WP4: Intelligent Video Gate

D4.2 Technical Proof of Concept and Roll-out and Implementation Plan
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Page 1 of 95
Version Control

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Executive Summary

The following Deliverable Report D4.2 focuses on the achievements and the used methods within the Workpage 4 of the FR8HUB-Project within the Shift2Rail-Programme. A part from contributions transfer the requirements and findings from the previous Deliverable Report D4.1, two main tasks have been carried out in this deliverable D4.2; a technical Proof of Concept (PoC) and a general Rollout & Implementation Plan (RIP).

The PoC has been vital for the further project work to achieve higher TRLs and in chapter 2 a detailed description is presented regarding the developments that have been carried out to produce a proof of concept for the IVG. To test the functionalities of the logical modules, software and algorithms, the approach followed was to use a train model as the physical input to the system in a laboratory environment. The image processing functionalities developed were also tested with real images obtained on-site with two different cameras, which also provided successful results in the detection and identification of ILU and UIC codes, as well as different dangerous cargo signs.

In chapter 3 methods, concepts and suitable applications for sharing and exploitation are presented resulting in the Internet of Logistics (IoL) concept presented in chapter 3.1 and simulation of improved terminal operation in chapter 3.2., where it is shown that it is possible to use optimization methods and rolling planning to schedule crane movements at a terminal, achieving high-quality schedules within reasonable time.

Chapter 4 presents the Rollout & Implementation Plan (RIP) for potential sites in Sweden and Germany. The main aspects considered are categorized as administrative preparation, construction requirements, business impact and stakeholders involved. The potential sites considered in Sweden are Malmö intermodal terminal, Port of Gothenburg, Eskilstuna and Katrineholm intermodal terminal. The most likely site for a pilot seems to be Malmö intermodal terminal. The potential site considered in Germany is DUSS-Terminal Cologne Eifeltor.

The following results could be achieved for the Intelligent Video gate Concept (IVG), PoC and RIP:

- Identification of wagon numbers by means of OCR (model train + real life images)
- Identification of wagon numbers by means of RFID (model train)
- Identification of loading unit numbers by means of OCR (model train + real life images)
- Identification of dangerous goods (model train + real life images)
- Comparison of the actual data with data preview with deviation report
- High-resolution images with wagon separation and loading units thereon for damage documentation and claim support (model train + real life images, one-sided in the test environment)
- Variant representation for IVG-layouts in different track environments (single track, double track)
- Simulation for optimization of terminal operations and data concept
- Presentation of potential implementation sites
- Presentation of general business impacts

Within this project phase some of the requirements have been focused more than others since the Proof of Concept and the realization of a technical test environment were carried out in an agile mode to create, implement, test, show and describe the different functionalities in more in depth. During this phase a model train set as well as real life images captured in an installation in Italy were used to describe, analyse and adjust use cases to fulfil the requirements.
The achieved technological development as well as the analysis and impact studies for the focus areas were agreed between the partners according to their special ability to contribute to these parts.

This report also addresses open issues in a qualitative way that need to be considered in further work and IVG-implementation. The report does not claim to cover all kinds of aspects finally and completely, as IVG-technology itself is a rather technical part, but driven by fast developments in optics, sensors and new materials. But also the user perspective, the data concept and utilization around it can become very fast changing, complex and stakeholder driven if individual requirements of stakeholders and general expectations change. At the moment and during the working period a focus on reduced complexity for testing was necessary to ensure reasonable and applicable test results. The report therefore provides also fundamental knowledge and guideline about the state of the art, possible solutions and wants to invite interested readers to introduce and adopt more standardized procedures to a growing and interesting future rail transport market.
Table of content

Executive Summary .................................................................................................................. 3
Abbreviations .......................................................................................................................... 9

1 Introduction .......................................................................................................................... 10
  1.1 Foundation from Deliverable 4.1 .................................................................................... 10

2 Technical proof of components, software and algorithms ............................................... 11
  2.1 Proof of concept for the logical components and data flows ...................................... 12
    2.1.1 Demonstrator system (IT) architecture ................................................................... 12
    2.1.2 Generation of data from test components (Train Model) ...................................... 12
      2.1.2.1 Train Model Set ............................................................................................... 13
      2.1.2.2 Test components for image acquisition .......................................................... 13
      2.1.2.3 Test components for the RFID system .............................................................. 14
      2.1.2.4 Physical architecture of the model .................................................................... 15
      2.1.2.5 Codes ............................................................................................................. 17
    2.1.3 Development and adjustment of software and algorithms ..................................... 19
      2.1.3.1 First process (DIS+TIC) .................................................................................. 19
      2.1.3.2 Second Process (RI) ....................................................................................... 25
      2.1.3.3 Third process (FIM) ........................................................................................ 26
      2.1.3.4 4th process (GUI) .......................................................................................... 26
    2.2 Simulation of Data Flows .............................................................................................. 29
      2.2.1 Data Outputs ....................................................................................................... 30
    2.3 Test concept for integrated system .............................................................................. 30
      2.3.1 Definition of use cases and testing requirements .................................................. 31
      2.3.2 Ongoing evaluation/proof of concept ................................................................. 32
        2.3.2.1 Use Case 1 ..................................................................................................... 33
        2.3.2.2 Summary of Use Cases ............................................................................... 37
    2.4 Technical proof of the selected components in a real environment ............................. 43
      2.4.1 Results with previously-installed camera (Spyder 3GigE Vision SG-14) ............. 44
      2.4.2 Results with new selected camera ....................................................................... 46

3 Data sharing and exploitation ............................................................................................... 48
  3.1 State of the art and best practice – the IoL concept ....................................................... 48
  3.2 Simulation of improved terminal operation ..................................................................... 55
    3.2.1 Connection of the scheduling problem to the IVG ............................................... 56
    3.2.2 Basic Optimization Model ..................................................................................... 56
    3.2.3 Complexity and execution times ............................................................................ 58
    3.2.4 Rolling planning .................................................................................................... 60
      3.2.5 A More Advanced Terminal Model ................................................................. 60
        3.2.5.1 Designated Areas for Temporary Storage of Different Types of ILUs .......... 61
        3.2.5.2 Different Handling of Different Types of ILUs .............................................. 61
        3.2.5.3 Optimized Truck Locations and Fixed Locations for Temporary Storage ...... 61
        3.2.5.4 Time ............................................................................................................. 62
        3.2.5.5 Rolling Planning ............................................................................................ 62
        3.2.5.6 Objective and Constraints ............................................................................. 63
        3.2.5.7 Evaluation ..................................................................................................... 64

4 Roll-out and implementation plan for selected terminals ................................................ 66
  4.1 Administrative preparation, permissions for selected sites .......................................... 66
  4.2 Construction requirements for selected sites .................................................................. 66
    4.2.1 Common requirements ............................................................................................ 70
4.2.2 Construction requirements ................................................................. 71
4.2.3 Maintenance and Life Cycle Support ...................................................... 71
4.3 Real life application of the IVG concept .................................................... 72
4.4 Implementation Aspects for Potential Sites ................................................ 74
  4.4.1 Port of Gothenburg ............................................................................. 74
  4.4.1.1 Current situation ............................................................................. 74
  4.4.1.2 Proposal ......................................................................................... 76
  4.4.2 Malmö Intermodal Terminal ................................................................. 78
    4.4.2.1 Selection of site ............................................................................ 79
    4.4.2.2 Data collection .............................................................................. 80
    4.4.2.3 Simulation and simulation results .................................................. 82
  4.4.3 Eskilstuna Intermodal Terminal .............................................................. 84
  4.4.4 Katrineholm’s Logistics Centre ............................................................... 85
  4.4.5 DUSS-Terminal Cologne Eifeltor ............................................................ 86
4.5 Business Impacts ....................................................................................... 87
  4.5.1 Expected changes on terminal operations .............................................. 87
  4.5.2 Optimization potential of terminal and inter-terminal operations .......... 89
  4.5.3 Expected changes in costs .................................................................. 89
4.6 Stakeholders and their responsibilities ....................................................... 91
5 Conclusion and Recommendations .................................................................. 92
  5.1 Further studies ......................................................................................... 93
6 References .................................................................................................... 94

List of figures

Figure 1-1. Work packages in the FR8HUB project within Shift2rail and innovation programme 5 .......................................................... 28
Figure 2-1. Technical components used for the proof of concept ................................................................. 27
Figure 2-2. System (IT) architecture of demonstrator .............................................................................. 21
Figure 2-3. Train Model Set .................................................................................. 20
Figure 2-4. Image acquisition equipment (camera and LED light) ................................................................. 19
Figure 2-5. RFID System ..................................................................................... 18
Figure 2-6. TAG installed in the demo ....................................................................... 17
Figure 2-7. Concept for the physical architecture of the model ................................................................. 16
Figure 2-8. Real image of the physical model .............................................................................. 15
Figure 2-9. ISO and UIC Codes ............................................................................. 14
Figure 2-10. ILU code model .................................................................................. 13
Figure 2-11. Signalling of dangerous cargo at the sides of the load unit ............................................................... 12
Figure 2-12. Example Dangerous Placards that are difficult to identify by the IVG ........................................ 11
Figure 2-13. RID/ADR orange placards ........................................................................ 10
Figure 2-14. Diamond-shaped placards .......................................................................... 9
Figure 2-15. SDK Vimba ......................................................................................... 8
Figure 2-16. Background subtraction ........................................................................ 7
Figure 2-17. Definition of Region of Interest ........................................................................ 6
Figure 2-18. ROI for the ILU and UIC code .................................................................. 5
Figure 2-19. OCR Flow Scheme ............................................................................... 4
Figure 2-20. Matching Timestamps for TAG-WAGON ........................................................................ 3
Figure 2-21. Last Train Page .................................................................................... 2
Figure 2-22. Search Train Page ................................................................................ 1

Page 6 of 95
Figure 2-23. Check Trains Page ................................................................. 29
Figure 2-24. Data flows ........................................................................ 29
Figure 2-25. Train data tables .................................................................. 30
Figure 2-26. Images captured for UC1 ...................................................... 34
Figure 2-27. XML file of “Departures” (UC1) ............................................... 35
Figure 2-28. XML file of “Arrivals” (UC1) ................................................ 36
Figure 2-29. Cameras installed in real site .................................................. 43
Figure 2-30. Previous Camera - OCR detection for a real wagon with one container 44
Figure 2-31. Previous Camera - OCR detection for a real wagon with two containers (separated) 45
Figure 2-32. Previous Camera - OCR detection for a real wagon with two containers (together) 45
Figure 2-33. Previous Camera - OCR detection for a real wagon with three containers 45
Figure 2-34. Previous Camera – Computer Vision for dangerous cargo signs for a real wagon 1 46
Figure 2-35. Previous Camera – Computer Vision for dangerous cargo signs for a real wagon 2 46
Figure 2-36. New Camera - OCR detection for a real wagon with two containers (separated) 47
Figure 2-37. New Camera - OCR detection for a real wagon with one container 1 47
Figure 2-38. New Camera - OCR detection for a real wagon with one container 2 47
Figure 3-1. Information barriers along the logistic chain and how to use digitalization to overcome them ................................................................. 48
Figure 3-2. Unique ID for Logistics Objects - URL ........................................ 51
Figure 3-3. The RDF Data Graph grows with new information and relationships along the shipment 52
Figure 3-4. Distributed Databases record information generated by IVGs at each terminal 52
Figure 3-5. Freight Trains connects two terminals, each one features its own IVG 53
Figure 3-6. Each Multimodal Terminal manages its own RDF database and digital image of the same train 53
Figure 3-7. Verify Damage or Discrepancies at different checkpoints 54
Figure 3-8. The correlation between the lol concept and S2R integration layer 54
Figure 3-9. Three different test sets, each bar representing 10 problem instances 59
Figure 3-10. The variance in execution time for finding the optimal loading sequence of different number of ILUs 59
Figure 3-11. An example of rolling planning showing six plans 60
Figure 3-12. Schematic picture of part of the modelled terminal 61
Figure 3-13 Timeline for the planning and execution of a planning period 63
Figure 3-14. Solving times in seconds for 20 planning periods (number of units in each period indicated on the x axis) 65
Figure 4-1. Scenario 1, single track with train operation 68
Figure 4-2. Scenario 2a, double track with single train operation 69
Figure 4-3. Scenario 2b, double track with parallel train operation 70
Figure 4-4. Distances needed along rail tracks for IVG camera and related sensors 70
Figure 4-5 Example of placement of RFID reader along rail tracks 71
Figure 4-6. High resolution image obtained by the TCCS system (grey scale) 74
Figure 4-7. Intermodal nodes that are connected to intermodal terminals from Gothenburg (left) and nodes for conventional cargo loading traffic (right). (Railport, 2018) 75
Figure 4-8. Terminal operators in the Port of Gothenburg (Railport, 2018) 75
Figure 4-9. The Port of Gothenburg and adjacent railway lines (OpenRailwayMap, 2019) 76
Figure 4-10. Speed limits in the Port of Gothenburg and adjacent railway lines (OpenRailwayMap, 2019) 76
Figure 4-11. Suggestion for placement of an "Intelligent video gate". (OpenRailwayMap, 2019) 77
Figure 4-12. Suggestion for placement of an "Intelligent video gate". (OpenRailwayMap, 2019) 77
Figure 4-13. Suggestion for placement of an "Intelligent video gate". (OpenRailwayMap, 2019) 78
Figure 4-14. Possible placements of IVGs at Malmö intermodal terminal 79
Figure 4-15. Malmö intermodal terminal transshipment area design 80
List of tables

