot be detected by the view of the camera position (e.g. Axles, Bogies), the integration of on-board sensor data is necessary. Especially in the area of measuring systems (numerical data), there have been problems in the past with regard to the certification of measuring equipment.

However, it has become apparent in recent years that the quality of the systems has been steadily improved by the manufacturers. Although the requirements and costs of a measuring system approval are still high, the willingness of the system manufacturers to attempt this certification is increasing. Rail freight transport usually covers long distances and is usually cross-border. Therefore, it is not always necessarily necessary to record all data of a wagon at a single point (checkpoint). As a rule, it is sufficient to record the complete condition over the course of the train. This way, maintenance measures can be taken at the end of the train run. (In case of operational danger, of course, immediate action must be taken).

Due to the possibility of recording the condition data distributed over the train run, the ideal position can be used for each system (e. g. in the tunnel, slow speed point, curve, straight line, etc.) - assuming a cost-effective power and data connection. This results in a Europe-wide network of condition monitoring systems that complement each other. However, this also require standardisation in many areas in order to be able to work with the data across countries and to embed these data evaluations in the processes (measurement accuracy, data format, etc.) and a clear understanding of different roles and responsibilities.

8. Conclusions

Regarding the IVG concept, it can be summarised that concept was described and show cased on model train with the Shift2Rail project FR8HUB and the full-scale demonstration within FR8RAIL III, including installation of gate in Gothenburg, Sweden for terminal purposes, while for yard purposes the gate in Nurnberg yard in Germany was used. The work will now continue within FP5 with extending the concept with further functionalities for terminals, yards and borders and to more European countries. Hence the concept name goes from "Intelligent Video Gate" to "Standardised European Checkpoints".

It's worth restating the challenges experienced during the Shift2Rail projects. Firstly, regarding installation challenges; one should consider all the required steps i.e. finding a suitable location, contracting sub provider, purchase of components, transportation of equipment, construction, fine tuning and estimating costs and effort for each step. As for the technical challenges and the image processing, hit rates over 95% for character recognition (codes) are required i.e. ability to recognize more code types e.g. domestic ILU codes differ and are hard to recognize, as well as improved damage detection abilities (apart from Graffiti detection). Regarding the technical challenges with data exchange and information security, it is worth considering that handling information of dangerous goods is strictly regulated.

Regarding Wayside monitoring systems (WMS) based on other detection technologies, the industry is already providing sensors and systems to monitor a large number of freight wagon conditions. Unfortunately, there are still areas of freight wagons that are difficult or impossible to monitor with stationary or on-board sensors. A much bigger problem, however, is the cost of comprehensive monitoring of freight wagons, which makes the comprehensive use of sensors more difficult. The costs result, for example, from the requirements for railway-specific installations in the track area, approval as a measuring system, monopolies when installing and operating sensors in the infrastructure or high costs for power and data connections along the tracks. The challenges are similar for all railway undertaking (RU). It will not be possible to deploy a comprehensive condition detection solution at one time. Therefore, all RU will try to integrate the upcoming sensors and the resulting status data into the processes step by step. The gradual integration of domestic and international data will also present us with economic, technical and legal challenges. On the other hand, the railway sector agrees that for the entire system to become future-proof the targets and challenges must be approached jointly, even if the final state can only be reached in decades.

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