Table 2-1. Summary of Use Cases ............................................................... 32
Table 2-2. Description of Use Case 1 ........................................................... 33
Table 2-3. Results and Outputs of all the Use Cases ..................................... 37
Table 4-1. Technical specification of Malmö Intermodal terminal .................. 80
Table 4-2. Expected changes in costs for intermodal rail freight terminal connected to IVG implementation. Categorization of fixed and variable costs is based on terminal characteristics presented by Wiegmans and Behdani (2018). ......................................................... 90
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>ACCR</td>
<td>Automatic Container Code Recognition</td>
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<tr>
<td>ADR</td>
<td>European Agreement Concerning the International Carriage of Dangerous Goods by Road</td>
</tr>
<tr>
<td>ARH</td>
<td>Adaptive Recognition Hungary</td>
</tr>
<tr>
<td>BIC</td>
<td>Bureau International des Containers et du Transport Intermodal</td>
</tr>
<tr>
<td>CDT</td>
<td>C/C++ Development Tools</td>
</tr>
<tr>
<td>DB</td>
<td>Deutsche Bahn</td>
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<tr>
<td>DIS</td>
<td>Detecting and Imaging Subsystem</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision Support System</td>
</tr>
<tr>
<td>DUSS</td>
<td>Deutsche Umschlaggesellschaft Schiene-Straße</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic Compatibility</td>
</tr>
<tr>
<td>FIM</td>
<td>Field Information Matching</td>
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<tr>
<td>FPS</td>
<td>Frames-per-Second</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HD</td>
<td>High Definition</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>ID</td>
<td>Identification</td>
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<tr>
<td>ILU</td>
<td>Identification of Intermodal Loading Units</td>
</tr>
<tr>
<td>IMDG</td>
<td>International Maritime Dangerous Goods Code</td>
</tr>
<tr>
<td>IoL</td>
<td>Internet of Logistics</td>
</tr>
<tr>
<td>IVG</td>
<td>Intelligent Video Gate</td>
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<tr>
<td>ISO</td>
<td>International Standard Organisation</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
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<tr>
<td>m</td>
<td>meters</td>
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<tr>
<td>OCR</td>
<td>Optical Character Recognition</td>
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<tr>
<td>RID</td>
<td>Règlement concernant le transport international ferroviaire de marchandises Dangereuses</td>
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<tr>
<td>RFID</td>
<td>Radio-frequency Identification</td>
</tr>
<tr>
<td>RI</td>
<td>RFID Identification</td>
</tr>
<tr>
<td>TIC</td>
<td>Train Identification and Classification</td>
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<tr>
<td>TMT</td>
<td>Technical Management Team</td>
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<tr>
<td>TSLDHV</td>
<td>Time Sensitive Low Density High Value goods</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra-High Frequency</td>
</tr>
<tr>
<td>UIC</td>
<td>Union Internationale des Chemins de fer (International Union of Railways)</td>
</tr>
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<td>Work Package</td>
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1 Introduction

1.1 Foundation from Deliverable 4.1

FR8HUB WP4 is divided into two parts where the first deliverable report, D4.1, summarized the current situation regarding intermodal terminals and intermodal transport chains from a Swedish and German perspective. Moreover, a description of functional and technical requirements for the IVG concept was presented as well as a presentation of components for the concept combined with the selection process for the technical components.

Today’s intermodal terminals in Europe consist of a number of crane modules where the rail tracks for transhipment can be designed with access at only one side or with a connection on both sides. The IVG concept described in deliverable 4.1 is installed on the entrance/exit tracks of the terminal. Ideally, all rail movements in the terminal run over one entrance and exit track. This can however not be achieved in all terminals (for example terminals with several routes and tracks into the terminal), thus other configuration the IVG concept could be required.

As a 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 and image processing
- Illuminators
- RFID antennas and tags
- Wheel sensors

The idea behind the selection process was to provide a formal methodology for selecting a component. The selection of components is depending on the real terminal characteristics, such as number of tracks, installation position, environmental conditions etc. Further work is however needed to better test the components in laboratory and in relevant environment and to highlight unexpected positive or negative characteristics, hence the technical proof of concept as well as the roll-out and implementation plan in this deliverable.

Figure 1-1. Work packages in the FR8HUB project within Shift2Rail and innovation programme 5
2 Technical proof of components, software and algorithms

The technical proof of concept for the IVG has been structured into two phases:

1. **Proof of concept for the logical components and data flows in a controlled environment (laboratory):** image acquisition, RFID, identification and detection, GUI (graphical user interface) modules, including the development and technical proof of software and algorithms.

   The aim of this stage is to develop a complete practical system that allows the demonstration of the functionalities of the IVG: acquisition of data, processing and data visualization and sharing.

   For this phase, a train model will be used to generate data, simulating a real scenario (using test components). For this stage, the different logic components will be developed and connected (via interfaces). Due to the specific characteristics of the model, some developments will be customized to receive the data generated from the test source.

2. **Technical proof of components selected:** The aim of this stage is to test the logical system and image processing modules developed in the previous stage with images generated in a real environment with real technical components.

The table below summarizes the different technical components used for the two phases:

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<th>Digital Camera</th>
<th>RFID</th>
<th>Illuminator</th>
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<tr>
<td>Laboratory Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Train Model)</td>
<td>Color Camera (Mako G-234)</td>
<td>Ha-VIS RFID Reader RF-R500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Continuous LED light (50Hz)</td>
</tr>
<tr>
<td>Real environment</td>
<td>Spyder 3GigE Vision SG-14</td>
<td></td>
</tr>
<tr>
<td>(Previously installed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>camera)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real environment</td>
<td>Dalsa Linea GigE Vision</td>
<td></td>
</tr>
<tr>
<td>(New camera, selected</td>
<td>Monochrome CMOS Line Scan</td>
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<td>in D4.1)</td>
<td>Cameras Teledyne DALSA</td>
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*Figure 2-1. Technical components used for the proof of concept*
2.1 Proof of concept for the logical components and data flows

2.1.1 Demonstrator system (IT) architecture

The system architecture (logical components, modules and connecting interfaces) of the demonstrator conceived for the proof of concept is based on the scheme provided in the previous deliverable (D4.1), where the different logical components of the system are described. The diagram below shows this system architecture:

![Diagram of the system architecture](image)

Figure 2-2. System (IT) architecture of demonstrator

The physical model of the train (the test components of the train model) used to generate data in this phase is described in 2.1.2.1.

The DIS and RI modules are described in detail in the section 2.1.2.2 and 2.1.2.3. These modules are responsible for obtaining the relevant data (images and RFID information) from the physical model.

The TIC, FIM and GUI modules and all the software and algorithms developed and used are described in detail in the section 2.1.3.4. These modules are responsible for processing the data captured by the DIS and RI modules, matching all the information received, storing it in the database and providing the different data outputs (visualization tools, xml files for data management...).

2.1.2 Generation of data from test components (Train Model)

The test components of the train model can be sorted into three main categories: technical components for image acquisition, the RFID system and the train model set (tracks, wagons, containers, codes, power supply...).
2.1.2.1 Train Model Set

The train model used in this proof of concept was a set of a locomotive, two wagons, two containers and a tank with a H0 scale (1:87). This is the most popular railway model scale in the world, with the rails spaced 16.6mm apart. The wagons and containers are from Märklin, a German toy manufacturer well known for model railways, which provides high-quality and accurate models. The Figure 2-3 shows the complete set used:

![Train Model Set](image)

2.1.2.2 Test components for image acquisition

Acquiring good quality images is essential in any computer vision application to obtain the best results from the image processing and analysis.

For the demonstration of the IVG planned for this phase of the project, a components selection process was carried out in which the following components were carefully chosen based on the physical train model characteristics and limitations:

- **Camera** [Colour Camera (Mako G-234)]: First tests were carried out with a NIR camera (Near Infrared). Although this monochrome camera offers overall a higher frame rate and a better resolution, colour images offer higher success rates for detecting ILU/RID/UIC codes to the Image processing algorithms used (based on Optical Character Recognition (OCR) technology). The image processing is influenced by different camera factors, the main ones being:
  - Minimum Contrast: This factor allows detection algorithms (OCR) to identify similar pixels, setting patterns that will result in the recognition of the characters.
  - Maximum and minimum letter size: This factor optimizes the character analysis by setting maximum and minimum values for the letter size, performing block scans that allows to discard irrelevant characters in a faster and easier way.
Once these requirements have been defined, the following configuration parameters are set to improve the image acquisition process:

- **Shutter speed**: This parameter controls the exposure time. In this case, in order to get a clear (sharp) picture of the moving train, the shutter speed needs to be fast so that it allows a high refresh rate (FPS). However, a low exposure time will cause darker images, making it necessary to light the scene with a continuous light source.
- **Gain [ISO]**: This factor converts the captured light of each pixel into a numerical value that determines its level of brightness. For coloured images, here is a gain factor for each colour channel (red, green and blue).
- **Aperture**: The aperture controls the amount of light entering the camera.
- **Frame rate (FPS)**: This parameter determines the number of frames captured by the sensor each second. In order to improve the refreshment rate and the overall process efficiency, the images are captured in RAW format and processed with a Bayer filter. It allows the system to obtain high resolution images in real time (without any delays derived from compression).

- **Continuous LED light**: Due to the lighting requirements set by the configuration parameters (30-41.2 FPS) and the lighting conditions of the demo site (indoor), a continuous LED light source was used (50Hz) to illuminate the scene and avoid any interfering from the on-site artificial lighting system that would produce null images.

![Figure 2-4. Image acquisition equipment (camera and LED light)](image)

### 2.1.2.3 Test components for the RFID system

The RFID UHF System is composed of readers, antennas and tags.

- **RFID Harting Reader**: The reader emits radio waves of specific frequencies through the RFID antennas. These waves transfer their energy to the RFID tags, which use this energy to emit their own ID. These IDs are captured by the reader through the antenna. The typical reading range is 0-12 meters. The reader processes then this data, which is integrated into the application developed. For this demo, the communication protocol between reader-tag chosen is ISP 6-c.
RFID Tags: Each wagon will have two RFID Tags attached, one on each side of the wagon. In which it is recorded the wagon number (UIC code), side indicator as well as its manufacturer/owner ID. These tags are powered by the electromagnetic energy produced by the reader.

RFID Antenna: The RFID antenna emits and receives waves that allow the detection of RFID tags when they cross the field created by these waves. The antenna used for this demo works in the gain width of 8.5-10dbi and a beam between 70° - 100°.

2.1.2.4 Physical architecture of the model

The images below show the final setting of the physical components of the model (concept and a real image of the model):

- The camera must be located 31cm away from the train tracks, pointing at them perpendicularly; this way it can cover an image width of 18cm, with enough margin for capturing the wagons in full (14cm).
- The continuous LED light must be located around the camera’s objective (to avoid shadows....)
- The RFID Antenna must be located just besides the tracks to allow a more precise tag read.
The rest of the equipment used for this demonstrator is:

- Computer (server)
- USB keys with OCR licenses
- Screen
- Keyboard and mouse
- Tracks controller
- Power supply (24V)
- Opaque black panel: this element was installed in order to improve the detection process. Locating facing the camera behind the train model
2.1.2.5 Codes

This section introduces the different codes detected by the application. The image below shows the three main (codes/signs) that will be analysed:

![Image of ISO and UIC Codes](image)

- **ISO/ILU/BIC code**: This code identifies the container. The purpose of this code is to achieve a single and uniform global identification of cargo units. In the European system it is referred to as ILU (Intermodal Load Unit).

<table>
<thead>
<tr>
<th>Owner Code – Registration code – Control code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner Code</td>
</tr>
<tr>
<td>Assigned by UIRR/BIC</td>
</tr>
<tr>
<td>Registration Code</td>
</tr>
<tr>
<td>Assigned by the owner</td>
</tr>
<tr>
<td>Control Code</td>
</tr>
<tr>
<td>Stipulated calculus procedure</td>
</tr>
</tbody>
</table>

![Image of ILU code model](image)

- **UIC code**: Every railway organization belonging to the "Union International des Chemins de Fer", UIC, numbers their vehicles according to a 12-digit code that identifies the type of wagon: motor vehicles or railcars, vehicles for transporting goods and cargo or passenger vehicles.

This code is structured as follows: 9-c-71-t-uvw-xyz-a. The first digit determines the type of vehicle. The second digit is a control number for the code; the third and fourth numbers specify the administration to which the vehicle belongs. The fifth number indicates the type of vehicle within a composition made up of several vehicles (motor-wise); sixth, seventh and eighth numbers define the series to which the vehicle belongs. The ninth, tenth and eleventh digits indicate order of the vehicle within the series, and the last number is an automatic “check” digit.
- **Dangerous cargo**: There are different legal standards related to dangerous placards and signs.

  - IMDG: International Maritime Code for Dangerous Goods (IMDG) contains internationally mandatory requirements for the handling and stowage of dangerous goods for shipping.
  - RID: “The Regulation concerning the International Carriage of Dangerous Goods by Rail (RID)” is Appendix C to the Convention concerning International Carriage by Rail (COTIF) and focuses specifically on mandatory regulations surrounding the international carriage of dangerous goods by rail in RID Contracting States. The regulations relate to procedural and transportation requirements and exemptions to ensure the safety during carriage.
  - ADR: European Agreement concerning the International Carriage of Dangerous Goods by Road.
  - UN numbers (United Nations numbers): four-digit numbers that identify hazardous materials and articles in the framework of international transport.

Every dangerous cargo unit needs to be signed at all sides of the load unit. Because there is no visibility for the IVG in the front and the rear, only the left and right long-side of the load units can be analysed. This enables the detection of most load unit types, except of intermodal semi-trailers. At this moment RID/ADR regulations allow other markings of semi-trailers (just rear and front as a minimum for rail transport). To enable also the effective detection of dangerous cargo at the long-side of semi-trailers a change of RID/ADR-regulations would be necessary or additional harmonized rules for marking of trailers need to be implemented by the partners of the transport chain. In case this is done, the following model also works for intermodal semi-trailers.

![Figure 2-11. Signalling of dangerous cargo at the sides of the load unit](image)

The main characteristics of these placards are:

1. Placards show the main classification of the hazardous substance by the main class number.
2. Placards show the sub classification of the hazardous substance by color and design pattern.
3. Placards are standardized according to international dangerous cargo law (RID / ADR / IMDG).
4. Placards can differ slightly in their appearance according to international regulations.
In this proof of concept two main different dangerous cargo signs have been detected:

- **RID/ADR orange placards** (double lined, upper line: “hazard information code” - formally known as “Kemler Code”-, lower row: UN number)

  ![RID/ADR orange placards](image1)

- **Hazardous materials placards / diamond-shaped placards**

  ![Diamond-shaped placards](image2)

### 2.1.3 Development and adjustment of software and algorithms

The workflow of the application is organized around four different processes working simultaneously:

#### 2.1.3.1 First process (DIS+TIC)

This process englobes the **image acquisition** (from the technical components) and **processing modules**.
The first step for creating this application was to develop a basic C++ program for image acquisition. In order to develop this program, different libraries were explored and analyzed. Finally, the following libraries and SDKs, Software Development Kit were selected:

- **SDK Vimba**: Developer Kit that will serve for internal camera configurations. The Vimba Viewer tool was used to set the parameters of exposure time, gain, capture format as well as to select the region of interest (ROI) of the images captured (this will be explained later below). This tool generates a XML file with these configurations.

  ![Figure 2-15. SDK Vimba](image)

- **SDK PvAPI**: Developer Kit that will be used to add functionality in the program related to the control of the camera (Mako G-234): driver and controller. This includes the sequences for start and end capturing images (trigger the camera).

- **OpenCV**: It is an open source programming library primarily oriented to real-time computer vision. The OpenCV library currently has more than 500 functionalities for vision processes, ranging from fields such as object recognition, camera calibration, stereo vision (3D) and robotic vision. The calibration and configuration of the cameras will be carried out with the Sdks that the cameras provide. OpenCV will be used exclusively for image processing.

A multi-thread C++ program was designed with an Eclipse CDT software with access to a Postgres database, managed with PgAdmin III (both are open license).

This program runs two threads simultaneously: the Acquisition Thread and the Processing Thread.

The first processing module, “**Acquisition Thread**” [DIS], is in charge of obtaining the images. Although it captures frames continuously, it only sends to the second thread (“Processing Thread”) those frames that are found valid via the workflow described below.
1. First, the thread is initialized and a reference frame is captured to allow the **background subtraction** of the wagons and containers detected. The background subtraction is a common technique and widely used to generate a foreground mask (that is, a binary image that contains the pixels belonging to moving objects in the scene) by using static cameras.

![Background subtraction](image)

**Figure 2-16. Background subtraction**

In the first place, an initial model of the background is obtained, followed by a second step in which this model is updated and adapted to possible changes in the scene. Particularly for the train model and the proof of concept designed, an opaque black panel is used as the background (due to the lighting limitations).

2. Then, the thread launches a “**train capturing loop**” in which the program is obtaining images from transits of train through the IVG. In each loop:

   - Each captured image is converted from its RAW Bayer format into black and white.
   - Next, the images are resized and scaled down in order to optimize and speed up the edge-detection algorithms.
   - Then, the edge-detection algorithms separate and isolate each wagon. This practice is performed by detecting the edges of each wagon and calculating their area, placing correctly the centre of mass of the edges detected. For this demo, and based on this process, three different types of “containers” can be identified:
     - Locomotive: It has the largest area, established by a minimum size
     - Container: Area with two main dimensions: upper and lower
     - Tank: Area with a maximum size
   - Once the centre of mass of the container is centred and in place (as the container is transiting through the IVG), the image captured is sent to the next thread (Processing Thread).
For each loop, the following considerations need to be taken into account:

- Timestamps are required to correctly identify the train, its composition and the complete sequence of the wagons. For this demonstrator, a detected wagon corresponds to a new train if the time elapsed after the last detected wagon is over 20 seconds.

- To avoid registering the same wagon twice (if the train has stopped and the centre of mass of a wagon is in position), this process is improved by detecting the transit of the centre of mass of the wagon in and out of the centralized pixel region, creating timestamps for these two events:
  - Initial timestamp: when the centre of mass of the wagon is positioned in place
  - Final timestamp: when the loop finishes doing all the process and checks whether it is a new train, wagon.

- The program will generate an auxiliary window in which the detection process can be monitored in real time.

It should be taken into account that this process for capturing each wagon has been designed for the demo proof of concept. In a real scenario it is expected that the capturing is triggered by the wheel sensor.

2.1.3.1.1 Recognition of defined numbers, sign

The Processing Thread (TIC) receives the image captured and run analysis algorithms that will extract the relevant information from the wagons and containers.

The demo designed for this proof of concept works with models on a small scale. This causes the train codes to look especially tiny, potentially producing certain reading errors or difficulty reading the codes to analyse. To solve this problem, the following workflow was designed:

First, the images will be cropped according to the placement of the codes, making cuts of ROI, Region Of Interest.

![Image](image_url)

Figure 2-17. Definition of Region of Interest
For the ILU/BIC code, as its placement is the upper right corner, the ROI is created with some margin of error, for that zone to be able to zoom, enlargement, and thus obtain the code with a larger size. The ROI then proceeds analogously with the UIC code.

Once the ROI are obtained, the OCR engines only work with the cropped images. This accelerates the search and avoid false positives.

**OCR (Optical Character Recognition)** is a software technology that imitates the human eye’s ability to recognize the characters contained in an image, scanned document or photograph, so that these become comprehensible or recognizable for a computer, obtaining as final result the chain of Characters.

Three different commercial licenses from ARH Hungary are used for the recognition of the ILU, UIC and ADR codes and signs described:

- **CARMEN®ACCR License**: This engine is used to recognize the ILU codes from the containers.
- **CARMEN® ADR**: This engine identifies the ADR signs
- **CARMEN® UIC**: This engine is used to recognize the UIC codes from the wagons

The process followed by the OCR is described below:

- Binarization
- Segmentation
- Thinning
- Pattern Comparison

![Figure 2-18. ROI for the ILU and UIC code](image)

![Figure 2-19. OCR Flow Scheme](image)
1. **Binarization**: In this process, a colour/greyscale image is converted into B&W, preserving its essential properties. Setting the correct threshold, each pixel is transformed into a black pixel or a white pixel, resulting in an image in which the characters and symbols are clearly differentiated. Through this process we obtain a black and white image where the contours of the characters and symbols that are part of the image are clearly marked. This will allow the isolation of the parts of the image that contain text (more transitions between black and white).

2. **Segmentation**: Detection by stochastic procedures of the outlines and regions of the image, based on spatial/intensity information, allowing the breakdown of the text into different logical entities. Thanks to the previous step, the pixels can be clustered together into homogeneous zones.

3. **Thinning**: In this process, each component identified is simplified by sequentially erasing the points of its outline, preserving its typology. In order to maintain the original proportions and avoid any image distortion, this process must be done following successive and parallel image scans, to correctly erase all of the pixels detected at the same time.

4. **Pattern Comparison**: In this last step, the characters obtained from the thinning process are compared with some predefined patterns from a database. Different comparison methods can be carried out in this phase. One of them is the projection method, in which vertical and horizontal projections of the character are obtained and compared with the alphabet of possible characters until a maximum coincidence is found.

OpenCV functions will be added to increase the contrast, to highlight the code and facilitate the recognition task for OCR engines. These functions will be used or not depending on the lighting conditions of the test room.

Once all the codes have been obtained using the OCR engines, they are registered into the Postgres database. To do so, each wagon will have a new register entry in the `Containers_wagons_info` database. Since this process will collect all the transits of wagons, each wagon will be associated to a `train_id` corresponding to the train to which it belongs.

An image will be created in which the different codes will be inserted (using the functions of OpenCV to insert text in image) to offer visual easiness when reviewing the images.

2.1.3.1.2 Recognition of dangerous cargo placards

Two different methods are being considered to identify the most suitable detection and classification system for dangerous cargo placards:

- **Computer Vision**: This method is based on performing each image transformation manually in order to train a model that is capable of obtaining the desired information (code numbers and type of placard).
Deep Learning: In this method, a model is trained with a large database of images so it would be capable of extracting automatically the information wanted from the image.

In order to obtain dangerous cargo placard information from the images, two steps have to be taken. These two steps could be implemented with either basic Computer Vision or Deep Learning. However, for the scope of this proof of concept, the technique selected to detect and classify the dangerous cargo placards and signs was the computer vision method. The Deep Learning model will be considered for future works.

Using the Computer Vision method, the two processes followed to recognize the dangerous cargo placards are (A) Placard detection and (B) Placard classification:

A) Placard detection
In this step, the placard is located within the image in order to be cut out. The following basic computer vision algorithm has been implemented:

1. Pre-processing: First, the contrast and brightness are adjusted in order to enhance the image. Then it is converted into a grey scale.
2. Segmentation: In this step, the ROI is applied and the placard is located. First, the image edges are detected and then some morphological operations are applied to isolate the placard in the image. Lastly, straight lines are found to detect the edges of the placard.
3. Post-processing: In this step the placard is cut out from the image by finding the placard’s centre.

B) Placard classification
In this step, the placard that has been detected is classified by a computer vision algorithm taking as a reference a database of dangerous cargo placards that has been previously defined.

1. First, the algorithm searches for relevant points in the image which can be differentiated from the rest of the image.
2. Then, the rest of the image information surrounding these points is analysed.

With all of this information, a comparison is made between this image and the database, identifying the placard detected as one of the different types defined.

2.1.3.2 Second Process (RI)
The program developed for this process is made of a socket in C++ that communicates the reader with the computer in order to read a RFID TAG in real time. To do so, this program registers the following measures for each tag:

1. Initial and final timestamps: This factor is used to correctly associate each tag to its corresponding wagon.
2. Number of times that the tag has been read
3. Registration of the information recorded in the tag

This process follows the workflow described below:

- The reader enters in an infinite loop in which it constantly asks the antenna for the readings of a TAG
• When the antenna detects a tag, it is read by the reader and the information that it contains, together with the timestamps, is recorded into a new rfid_info table.

2.1.3.3 Third process (FIM)

The previous image detection and train identification processes run in parallel without sharing information with each other. This process (implemented in Python) is in charge of matching each detected wagon with the correct RFID TAG read.

This process follows the workflow described below:

1. The system extracts the initial and final timestamp of the wagon from the table created in the first process (image capture module) for that wagon (containers_wagons_info table).
2. The system then searches the matching tag with the right timestamps in the tables generated in the second process (rfid_info): If the initial and final timestamps of the TAG are included between the wagon timestamps, the TAG are automatically assigned to that wagon. This could be represented as depicted in Figure 2-20.

![Figure 2-20. Matching Timestamps for TAG-WAGON](image)

If this is not the case, the absolute measure of the distance between the initial and final timestamps shall be calculated. This way it will be checked at all times the TAG that is closer to the wagon. The result that are obtained at the end of the loop is the TAG with less distance to the wagon that is being analysed in this nested root loop. The process is repeated for each wagon so that all wagons are matched with their corresponding TAG.

3. Finally, the tables in the database will be updated:
   - Containers_wagons_info table: The TAG field will be updated with its corresponding TAG.
   - Rfid.info table: A “used TAG” field will be updated prevent the TAG in question to continue being a potential candidate.

The data tables generated by the first and second process are independent, so that a failure of one of the process will not imply the failure of the other.

2.1.3.4 4th process (GUI)

This process displays the information obtained and stored in the database through a HMI platform developed in java for the terminals. This HMI was developed in the form of a webpage with three main pages:
- **Last Train**: this page shows in real time the last train that is transiting through the IVG. The page will refresh as the wagons pass through the IVG. Once all the wagon have passed, the page lists all the wagons, showing the information detected and processed stored in the database (tables):

  - The wagon position within the train composition
  - The timestamps indicating the time when the trains and wagons have passed through the gate
  - The information stored in the tag associated to the wagon (ID, UIC)
  - The UIC, ILU and RID codes of the wagon and container read by the OCR engines.
  - The type of wagon: locomotive, tank container, empty wagon (these are the cases considered for this demo and proof of concept).
  - An image of the wagon

This page is automatically updated as new trains are detected by the system.

![Last Train Page](image)

**Figure 2-21. Last Train Page**

- **Search trains**: This page shows the historical register of all the trains that have transited through the Intelligent Video Gate. It allows to search by date and number of trains. Once the desired train is selected, this page shows the same information as the last train page.
**Check Trains**: This page shows the matching information received by the terminal from a train transiting through the IVG installed in a “Departures (D)” terminal and an “Arrival (A)” terminal. The purpose of this tab is to allow the terminals and the operators to easily compare the information and check the integrity of the train composition, status and condition more efficiently. The tab presents the comparison between the wagons located at the same position of the two trains chosen, showing the correct matching of codes and signs in green, a discrepancy of information between two elements in yellow and an error of detection in red.

For the scope of this proof of concept, only a departure (D) and an arrival (A) terminal have been considered. However, additional nodes in the rail network can be considered to be included in order to recognize and compare the consistence of a train set running through the IVG.
2.2 Simulation of Data Flows

The figure below summarizes the process of how a train is captured by the IVG and the flow of data described in the previous section.

**Detection of first wagon**
- The first wagon is detected by the detection algorithms.
- A new train is registered into the database, and the system creates a new trains_info table and records the fields of train id and initial timestamp.
- The outputs resulting from applying the OCR (codes and signs) to the processed image of the first wagon and container are registered into the database following the structure described (the system creates a new containers_wagons_info table).
- The RFID tag associated to the wagon is read by the RFID reader, and the information is recorded into a new rfid_info table created by the system.

**Detection of successive wagons**
- Successive wagons are detected following the same process as the first one, updating the table trains_info.
- New data is collected and processed from the wagons, creating for each one of them new containers_wagons_info tables.
- The RFID reader collects the information of each TAG, which is registered in new rfid_info tables.

**Detection of next trains**
- 20 seconds after the last wagon has been detected and its final timestamp registered, the wagon count for the current train is completed, and the system updates the trains_info table with the final information.
- The next wagon detected by the system will launch this process again for a new train.
- In this part of the process, the system compares the tables rfid_info and containers_wagons_info, checking the correct association of each tag to the matching wagon detected, and completing the containers_wagons_info table.
2.2.1 Data Outputs

The system generates .xml files with the data outputs of the workflow and processes described. In particular, for each train three tables are created:

- The **trains.info table** collects the general information of the complete detected train (including its associated wagons and containers). The system creates one table for each train detected.
- The **containers_wagons_info table** saves the specific data associated to each container and wagon detected. The system creates one table for each wagon detected.

The tables public.trains_info and public.containers_wagons_info are closely related, as the data that they collect comes from the same process (detection).

- The **rfid.info table** collects the data read with the antennas of each tag. This table collects the data from a different process (RFID TAGs capture).

![Table images](image)

Figure 2.25. Train data tables

The fields included in these tables are explained in APPENDIX 1: Data Base Fields Description.

2.3 Test concept for integrated system

Each IVG generates a .xml file with all the data registered from each train transit. Each one of these files will be linked to its corresponding train in the database.

The WEB application developed will allow the comparison of two .xml files from different IVG linked to the same train, with the goal of checking the integrity of the train from its departure to its arrival, having the capacity of detecting any irregularity.
2.3.1 Definition of use cases and testing requirements

In order to test the system developed, the following use cases were defined. The aim of these use cases was to test in different scenarios the detection and recognition capabilities of the system. To do so, these tests were carried out with different train compositions and configurations (regarding containers and visibility of ILU, UIC, RID codes and RFID tags). These tests simulated the departure of a train from one terminal (D) and its arrival to another terminal (A) by passing twice through the IVG installed in the train model demonstrator described, performing these changes in between.

Preconditions for all the Use Cases:

- The light is ON.
- The camera is ON.
- The application is running.

The general process followed by all of the use cases is:

1. The train is set up with the “Departures” composition

2. The train with the “Departures” composition passes through the IVG and is captured by the detection system (camera and RFID antenna).

3. The data acquired is processed by the software modules developed and stored in the database (a new train_info table is created with the associated rfid_info and containers_wagons_info tables) as a train detected by the IVG of the Departure Terminal (D).

4. Next, the train composition is adapted manually to fit the “Arrivals” configuration. In this step, depending on the use case, specific codes or signs of the wagons and containers are covered with an opaque material.

5. The train with the “Arrivals” composition passes again through the IVG and is captured by the detection system (camera and RFID antenna).

6. This time, the data captured and processed is stored as a train that has passed through the IVG of the Arrival Terminal (A) (new train_info and associated rfid_info and containers_wagons_info tables are created).

7. The system then compares the train tables created from both terminals (A, D) and displays this information through the Check Trains page of the GUI.
The table below summarizes the use cases defined for this phase:

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Composition</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>UC 1</td>
<td>One empty wagon</td>
<td>Recognition of RFID TAG and UIC code</td>
</tr>
<tr>
<td>UC 2</td>
<td>One empty wagon</td>
<td>Recognition RFID TAG but not UIC code</td>
</tr>
<tr>
<td>UC 3</td>
<td>One empty wagon</td>
<td>Recognition of UIC code but not RFID TAG</td>
</tr>
<tr>
<td>UC 4</td>
<td>One empty wagon</td>
<td>No RFID TAG or UIC code recognition</td>
</tr>
<tr>
<td>UC 5</td>
<td>One wagon carrying a load unit</td>
<td>Recognition of ILU code</td>
</tr>
<tr>
<td>UC 6</td>
<td>One wagon carrying a load unit</td>
<td>No recognition ILU code</td>
</tr>
<tr>
<td>UC 7</td>
<td>One wagon carrying a Tank</td>
<td>Recognition of RID code and dangerous placards</td>
</tr>
<tr>
<td>UC 8</td>
<td>One wagon carrying a Tank</td>
<td>No recognition of RID code or dangerous placards</td>
</tr>
<tr>
<td>UC 9</td>
<td>Two wagons carrying each one a load unit</td>
<td>Recognition of TAGs, UIC, ILU and RID codes</td>
</tr>
<tr>
<td>UC 10</td>
<td>Two wagons carrying each one a load unit</td>
<td>Recognition of TAGs, UIC and RID codes for two wagons with load units, but not recognition of ILU code for one of the wagons</td>
</tr>
<tr>
<td>UC 11</td>
<td>Two wagons carrying each one a load unit</td>
<td>Recognition of TAGs, ILU and RID codes for two wagons with load units but not recognition of UIC code for one of the wagons</td>
</tr>
<tr>
<td>UC 12</td>
<td>Two wagons carrying each one a load unit</td>
<td>Recognition of TAGs and RID codes for the two wagons but not recognition of an ILU code for one of the wagons and an UIC code for the other wagon</td>
</tr>
</tbody>
</table>

2.3.2 Ongoing evaluation/proof of concept

In this section the results of the test described and the outputs of the twelve use cases considered are presented. These results are presented in their totality for Use Case 1, while for the remaining Use Cases only the summarized outputs are included. The complete results for each use case can be found in the Appendix 2: Use cases.
2.3.2.1 Use Case 1

Table 2-2. Description of Use Case 1

<table>
<thead>
<tr>
<th>Use case 1: One empty wagon – recognition RFID TAG and UIC code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author:</strong> INDRA</td>
</tr>
</tbody>
</table>

**Summary:**

Train configuration (Departures)
- Locomotive
- One empty wagon with visible UIC code and RFID tag

Train configuration (Arrivals)
- Locomotive
- One empty wagon with visible UIC code and RFID tag

**Process**

In this use case, the train is composed of the locomotive and one empty wagon. The passes through the IVG and is captured by the detection system (camera and RFID antenna).

The data acquired is processed by the software modules developed and stored in the database (a new train_info table is created with the associated rfid_info and containers_wagons_info tables) as a train detected by the IVG of the Departure Terminal (D).

Fifteen seconds later, the train with the exact train composition passes again through the IVG. This time, the data captured and processed is stored as a train that has passed through the IVG of the Arrival Terminal (A) (new train_info and associated rfid_info and containers_wagons_info tables are created).

The system then compares the train tables created from both terminals (A, D).

The expected result of this use case is that the system recognizes correctly the RFID TAG and UIC code of the wagon in both terminals and shows the result in green (as no failure).

**Preconditions:**
- The light is ON.
- The camera is ON.
- The application is running.
- The XML file received is always correct.

**Step #:**

<table>
<thead>
<tr>
<th>Step #</th>
<th>Step actions</th>
<th>Expected Results</th>
<th>Execution notes</th>
<th>Execution Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The XML file received from the terminal is inserted in the database of the terminal.</td>
<td>The data contained by the XML file is inserted in the database.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The train enters the terminal through a specific track and goes through a train gate.</td>
<td>The system should recognize that a train is coming/going through the gate and should start the gate systems.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gate starts systems for OCR recognition and RFID scan (the application is running).</td>
<td>System should be fully functional (status ready) before the first vehicle (locomotive/wagon) goes through the gate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>If a wagon goes through the gate, the system take a photo of the wagon.</td>
<td>The system takes a photo of the wagon.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The reader RFID take the TAG information from the wagon and stored in the TAGs database of the terminal.</td>
<td>A RFID TAG is detected and stored in the database.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td>Verification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>The system recognizes what type of wagon is (locomotive, container, tank or empty wagon).</td>
<td>The type of wagon (and load unit) is recognized.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>UIC code identification.</td>
<td>The OCR recognizes the UIC code of the wagon.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Steps 4-7 are repeated until the last wagon passed through the train.</td>
<td>After the last wagon passed the system should wait further 15 seconds to recognize the next train.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>The different data obtained is stored in the train database of the terminal.</td>
<td>Data stored properly in the database.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>The TAGs detected are assigned to each wagon in the database.</td>
<td>The obtained TAGs are assigned to each wagon in the database.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>The complete obtained data should be compared with the data received by the previous terminal.</td>
<td>The system compares the information obtained with the received by the previous terminal and mark what is correct and what is wrong or missing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>The database of the train is converted in a XML file.</td>
<td>The XML file is obtained properly from the database.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Execution type:** Manual  
**Estimated exec. duration (min):** 3 mins

The images captured by the IVG at the “Arrivals” (A) terminal are:

![Locomotive UIC: 1091](Image) ![Wagon UIC: 318044250054](Image)

*Figure 2-26. Images captured for UC1*
The .xml file generated at the “Departures” Terminal:

```xml
<train_description value="114">
  <train_id>114</train_id>
  <train_code>code</train_code>
  <train_type>TRAIN.TYPE</train_type>
  <train_type_id>0</train_type_id>
  <train_status>0</train_status>
  <terminal_code>Madrid</terminal_code>
  <terminal_id>300</terminal_id>
  <time_stamp_init>2019-05-23 17:24:15.911000</time_stamp_init>
  <time_stamp_end>2019-05-23 17:24:17.865000</time_stamp_end>
  <containers_amount>2</containers_amount>
  <wagons_amount>2</wagons_amount>
  <wagons_description amount="2">
    <wagon id="1">
      <train id="114">
        <wagon id="1">
          <time_stamp_init>2019-05-23 17:24:15.911000</time_stamp_init>
          <time_stamp_end>2019-05-23 17:24:15.911000</time_stamp_end>
          <cloud_point_path>CLOUD_POINT</cloud_point_path>
          <overview_image_path>ISO_Detected/2019523_16:57:34/SUCCESS_2019523_17:24:17.bmp</overview_image_path>
          <detail_image_path>ISO_Detected/2019523_16:57:34/SUCCESS_2019523_17:24:17.bmp</detail_image_path>
          <process_state_code>No Info</process_state_code>
          <process_state_id>1</process_state_id>
          <tag code="31040101911" tag_id="1">
            <tag_id>Email</tag_id>
            <tag_rsi_mean>1.0</tag_rsi_mean>
            <sic_code>1001</sic_code>
            <confidence_sic_code>90</confidence_sic_code>
            <wagon_owner_code>GreenCargo</wagon_owner_code>
            <containers_description amount="1">
              <container id="1">
                <container_id>1</container_id>
                <type_container_code>Locomotive</type_container_code>
                <bic_code>Locomotive</bic_code>
                <dangerous_sign>No result</dangerous_sign>
                <confidence_dangerous_code>90</confidence_dangerous_code>
                <container_description/>
              </container>
            </containers_description>
          </tag_code>
        </wagons>
      </wagons>
    </wagons>
  </wagons>
</train_description>
```

Figure 2.27. XML file of “Departures” (UC1)
The .xml file generated at the “Arrivals” terminal:

![XML file](image)

Figure 2-28. XML file of “Arrivals” (UC1)
### 2.3.2.2 Summary of Use Cases

The tables below summarize the results of these use cases:

#### Table 2-3. Results and Outputs of all the Use Cases

<table>
<thead>
<tr>
<th>Use Case 1: One empty wagon – recognition of RFID TAG and UIC code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Train configuration (Departures)</strong></td>
</tr>
<tr>
<td><strong>Train configuration (Arrivals)</strong></td>
</tr>
<tr>
<td><strong>Expected Result</strong></td>
</tr>
</tbody>
</table>

#### Use case 2: One empty wagon – recognition RFID TAG but not UIC code

| **Train configuration (Departures)** | 1) Locomotive | 2) One empty wagon with visible UIC code and RFID tag |
| **Train configuration (Arrivals)** | 1) Locomotive | 2) One empty wagon with visible RFID tag but hidden UIC code |
| **Expected Result** | The system recognizes correctly the RFID TAG and UIC code of the wagon in the Departure terminal but does not identify an UIC code of the wagon in the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals). |

#### Use case 3: One empty wagon - Recognition of UIC code but not RFID TAG

| **Train configuration (Departures)** | 1) Locomotive | 2) One empty wagon with visible UIC code and RFID tag |
| **Train configuration (Arrivals)** | 1) Locomotive | 2) One empty wagon with visible UIC code but “hidden” RFID tag |
| **Expected result** | The system recognizes correctly the RFID TAG and UIC code of the wagon in the Departure terminal but does not read a RFID signal from the wagon in the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals). |
### Use case 4: One empty wagon - No RFID TAG or UIC code recognition

**Train configuration (Departures)**
1) Locomotive  
2) One empty wagon with visible UIC code and RFID tag

**Train configuration (Arrivals)**
1) Locomotive  
2) One empty wagon with “hidden” RFID tag and UIC code

**Expected result**
The system recognizes correctly the RFID TAG and UIC code of the wagon in the Departure terminal but does not read a UIC code and a RFID signal from the wagon in the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals).

### Use case 5: One wagon carrying one ILU – Recognition ILU code

**Train configuration (Departures)**
1) Locomotive  
2) Wagon with visible UIC code and RFID tag carrying a container with visible ILU code

**Train configuration (Arrivals)**
1) Locomotive  
2) Wagon with visible UIC code and RFID tag carrying a container with visible ILU code

**Expected result**
The system recognizes correctly the RFID TAG and UIC code of the wagon and the ILU code for the container in both the Departure terminal and the Arrival terminal, presenting the result in green (showing the correct match of information from both terminals).
### Use case 6: One wagon carrying one ILU – No recognition ILU code

| Train configuration (Departures) | 1) Locomotive  
2) Wagon with visible UIC code and RFID tag carrying a container with visible ILU code |
|---------------------------------|--------------------------------------------------|
| Train configuration (Arrivals)  | 1) Locomotive  
2) Wagon with visible UIC code and RFID tag carrying a container with hidden ILU code |
| Expected result                 | The system recognizes correctly the RFID TAG and UIC code of the wagon and the ILU code for the container in the Departure terminal but does not detect an ILU code at the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals). |

#### UC Output

![UC Output Image]

### Use case 7: One wagon carrying a tank with a RID code - Recognition of RID code and dangerous placards

| Train configuration (Departures) | 1) Locomotive  
2) Wagon with visible UIC code and RFID tag carrying a tank with visible dangerous placard, ILU and RID code |
|---------------------------------|--------------------------------------------------|
| Train configuration (Arrivals)  | 1) Locomotive  
2) Wagon with visible UIC code and RFID tag carrying a tank with visible dangerous placard, ILU and RID code |
| Expected result                 | The system recognizes correctly the RFID TAG and UIC code of the wagon and the ILU, RID code and dangerous placard of the tank in both the Departure terminal and the Arrival terminal, presenting the result in green (showing the correct match of information from both terminals). |

#### UC Output

![UC Output Image]
### Use case 8: One wagon carrying a tank with a RID code - No recognition of RID code or dangerous placards

<table>
<thead>
<tr>
<th>Train configuration</th>
<th>1) Locomotive</th>
<th>2) Wagon with visible UIC code and RFID tag carrying a tank with visible dangerous placard, ILU and RID code</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Departures)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Arrivals)</td>
<td>1) Locomotive</td>
<td>2) Wagon with visible UIC code and RFID tag carrying a tank with visible ILU code but hidden dangerous placard and RID code</td>
</tr>
<tr>
<td>Expected result</td>
<td>The system recognizes correctly the RFID TAG and UIC code of the wagon and the ILU, RID code and dangerous placard of the tank in the Departure terminal but does not detect a RID code or a dangerous placard in the tank at the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals).</td>
<td></td>
</tr>
</tbody>
</table>

#### UC Output

<table>
<thead>
<tr>
<th>Wagon(UIC)</th>
<th>Load Unit(ILU/BIC)</th>
<th>Dangerous Code(RID)</th>
<th>TAG</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 1091</td>
<td></td>
<td></td>
<td>731301-1091</td>
<td></td>
</tr>
<tr>
<td>A 1091</td>
<td></td>
<td></td>
<td>731301-1091</td>
<td></td>
</tr>
<tr>
<td>D 218044251724</td>
<td>VTGU866007B</td>
<td>903082</td>
<td>4060709-218044251724</td>
<td></td>
</tr>
<tr>
<td>A 218044251724</td>
<td>VTGU866007B</td>
<td>No result</td>
<td>4060709-218044251724</td>
<td></td>
</tr>
</tbody>
</table>

### Use case 9: Recognition of TAGs, UIC, ILU and RID codes for two wagons with load units.

<table>
<thead>
<tr>
<th>Train configuration</th>
<th>1) Locomotive</th>
<th>2) 1st wagon with visible UIC code and RFID tag carrying a container with visible ILU code and dangerous placard, ILU and RID code</th>
<th>3) 2nd wagon with visible UIC code and RFID tag carrying a container with visible ILU code</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Departures)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Arrivals)</td>
<td>1) Locomotive</td>
<td>2) 1st wagon with visible UIC code and RFID tag carrying a container with visible ILU code and dangerous placard, ILU and RID code</td>
<td>3) 2nd wagon with visible UIC code and RFID tag carrying a container with visible ILU code</td>
</tr>
<tr>
<td>Expected result</td>
<td>The system correctly recognizes and detects the RFID TAGs, UIC codes of the wagons and the ILUs, and the RID code and dangerous placard of the container in both the Departure and the Arrival terminals, presenting the result in green (showing the correct matching of information from both terminals).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### UC Output

<table>
<thead>
<tr>
<th>Wagon(UIC)</th>
<th>Load Unit(ILU/BIC)</th>
<th>Dangerous Code(RID)</th>
<th>TAG</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 1091</td>
<td></td>
<td></td>
<td>731301-1091</td>
<td></td>
</tr>
<tr>
<td>A 1091</td>
<td></td>
<td></td>
<td>731301-1091</td>
<td></td>
</tr>
<tr>
<td>D 318044250054</td>
<td>HCU40610544261</td>
<td>No result</td>
<td>4060709-318044250054</td>
<td></td>
</tr>
<tr>
<td>A 318044250054</td>
<td>HCU40610544261</td>
<td>No result</td>
<td>4060709-318044250054</td>
<td></td>
</tr>
<tr>
<td>D 258444354124</td>
<td>COSU4135264</td>
<td>No result</td>
<td>4060709-258444354124</td>
<td></td>
</tr>
<tr>
<td>A 258444354124</td>
<td>COSU4135264</td>
<td>No result</td>
<td>4060709-258444354124</td>
<td></td>
</tr>
</tbody>
</table>
### Use case 10: Recognition of TAGs, UIC and RID codes for two wagons with load units, but not recognition of ILU code for one wagon

<table>
<thead>
<tr>
<th>Train configuration (Departures)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Locomotive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) 1st wagon with visible UIC code and RFID tag carrying a container with visible ILU code and dangerous placard, ILU and RID code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) 2nd wagon with visible UIC code and RFID tag carrying a container with visible ILU code</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Train configuration (Arrivals)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Locomotive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) 1st wagon with visible UIC code and RFID tag carrying a container with visible ILU code and dangerous placard, ILU and RID code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) 2nd wagon with visible UIC code and RFID tag carrying a container with hidden ILU code</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Expected result

The system detects and recognizes correctly all the tags and codes of the wagons and containers in the Departure terminal but does not detect a ILU code in the container of the second wagon at the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals).

### UC Output

![UC Output](image)

### Use case 11: Recognition of TAGs, ILU and RID codes for two wagons with load units but not recognition of UIC code for one wagon

<table>
<thead>
<tr>
<th>Train configuration (Departures)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Locomotive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) 1st wagon with visible UIC code and RFID tag carrying a container with visible ILU code and dangerous placard, ILU and RID code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) 2nd wagon with visible UIC code and RFID tag carrying a container with visible ILU code</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Train configuration (Arrivals)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Locomotive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) 1st wagon with visible RFID tag and hidden UIC code carrying a container with visible ILU code and dangerous placard, ILU and RID code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) 2nd wagon with visible UIC code and RFID tag carrying a container with visible ILU code</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Expected result

The system detects and recognizes correctly all the tags and codes of the wagons and containers in the Departure terminal but does not detect the UIC code in the first wagon at the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals).

### UC Output

![UC Output](image)
Use case 12: Recognition of TAGs and RID codes for two wagons with load units but not recognition of ILU code for one of the wagons and UIC code for the other.

| Train configuration (Departures) | 1) Locomotive  
|                                 | 2) 1st wagon with visible UIC code and RFID tag carrying a container with visible ILU code and dangerous placard, ILU and RID code  
|                                 | 3) 2nd wagon with visible UIC code and RFID tag carrying a container with visible ILU code  
| Train configuration (Arrivals)   | 1) Locomotive  
|                                 | 2) 1st wagon with visible RFID tag and UIC code carrying a container with hidden ILU code and visible dangerous placard and RID code  
|                                 | 3) 2nd wagon with visible RFID tag and hidden UIC code carrying a container with visible ILU code  
| Expected result                 | The system detects and recognizes correctly all the tags and codes of the wagons and containers in the Departure terminal but does not detect the ILU code of the container in the first wagon and the UIC code of the second wagon at the Arrival terminal, presenting the result in yellow (showing the discrepancy of information from both terminals).  
| UC Output                       | ![UC Output](image)  

The analysis of the UC outputs shows that the proof of concept of the IVG system developed behaves as expected in all of the use cases. These tests have demonstrated the capabilities of the system to detect, classify, show and compare the information of the train models passing through the IVG, as well as the correct functioning of all the interfaces, software and algorithms developed.
2.4 Technical proof of the selected components in a real environment

The image processing capabilities of the IVG system developed in the previous stage has been tested with two different sets of images captured in a real using the technical cameras identified and selected in the previous deliverable:

- First, the system was tested with a batch of images obtained with a Spyder 3GigE Vision SG-14 linear camera, installed in site for a long period for the scope of this project.

- Then, the system was tested with a sample of images obtained with a Dalsa Linea camera (2K GigE Vision Monochrome CMOS Line Scan Cameras Teledyne DALSA), selected in the process carried out in the previous deliverable D4.1, and installed on the same site as the previous camera.

The selected testing site has been the Train Conformity Check System (TCCS) Installation of Carbonara Scrivia in North Italy, better described in section 4.3. This site has been commissioned by the Italian Railway Infrastructure Manager (RFI) and commissioned by Hitachi Rail STS. The installed TCCS offered a good opportunity for performing these tests as it already had the basic infrastructure and facilities needed for wayside train image acquisition with linear cameras. This included wheel sensors and algorithms for train detection and vehicle recognition, power supply and telecommunication systems, civil structures for camera easy installation, permissions for site tests, etc. The old Spyder3 camera has been installed in a more fixed way and leaved in operation for several months, while the new Linea camera has been tested in a temporary setup during a single acquisition day.

It is important to highlight that in this stage of the project the test of the technical components in the real environment has been limited to the cameras and the images obtained with them, leaving out of the scope the RFID identification module. In addition, since the images obtained correspond to several trains passing through one single gate in the real environment, the “Check Trains” functionalities of the GUI could not be tested, as it would be required for the same train to pass through two different gates (or, as in the case of the proof of concept with the train model, twice through the same gate).
The detection and classification algorithms developed (OCR and dangerous cargo signs) have been adapted in order to demonstrate their capabilities with real images:

- The Image acquisition thread has been adapted to obtain the images from an existing database
- The Image processing thread has been adapted to identify more than one container per wagon.
- Likewise, the OCR function has been modified to return more than one ISO code and print red frames around each character recognized by the OCR engine.
- The characters’ size of the OCR file has been changed to improve the recognition of the codes.
- The computer vision function for the detection and classification of dangerous placards has been adapted and updated to detect the signs of the real images.

### 2.4.1 Results with previously-installed camera (Spyder 3GigE Vision SG-14)

The ILU codes capabilities of the OCR were tested with four different container compositions for one single wagon: one container, two containers (separated and together) and three containers. As it can be seen in the images below, the algorithms were able to successfully detect and process the UIC codes of the wagons and the ILU codes for the different container settings, providing more than one ISO code for those images with several containers (results of the codes detected can be observed at the top left side of the images).

![Image of wagon with OCR detection]

Figure 2-30. Previous Camera - OCR detection for a real wagon with one container
The computer vision capabilities to identify dangerous cargo signs was also tested with real images of tank containers. The system could successfully detect the ADR codes and hazardous materials placards (diamond-shaped), as depicted in the images below. The Figure 2-35 shows how the system could also identify and classify two different dangerous cargo placards, together with an ADR dangerous code.
The overall quality of these images has been very good and sufficient for all recognition purposes. Anyway, given the obsolescence of this cameras based on the fact that they are actually out of production, it was decided to test also the new Dalsa Linea camera as described in following paragraph.

2.4.2 Results with new selected camera

The Dalsa Linea camera (2K GigE Vision Monochrome CMOS Line Scan Cameras Teledyne DALSA) was installed on the same site as the previous camera with a temporary setup. This camera used the same image processing software as the previous one. However, some adjustments needed to be done in order to allow the algorithms developed and the OCR engines to successfully detect and identify the ILU and UIC codes: the parameter controlling the proportion between horizontal and vertical size of the images was adapted, as well as the acquisition line rate. The new camera has a
lower sensitivity than the previous one used (anticipated by the data sets on D4.1), so the optics iris had to be more open and the analogue gains had to be tuned more precisely; additionally, the exposure also needed to be adjusted (especially in night conditions and when the sunlight hits the optics directly).

The image processing module was tested with this new batch of images. The algorithms developed were able to identify and process the UIC codes of the wagons and the ILU codes of the containers, providing more than one ISO code for those images with several containers, as it can be seen in the figures below.

Figure 2-36. New Camera - OCR detection for a real wagon with two containers (separated)

Figure 2-37. New Camera - OCR detection for a real wagon with one container 1

Figure 2-38. New Camera - OCR detection for a real wagon with one container 2
3 Data sharing and exploitation

The data produced by an IVG, as described in section 2.1.1, can be used and exploited in different kinds of monitoring and decision support systems. It is common with information barriers along the logistic chain. These barriers often lead to manual work in e.g. copying information from one source into local system as well as writing out on real paper, see Figure 3-1.

![Figure 3-1. Information barriers along the logistic chain and how to use digitalization to overcome them](image)

In order to improve the efficiency of the information processing which is crucial for monitoring and planning it is important to make information readily available along the logistic chain. To do this, the communication must be standardized.

The purpose of this section is to describe two such examples.

3.1 State of the art and best practice – the IoT concept

Shipping goods via multi-modal transport requires the full collaboration of many parties, as each participant in the supply chain can create, modify or read data, where logistics data is extremely valuable to increase visibility and efficiency in the shipping process. Today, many supply chain participants are indeed exchanging data between each other, but only in direct peer-to-peer links, with little or no flexibility to share data with multiple actors. This leads to a complex and rigid structure and reinforces a fragmented, low-margin market. The development of Intermodal Transport is crucial to ensure sustainable growth of Supply Chains that enable efficient Industrial operations and retail eCommerce transactions, therefore numerous important organizations and research groups have developed proposals to increase the level of digitalization of transport supply chains. Among those the most active is the International Air Transport Association (IATA), a trade association of the world’s airlines, consisting of 290 airlines, primarily major carriers, representing 117 countries. IATA, that supports airline activity and helps formulate industry policy and standards,
has launched the “ONE Record” project in order to introduce paperless processes and foster the achievement of digital logistics supply chains, where data is easily and transparently exchanged across cargo stakeholders, communities and data platforms. IATA recognized that today’s digital infrastructure is built on data sharing, on the maturity of the web technology, and commercial availability of cloud hosting and distributed databases. In June 2018 IATA has kicked-off the ONE Record Task Force (ORTF) to provide the air cargo industry with a standard for data sharing, based on web API along with a common data mode: “ONE Record is a proposed standard for sharing data and provide a view of a single virtual shipment record. It focuses on data structures and accessibility and will facilitate the emergence of digital cargo, where logistics and transport providers will easily interact over an internet of logistics 1. Our approach is to extend the Internet of Logistics concept into other sectors of Freight Transport and Rail Freight in particular, because it provides a strong innovation platform for all domains of multimodal transport.

A fundamental principle of the Internet of Logistics is to provide to the cargo industry with a standard data semantic structure and a defined data ownership, in order to capture and share the data generated across the supply chain. The key technology adopted to create such a semantic structure is the so-called “Semantic Web”, which is a framework of technical standards and information management tools that provide a method to store and publish digital data, so that the information sources can be interlinked and more easily searched, cross-referenced and processed by computers. The standards that are at the basis of the “Semantic Web”, have created a set of specifications, technologies and data storage solutions, that enable the federation of disparate databases that reside on separate servers, but share the same common vocabulary and identification mechanism. Such important features allow multiple parties to exchange information without the need to create a common central database. Ericsson has been an active member of the One Record program and has adopted the Internet of Logistics for its own supply chain for the delivery of telecommunication gear across the world, by sharing its logistics data with major carriers and 3PL operators.

Tim Berners-Lee, inventor of the World Wide Web and Director of the World Wide Web Consortium (W3C)², originally coined the term “Semantic Web” in 2001³, and he expanded further the concept in 2006, when he published a note about the Semantic Web project⁴, that described the principles of Linked Data. The Semantic Web is an extension of the World Wide Web, a collection of standards, common data formats and exchange protocols that “allow data to be shared and reused across application, enterprise and community boundaries”⁵. As such, Semantic Web technology provides an convenient solution for the exchange of data among the various enterprises that interact and collaborate to fulfil a cargo shipment, either in multimodal trade over long-term maritime and road transport or fast international airfreight shipments, when multiple transport and service providers or custom authorities need to exchange documents, instructions, invoices, addresses, bills of lading, proof of delivery notes etc. across terminals, warehouses, vehicles/aircrafts, destinations. Logistics chains are by their very nature, distributed and collaborative so that logistics data exchange calls for the principles of data distribution and collaborative content creation, that have driven the development of the World Wide Web. As in the WWW, the flexible access to information must abide

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¹ IATA website – www.iata.org
⁴ Citation (Berners-Lee, Linked Data, Design Issues, 2006)
⁵ Citation (W3C, 2011)
to the limits of personal privacy and the protection of confidential or critical information. Likewise, the Transport & Logistics operators need to exchange information with business partners, but also to protect access from competitors, as well as to ensure the protection of sensitive (e.g. data dangerous goods).

The proposed approach, that has the objective to model distributed databases and information produced across a logistic chain, can also be defined as “Internet of Logistics”, since it has the purpose to create a common, distributed and interoperable data exchange infrastructure that matches the principles of the Big Internet. As such the Internet of Logistics overcomes the limitations of traditional supply chain communication system that cover only one2one messages (e.g. EDI), and the complexity associated to ad-hoc IT system implementations that are needed to build interfaces between legacy systems. The adoption of web standards, that are part of the Semantic Web framework, can open new possibilities for the digitalization of business processes and operations in the Freight sector.

Within the current wave of digitalization projects, Shippers and Transport operators deploy detection systems and sensors, that are either physically bound to the shipment (container or pallet or package) or that are installed on the transporting vehicle (on-board telematics unit). The historical data can be used to improve forecasting and operations scheduling, based on optimization algorithms. Conversely Real time logistics data can be leveraged to increase flexibility, to handle exceptions in a timely manner, and to minimize the impact of disruption, such as unplanned delays or handling errors. B2B customers of the Rail Freight sector count on Transport Operators to ensure predictability of their own supply chains, reduce their buffer inventories and smooth the production process.

The Freight sector has become increasingly diverse, and it includes many different actors such as shippers, rail network managers, truck operating companies, freight forwarders, terminal operators etc. Various operators share the transport infrastructures and physical resources, but they rarely exchange digital information. Technical complexity discourages from the adoption of a traditional IT implementation, which would be needed to consolidate logistic data into a single central IT system. The incredible growth of the WWW has been based on a completely distributed approach, where a distributed network of web pages and documents can refer to one another with global links such as Uniform Resource Locators (URLs). The World Wide Web is now so universally adopted, that its concepts and standards are familiar to anyone, and virtually everyone can use a standard tool, like a web browser, to make free text searches and to navigate across an extensive web of relationships that connect disparate subjects. In a similar way, the fundamental concept of Semantic Web is to structure the information available, as a Graph of Data items, such that people, events, documents, pictures and multimedia files etc. are connected by properties that relate such disparate items. The Web, as a global information space, evolves from linking documents (such as web pages linked with URLs), to linking both documents and data\(^6\), so to supports the design of innovative applications and relationships between elements of information (Curé, 2015). The 2001 Scientific American article\(^7\) by Berners-Lee, Hendler, and Lassila described this expected evolution of the existing Web to a Semantic Web, to be intended as web of data that can be processed by machines—that is, one in which the meaning is machine-readable\(^8\).

\(^6\) From “RDF Database Systems” Olivier Curé and Guillaume Blin – Elsevier Inc. 2015
\(^7\) (Berners-Lee, The Semantic Web, 2001)
\(^8\) (Berners-Lee, The Semantic Web, 2001)
As such the **Semantic Web** enables the access and sharing of information, in ways that are much more efficient and more open than traditional database IT solutions. The Semantic Web supports links between distributed data sources, with a structure that is defined and managed by open standards and tools. The World-Wide Consortium (W3C) has defined these tools in the form of standard Semantic Web languages, complete with abstract syntax, model-based semantics, reference implementations, test cases (Hendler, 2011). The standard that the Semantic Web uses to model a distributed web of data, is called the **Resource Description Framework** (RDF) and it precisely structures the information as a Graph Database, as specified by W3C (W3C, 2018).

When we want to share and correlate digital resources that are described and stored over different databases, we need a global way to identify the objects and topics that we are talking about. By using a global identification mechanism, we can be sure that two pieces of information that reside in separate servers, refer to the same entity. The standards of the Semantic Web have defined such a global reference that is called Uniform Resource Identifier (URI), and that is somewhat similar to a web address. In fact, a web address that is described by a Uniform Resource Locator (e.g. http://www3-org...) is a global name on the Web, and a URI is a generalization of a URL. Therefore using the Internet of Logistics is possible to identify every logistics objects (shipment, parcel, container etc.) with URL, a unique identifier that is used to relate the shipment to all relevant stakeholders and accompanying documents, as shown in the below picture:

![Unique ID for Logistics Objects - URL](https://<LDI_Domain>/ <Company_ID_on_LDI_Domain>/ <LO_Identifier>)

As the Freight Shipment progresses further along the delivery chain, more nodes and edges are added to the graph structure. Each node is identified by a unique identifier (URI/URL) and the edges connect the objects with their properties and relationships (e.g. a Container loaded on Truck, a Wagon that is part of Train composition). The progressive expansion of information that is detected along the process, builds up a rich information base. This data structure allows to add information and documents, for example Bill of Landing document that is associated to an Intermodal Logistic Unit (see picture below).

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9 The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. Led by Web inventor and Director Tim Berners-Lee and CEO Jeffrey Jaffe, W3C’s mission is to lead the Web to its full potential. Contact W3C for more information - Copyright © 2018 W3C - [https://www.w3.org/Consortium/](https://www.w3.org/Consortium/) (W3C, About W3C, 2018)
All relationships (graph edges) between data entities (graph nodes) are tagged with the exact time when the information was recorded, so to make it possible to retrieve exact chronology of events and measurements.

A key design choice is to maintain the flexibility of a distributed data architecture, where a separate database instances will be deployed for each site, and each Rail Terminal will be able to decide when to develop its own RDF database and join the overall network.

The Semantic Web provides standard languages and tools to model data in RDF format and to define a common vocabulary, also known as “ontology” that describes the structure of the knowledge. An ontology, or semantic model, takes the role of a glue between federated data sources, so we can describe how they fit together. Therefore, the structure of RDF databases provides the ability to merge two data sets together and simplifies the issue of federating data that are housed in multiple servers, possibly coming from different vendor sources. The application of Semantic Web standards and tools will allow the creation of a network of federated databases, where knowledge will be based on the merge and combination of all the federated data sources implemented at each terminal (see figure below).
With this approach, logistic databases will be stored, managed and published at each step of delivery, so that Transport Operators will establish a web of connected databases where data items (i.e. load units, vehicles, shipping documents, images and 3D scans, train composition, event timestamps etc.) will be structured according to Semantic Web Principles.

Consider a specific use case that can be enabled by the Internet of Logistics and that includes a typical scenario where a freight trains runs between 2 different Multimodal Terminals, like shown in the following picture.

![Figure 3-5. Freight Trains connects two terminals, each one features its own IVG](image1)

Each Multimodal Terminal has installed its own Intelligent Video Gateway and is able to scan the train and to produce a digital representation of the same train, wagons, containers and all images and properties that are associated to each Intermodal Logistics Unit. Each Multimodal Terminal is able to generate and store the train information into its own instance of RDF Database, which is therefore available to inquiries, searches, data analysis and comparisons. Each Multimodal Terminal manages its own RDF database and digital image of the same train.

![Figure 3-6. Each Multimodal Terminal manages its own RDF database and digital image of the same train](image2)
The analysis and comparison of the 2 databases is performed by using semantic web analytic tools that allow the identification of mismatch and differences, e.g. damage or change is detected with one on the containers. Semantic Web tools cross check the information available at the 2 Multimodal Terminals and detects a discrepancy in the status and conditions of one of the Intermodal Logistics Unit.

Figure 3-7. Verify Damage or Discrepancies at different checkpoints

- IoL ties together
  - multi-modal customer needs/data (blue)
  - railway transportation/terminal data (orange/brown)

Figure 3-8. The correlation between the IoL concept and S2R integration layer.
3.2 Simulation of improved terminal operation

As both hardware and software develops, tasks that previously could not be solved due to complexity reasons are now within reach. It is estimated that solution times for large scale optimizations are decreased with a factor of three every year\(^\text{10}\), meaning that a problem that took 24 hours to solve to optimality 10 years ago nowadays take 1.5 seconds. With this kind of speedups hard scheduling problems are now within reach to model and implement as an advanced decision support system (DSS). Other transport sectors are currently taking advantage of this software development. For example, the flight industry has over many years modelled, implemented and used advanced planning systems, among others Lufthansa is using a system to schedule all flying personnel\(^\text{11}\), based on large scale optimization. We propose that emphasis is put on equipping the railway transportation sector with such systems, and propose that the different scheduling tasks at multi-modal terminals are addressed with such DSSs.

It is a complex task to continuously operate a terminal. The number of ways a sequence of loading and unloading of ILUs can be constructed increases dramatically with the number of ILUs. For example, consider a simplified scenario where a container train arrives at the terminal to unload 30 containers and then get another 30 containers loaded before leaving. Assume further that all the positions of the containers are given, i.e. on the train as well as on in the truck lane, then the number of different schedules for sequencing the loading and unloading of the ILUs is around \(7.7\times10^{73}\), which is in the same order of magnitude as the number of atoms in the universe currently known to humankind. Such problem instances, well modelled and implemented, can be solved to optimality within seconds by an ordinary laptop today.

A large number of sequences are easy to rule out as inefficient (in relation to some objective, usually to minimize the time required to complete the process of loading and unloading) and are not considered as alternatives, but there are still lots of alternatives to consider. Humans cope with such complexity by constructing rules of thumb, often based on experience, and use these rules to make strategic and tactic decisions about how to proceed.

Rules of thumb work well as long as the everyday repeats itself more or less. But as the everyday patterns starts to diverge, rules of thumb are not a feasible method any longer. There is then a need for a decision support system, to enhance planning capabilities and support the planning process (i.e. the planner, crane driver or whoever is in charge of the operation schedule).

With the advent of the information society there is a demand for increased flexibility and information availability, and railway operations are no exception. There is therefore a need to adapt to the demands from the “outside world”, e.g. when possibilities to rebook and monitor the transport increases.

DSSs for enhancing the planning capabilities at the terminal must be able to operate in real time. Therefore, the answer times from the system must be short. The data about ILUs, their arrival times, departure time, parking lots etc. must be reliable and available. When data is updated about e.g. arrival times the DSS must react to the new information. This implies that a schedule for e.g. crane movements must either be recalculated fast or be repairable/robust to “small changes”.

\(^{10}\) http://bob4er.blogspot.com/2015/05/amazing-solver-speedups.html

\(^{11}\) http://ww1.jeppesen.com/company/newsroom/articles.jsp?newsURL=news/newsroom/2008/Lufthansa_contract.jsp
There are in principle two approaches to solving the implementation for a continuous scheduling problem. Either the system reacts every time new information gets available, or it reacts with a recalculation which is performed in discrete steps. We propose the latter, since there is a need for the crane operator to have a time frame of a number of lifts ahead in order to be in control of the situation.

We have studied the problem of scheduling crane movements at a rail terminal for ILU handling. The task of scheduling crane movements is a quite well studied case in theory, see e.g. Boysen et.al. 2013, Stephen & Boysen 2017 and Cao et.al. 2010. The problem is an instance of the well-known traveling salesman problem, which in turn is known to be NP-hard. This means that in general one could expect the problem to be of high complexity and hard to solve in the general case. It also implies that the execution times to find the best schedule could vary a lot, and therefore special care must be taken when designing a system operating in a real time environment.

### 3.2.1 Connection of the scheduling problem to the IVG

When the train passes through the IVG gate, the IVG produces a complete data set that includes the identity, type and sequence of all rail cars that compose the train, the identity and type of each load unit, special content information and constraints (e.g. dangerous goods signs), as well as multimedia files, such as HD images and 3D laser scans. This data representation, made available in a standardized format e.g. as described in section 3.1 consists of a digital and faithful representation of the train that is generated automatically at the departure/arrival at the terminal. The same holds for the corresponding IVG for arrivals by trucks.

During the train travel, the data that was produced at the departure IVG could be cross-checked automatically at any IVG check-point (wayside IVGs) along the route and finally will be automatically validated at the arrival terminal. At arrival, the IVG will eventually confirm or raise exceptions to the information that has been announced by other IVGs. The data representing the train and its cargo acts as a “digital twin” of the train and provides valuable input for receiving interchange terminals and logistic companies that e.g. cover the last mile of shipping. Receiving terminals and logistic companies can use the “digital twin” to make informed decisions, schedule operators, drivers, vehicles, shunting personnel, cranes and forklifts, warehouses and terminal space etc. well in advance of the arrival of the train. As showed in Figure 3-1 this is in contrast with today’s situation where little is known in advance at e.g. terminals before the train actually arrives. The IVG and the data it produces forming the “digital twin” is an enabler for the stakeholders to monitor and take actions based on the overall transport production and is crucial for more advanced DSSs which support planning and operations at the terminal introduced in this chapter.

### 3.2.2 Basic Optimization Model

The Traveling salesman problem has been studied extensively in computational research. Here we give just a short introduction to the models we have used, based on Mixed integer programming (MIP). One paper among others that compare different MIP models for the traveling salesman is Orman and Williams 2006, from which we have chosen to base our basic modelling of the problem.

The basic problem to solve is to make one complete tour for the crane which preforms all the lifts of the ILUs. The best sequence (or, actually, circuit) is the one which takes the least amount of time to complete all the lifts. Thus we get a minimization problem.
Let $x_{ij}$ denote that ILU $j$ is lifted and moved after the lift and move of ILU $i$ is finished. The crane thus must move from where the ILU $i$ is left to where ILU $j$ is positioned. This distance is denoted by $C_{ij}$. Further let $u_i$ denote the sequence number when ILU $i$ is processed. The problem is then stated as:

$$ \min \sum_{ij} C_{ij} x_{ij}$$  

such that

$$\forall j: \sum_i x_{ij} = 1$$  

$$\forall i: \sum_j x_{ij} = 1$$  

$x_{ij}$ binary

The two sums (marked 1 and 2) are the so called flow constraints, stating that the crane moves to exactly one ILU at a time. With the above model there is nothing that states that the answer values to the $x_{ij}$ should form exactly one circuit covering all $n$ ILUs, there could be arbitrarily number of circuits formed. To get exactly one circuit we have to add further constraints, which basically introduce a sequence number for each move.

$$\forall ij: u_i - u_j + n x_{ij} \leq n - 1 \quad u_i \ integer$$  

This formulation however turns out to not be execution efficient when adding sequence dependent constraints later (i.e. that an ILU $i$ must be processed before another ILU $j$, expressed as $u_i < u_j$). It is actually more efficient to iterate solving the flow constraints and check whether the solution values of the $x_{ij}$ forms a single circuit. In section 3.2.5 a more elaborate model is presented which takes time into account instead of the sequence number $u_i$ turning the problem into a job-shop problem variant.

If solving the MIP model above renders a single circuit, this is the optimal solution. If not, the bindings of the $x_{ij}$s are forming more than one circuit. For each of these sub-circuits form a new constraint in the following way. Let the set $\Gamma_k$ denote the $k$:th circuit, containing all $x_{ij}$ forming this circuit, and let $n_k$ denote the number of elements in $\Gamma_k$. Then add the following constraints to the model:

$$\forall k: \sum_{x_{ij} \in \Gamma_k} x_{ij} \leq n_k - 1$$

Essentially these additional constraints forbid the sub-circuit to be part of the values of the variables $x_{ij}$ in the next iteration. When this process of iteratively solving the MIPs with additional constraints and adding new constraints renders a single circuit we have a solution.

One would think that this process would be insecure to terminate, but tests show that it is much faster than forcing the MIP model to only return single circuit solutions by the constraint marked with * above.


3.2.3 Complexity and execution times

We have studied under which circumstances the problem of scheduling the sequence of loading/unloading of ILUs by a gantry crane can be supported by optimization software. The DSS should operate in real time and the task should therefore be solved within a certain execution time. It is therefore important to study the time complexity of the problem that the DSS is posed with, i.e. how fast the time needed to solve the problem increases when the size of the problem increases. We have done such complexity studies on synthetic data, i.e. used a program to generate scenarios to schedule. The reason for this is twofold: firstly, it is hard to get real data and secondly it is easier to generate synthetic data that has the properties that are interesting to study from a research point of view. For model construction we have used real data made available to us from Jernhusen’s multimodal terminals in Malmö and Årsta in Sweden. In section 3.2.5, we present a more advanced model that takes more constraints into account. For that model, real data have been used in both construction and evaluation.

The basic setup for the complexity study was as follows. There is one truck lane and a number of rail tracks over which a gantry crane is positioned. The tracks are the rows of a matrix, numbered from one and up, and row 0 is the truck lane. The columns of the matrix are the positions in the trains, and the parking lots in the truck lane.

All the scenarios have as main task to unload the train(s) and load them again. The train(s) are fully loaded when arriving and fully loaded when departing. We have simplified the tasks so that they all have equally sized ILUs (i.e. no half sized etc.). The reason for not considering different sizes is that we want to concentrate on the complexity issues and the execution behaviour and not solve also the practical modelling and representational problems simultaneously. By using synthetic data we could concentrate on the important issues concerning complexity first and propose a working design principle before addressing all practicalities. On each wagon on arriving trains the ILU(s) must be unloaded before another ILU can be loaded onto the wagon.

We have then used a varying number of trains as well as a varying number of columns (positions on the train and lane) to study the search complexity. A selection of the results is shown in the graphs below. The test runs were performed in steps where the number of columns was increased with 5 in each step, i.e. in each step the number of ILUs in each problem instance increased with the number of tracks multiplied by 5, and then multiplied by 2 since each wagon should be both unloaded and then loaded again. So, for the test with 1 track and a parking lane, each step increased with 5*2=10 ILUs. Behind each bar in the bar chart in Figure 3-9 are 10 different problem data sets, randomly generated. On the X-axis are the total number of ILUs, i.e. the leftmost bar chart is one train and one parking lane. On the Y-axis is the execution time on a Lenovo Thinkpad T460S. So, for example for the data sets with one track (train), 30 by train arriving ILUs and 30 by train departing ILUs (60 ILUs in total), the average execution time to find the optimal solution was slightly more than 3 seconds.

In the middle barchart in Figure 3-9 another track is added, i.e. two trains are present simultaneously. This means that the task contains twice as many ILUs than as in the first case. As can be noted the execution times increases rapidly, due to increased complexity.

Please note that the scale for execution time is different in the three bar charts below, as well as the number of ILUs which increases with the number of tracks used.
Note that in the middle bar chart in Figure 3-9 for the case with 2 tracks and one parking lane, the mean execution time decreases when going from 80 to 100 ILUs. This is contra-intuitive as the execution time, in the general case, increases exponentially with the number of ILUs. In the figure below we could see that it was one problem instance for the 80-case that took much longer to solve than all other cases, which presumably caused this. This shows that it is important to not only look at the mean execution time, but maybe even more at the variance. This is because the proposed system is intended to be in a real time environment and therefore it will have to deliver an answer in a given time frame, and we have to make sure we do not get stuck in a long search for the solution.

The variance in execution time to find the optimal solution is high. This has to be addressed when implementing this as a support system, for example by keeping the number of ILUs in the planning period low and introducing a rolling planning scheme to cope with longer time frames, as presented in the next section. In addition the basic model we have studied so far has the advantage that it can be stopped at any time even if not a single optimal circuit has yet been found and form a good but not optimal solution. This is done by cutting each sub-circuit at some place and merge all sub-circuits into one resulting circuit. It will not be the optimal solution but a good approximation of it. This means that the execution can be interrupted (after the first set of circuits is found) at any time with
the currently calculated best approximation of the best sequence. This could be of crucial importance when designing a real time algorithm used in a real time environment.

### 3.2.4 Rolling planning

Rolling planning fits well in domains where changing conditions is an important aspect of the problem, and also lessens the complexity as the time frame is relatively short in each planning step. In rolling planning only an initial part of each plan is fixed and executed. The tail of the plan is concatenated with the time frame, in the Figure 3-11 referred to as “inherited from previous plan”. Then the next planning period is scheduled in the same manner as the first period, and the process is repeated.

Since the full plan concerns a longer period, data about the expected future is taken into consideration in the planning process by planning for a longer period than is fixed in each step. The following plan will be based on the part of the first plan that is under execution and on other available information.

It is possible to take new information into account in each step of the rolling planning algorithm, e.g. rebooking and new bookings of ILUs, delays or early arrivals etc. This makes rolling planning a good choice for a DSS in a changing environment. The length of the planning period should be chosen with respect to the complexity of the problem, the length of the horizon needed for the operator(s) and the “plausibility information horizon” (how far ahead could information be trusted).

![Image](image.png)

**Figure 3-11. An example of rolling planning showing six plans**

### 3.2.5 A More Advanced Terminal Model

The analysis in Section 3.2.3 gives a good idea of the complexity of a simplified crane scheduling problem. In a real-world decision support system, however, a more advanced model of the terminal is needed. Therefore, we have also implemented a model that takes more details into consideration and evaluated it on problem instances that are based on historical data from the terminal in Årsta. The historical data were extracted from the terminal operating system used at the terminal. Data from this terminal operating system can be accessed through an application programming interface, something which would make it possible to combine data from IVGs and data from the terminal operating system when planning in a real setting. The characteristics of the model will now be described, and the results of the evaluation will be presented.
3.2.5.1 Designated Areas for Temporary Storage of Different Types of ILUs

Our terminal model, which is based on the terminal in Årsta, has the following lanes, starting with the one closest to the tracks (see Figure 3-12): a lane with slots for trailers that will be loaded onto trains, a driving lane for trucks, two lanes with slots for temporary storage of containers, and a lane with (tilted) slots for trailers that will be picked up by trucks. There are no other areas for temporary storage and no terminal tractors or reach stackers that move units (ILUs) within the terminal (as might be the case in a larger terminal). In other words, units remain where they are unless they are moved by a crane or a truck. Figure 3-12 only shows part of the terminal – in total, the model has 32 slots for trailers that will be loaded onto trains, 64 slots for containers (32 in each lane) and 96 slots for trailers that will be picked up by trucks. We assume that there is only one crane in operation and thus that it operates over the full length of the terminal.

3.2.5.2 Different Handling of Different Types of ILUs

Both containers and trailers must be lifted to and from trains using the crane, but containers must also be lifted to and from trucks, while trailers can be delivered and picked up by trucks without the assistance of a crane. In case truck and train are not present at the terminal at the same time, so that the unit must be temporarily stored at the terminal, this means the crane must move each container twice (to and from one of the lanes for temporary storage), while each trailer only has to be moved once.

3.2.5.3 Optimized Truck Locations and Fixed Locations for Temporary Storage

Instead of assuming that trucks that deliver or pick up containers are parked in fixed slots in the driving lane, the model makes it possible to calculate the parking slot to use for each truck from a solution to the crane scheduling problem and some additional information. This contributes to minimizing the time needed for the crane movements.

In contrast to this, the locations at the terminal for trailers and temporarily stored containers are decided before the optimization. For trailers, deciding the locations in the terminal is the first step in the planning of each planning period. Each trailer that arrives by train and that is included in the
planning period (see Section 3.2.5.5 for a description of how units for the planning periods are selected) is assigned to one of the locations that are free when the period begins. Similarly, each trailer that will arrive by truck during the planning period (or before it, in the case of the first period) is assigned to a free location. In contrast to the handling of trailers, each container that must be stored at the terminal is assigned to a location that is unique among the containers arriving or departing by train during the same day. This is done before the first planning period. Deciding the locations of all containers at once makes the planning process easier. However, the method might use the space at the terminal inefficiently.

Trailers and stored containers are given locations sequentially, so that each unit receives a location, among those locations that have not already been allocated to other units, that has the shortest distance to the location of the unit on the train (in one dimension only, namely the one along the tracks). In order to simplify the modeling, we assume that containers are never stacked (stored on top of each other). As in the complexity study, we assume that all slots and units are equally large (about the size of a 40-feet container). Finally, we assume that there are no units present at the terminal except the ones that arrive or depart by train during the day for which planning is done. This results in more free temporary storage locations than would otherwise be the case.

3.2.5.4 Time

Instead of just regarding the terminal as a two-dimensional matrix of squares, where the crane can move equally fast in both dimensions, we use time measurements for one of the cranes at the terminal in Årsta. The crane can move in both directions at the same time, so the direction that takes most time decides the total time needed for each movement. The crane needs 5 seconds to move between two adjacent tracks or lanes and 15 seconds to move between two adjacent slots that belong to the same track or lane. The time for each loaded crane movement (that is, when the crane actually moves a unit) includes the time needed to pick up and drop the unit. Picking up or dropping a unit takes 1 minute. Also, arrival and departure times for trucks and trains decide a time window for each loaded movement (the earliest and latest possible time to do it). Finally, a loaded movement might have a predecessor, that is, a movement that must be done before it. If a unit is to be loaded onto a train, a unit that is to be unloaded from the same location on the train is its predecessor. Also, for a container that is moved twice (to and from temporary storage), the first movement is the predecessor of the second.

3.2.5.5 Rolling Planning

The model has been evaluated in a basic rolling planning context. Before the crane schedule for a certain planning period has been constructed, we don’t know how much time it will actually take to execute it. Therefore, we decide approximately how long we wish a planning period to be, estimate the maximal number of units the crane can move during that time, and select at least that number of units among the ones that will be available during the period (considering their time windows). We believe that it is reasonable to have a planning period of 90 minutes (yellow in Figure 3-13), where the first 60 minutes (dark and light green) is the part to execute and the remaining 30 minutes are a look-ahead into the expected future. The first 15 minutes of the part to execute are inherited from the previous plan (dark green). The information about planned arrivals and departures during the next 90 minutes (after the time needed for the planning) should be reasonably reliable, and always having a plan for at least the next 15 minutes (corresponding to the part inherited by the next plan) should be enough for the crane operators to be in control of the situation, even if they are not used to being aided by a decision support system.
Considering that a crane can at most move approximately 20 units per hour, a planning period of 90 minutes corresponds to moving at most 30 units. The number of units per period is thus considerably smaller than in the larger problems in Section 3.2.3, something which decreases the risk that a very long time will be needed to find a good solution for some planning period. We let each planning period include all known units that have not yet been moved and whose latest possible move time is within 90 minutes from the start of the planning period. If this results in a set of less than 30 units, we select more units among the ones that are available at the terminal within 90 minutes, until we have 30 units or there are no more units available. If a too large number of units must be moved within a certain time (due to their latest possible move time), it might be impossible to find a plan for the corresponding planning period, and some automatic or manual procedure would have to select which units to delay. Currently, we assume that such situations will not arise. Further, we assume that the units that are scheduled to be moved within the first 60 minutes (the part to execute) will actually be moved, that is, that no delays in the arrivals of trains and trucks will occur during that period. If this turns out to be unrealistic, the part to execute could be shortened to make the forecasted arrival times more reliable, or we could drop the assumption and move delayed units to some planning period that begins after the current part to execute.

Planning (light blue in Figure 3-13) begins 15 minutes before the start of the execution of each planning period. This should generally provide enough time to find a sufficiently good plan for the period (see the evaluation in Section 3.2.5.7). In case it takes more time than expected to find a plan of sufficient quality, we can accept temporarily having a plan for less than 15 minutes and use the part inherited from the previous plan as extra buffer time to complete the planning.

### 3.2.5.6 Objective and Constraints

For each planning period, the objective of the optimization is to find a schedule that finishes the process of moving the chosen set of units as soon as possible. In order to make the optimization process faster, it is decided before the optimization starts which unit will be moved first and which unit will be moved last. The idea is that the first unit to move should be an urgent one, so the decision is based on the time windows of the units. Also, the first unit must have no predecessor. Similarly, the last unit should be a non-urgent one and cannot be the predecessor of any unit.

As mentioned, the crane scheduling problem studied here is an instance of the travelling salesman problem, which has been widely studied in the literature. However, our problem is not a basic travelling salesman problem, but is in five ways a specialized version:
The problem is asymmetric, that is, moving unit A and then moving the crane to the start position of unit B does not necessarily require the same amount of time as moving unit B and then moving the crane to the start position of unit A.

- There can be predecessor relations between movements.
- There are time windows for the movements, defined by the earliest and latest possible move times.
- The problem is open, that is, the crane does not need to return to the starting point
- The first movement and the last movement are decided before the problem is solved.

These specializations have also been studied in the literature (see, for example, Ascheuer et al. 1999, Čičková et al. 2013, and O’Neil and Hoffman 2018). The optimization model that we have implemented to solve the problem is based on another idea than the one described in Section 3.2.2. The model uses binary variables $Y_{ij}$ indicating whether movement $i$ is performed before (but not necessarily immediately before) movement $j$ or not. This idea has, for example, been used previously by Sarin et al. 2005. For each movement $i$ there is also a variable $t_i$ indicating the point in time when the movement is to be performed. Solving the problem using our model means finding values for all $Y_{ij}$ and $t_i$ while minimizing $t_n$ (the point in time when the last unit is moved) and fulfilling the following constraints, expressed using the $Y_{ij}$ and $t_i$ variables:

- No movement is performed before the decided first movement.
- The decided last movement is performed after all other movements.
- All other predecessor relations are respected.
- If movement $i$ is performed at some point in time before movement $j$, the distance in time between movement $i$ and movement $j$ is at least the minimum distance in time for performing $i$ immediately before $j$.
- If movement $i$ is performed before movement $j$, movement $j$ is not performed before movement $i$.
- Each movement is performed within its time window.
- If any movements are done during the part inherited from the previous planning period, the last of these movements becomes the first in the current problem, and it is performed at the previously decided point in time.

A solution to this problem\textsuperscript{12} thus indicates when each movement is to be performed, and using the solution and information saved when the problem is generated, the corresponding parking slot for each truck can be calculated.

### 3.2.5.7 Evaluation

The model has been evaluated on historical data that concern trains from different days at the terminal in Årsta. The historical data do not contain information about the composition of the trains (that is, where on the trains the units were placed), so the order in which the units were unloaded and loaded has been used as the basis for an assumed composition. In order to make the problem harder and put pressure on the model, the trains have been duplicated, moved and compressed in time in such a way that all the tracks of the terminal are mostly occupied by the resulting eight trains during an imaginary day. The time windows for the crane movements are based on real arrival and departure times for trucks and trains (with some adjustments when times were unavailable or made the problem infeasible).

\textsuperscript{12} This formulation of the problem makes it a job-shop scheduling problem for one machine with setup times
When rolling planning according to Section 3.2.5.5 is applied to these data, we get 46 planning periods, excluding periods that contain only one unit to move. The solving times (using the same computer as in Section 3.2.3) for all 20 planning periods that contain more than 10 units are shown in Figure 3-14, where the number of units in each planning period is indicated on the x axis. As expected, the solving times generally increase with the number of units. When there are 27 units or more per planning period, we generally use the allocated 15 minutes (900 seconds) without finding a solution proven to be optimal.

However, some solution is found for every planning period – it always takes significantly less than a second to find a first solution – and the time needed to execute the best of the found crane schedules is always rather close to the proven lower bound. To be more exact, the gap between the best solution and the lower bound is at most 7.4 percent of the solution, and in many cases much smaller than that. It is likely that there are problem instances that would result in a larger gap, but it should generally be possible to find good crane schedules in reasonable time. Thus, the evaluation suggests that our optimization model and rolling planning strategy should be practically useful in a real-time decision support system.

Figure 3-14. Solving times in seconds for 20 planning periods (number of units in each period indicated on the x axis)
4 Roll-out and implementation plan for selected terminals

In this section an indicative roll-out and implementation plan for potential terminal sites are presented. The plan is based on previous tasks carried out in the project and takes into account necessary administrative permissions, construction requirements and business impact on the local pilot sites and terminal processes as well as the stakeholders and their responsibilities.

However, further work is going to be developed and deployed in the future project FR8RAIL III within the Shift2Rail initiative, where the requirements for the IVG concept in an intermodal terminal will be retrieved from the FR8HUB project and compared to the requirements for an IVG in a yard. Similarities and differences will be explored and presented. A concept for prototype demonstrator (technical specification: number of cameras, location and type of cameras; etc.) will be developed and based on the developed demonstrator concept at least one IVG will be installed in an intermodal terminal in Sweden and one installed in a shunting yard in Germany. Moreover, further functionalities not included in FR8HUB will be explored in FR8RAIL III regarding automation possibilities of processes in yards and terminals e.g. brake test and damage detection.

4.1 Administrative preparation, permissions for selected sites

In order to find and evaluate proper IVG sites there are several aspects to consider. First there is the logistical aspect, to find the best location for track and trace wagons, containers etc. A second aspect regards if the site/location is valid based on local regulations as well governmental demands. As a third aspect possibility to practical installation with power and communication facilities as well as access to in-house installations for main computing and data storage has to be fulfilled.

In Sweden, a number of potential sites for pilot installations have been investigated: Malmö intermodal terminal, with an installation just outside the terminal on land owned by Trafikverket; Katrineholm intermodal terminal with installation at the terminal area and a single track for in/out access; the Port of Gothenburg, with an site installation at Kville, a location at Trafikverket’s infrastructure; Årsta intermodal terminal with an already installed Video Gate could also be of interest with some complement at the installation.

The most likely site for a pilot seems to be Malmö intermodal terminal with a single track for in and out band traffic. At the site there is plenty of space for the installation and there is already an RFID reader installed that might be used. In addition to this it is close to the terminal server installations, thus makes it easy to connect the gate to the server inside the terminal with a fiber cable or by radio link. The owner of the terminal in Malmö is Jernhusen and operates by Mertz Transport AB. Both parties are positive to a pilot installation with the possibilities to keep track of wagons and containers in and out of the terminal.

When final location is decided a more detailed “on site” preparation has to be done to secure details as power connections, installation demands etc. with a local approved/certified installation team. Certified axel sensors are to be used for installation at the track.

4.2 Construction requirements for selected sites

Based on construction requirements, the expected workflow results of identification and data matching, the different scenarios of local conditions need to be considered. The draft corresponds to general minimum distances in construction works near/at railways including gauge guidelines,
emagnetic impact guidelines etc. in order to avoid heavy tests for homologation and interference with other infrastructures or rolling stock.

One single camera can get a high definition picture of the entire side of a wagon. The image definition is enough to detect load unit code as well as UIC-wagon code, the UIC code will also be detected by the RFID reader, it will be a complement to each other. The camera detection if there is no RFID tag on the vehicle. Depending on the environment then light panels should be dimensioned.

If damages detection is required, a 3D system should be the better solution. As described in first deliverable this function should be carried out using laser scanners (or calibrated cameras for 3D pictures).

The realization of data and image acquisition from both sides of the train to get full coverage of the digital twin would demand at least more hardware costs and a higher effort for software implementation and algorithms with more options for automatic decision making in case of differences. Full data collection on both sides of the train surely leads to more precise results and higher reliability of data. Assumed the left side of the train for reading was 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. For this reason, terminal operators should give priority to implement either secondary control staff or to spend more investment and adjustment in double-sided identification systems to get better data quality. In scenario 1 and 2 reasonable quality of wagon and load units are assumed and necessary. The organizational requirement to all partners in the transport chain for good quality in rail transport “right from the start” is that only such equipment is used and allowed for transport and transshipment which is clearly approved and can be identified with high level of certainty. So, the image cameras on the right side are just for documentation of potential damages to complete the views onto the train.

If shunting is done through the gate, i.e. wagons passes several times in random pace, the solution described in Deliverable 4.1 and continued here will not work. This also applies when the train goes very slow, stops or restarts. Minimum speed should be above 15 km/h.

In case of uneven speed, it will be handled by the system as long as the train remains above 15 km/h or 20 km/h which will be even better.

The RFID tag reading will work in 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.

**Scenario 1: Single track – gate**

![Diagram of single track gate](image)

Scenario 1 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 on the left side are for image acquisition for later number checks and damage documentation. The RFID-antenna unit is responsible for collection of RFID-Tag-data of the wagon.

**Scenario 2: Double track – gate**

For double track operations several additional aspects need to be considered. Cases 2a (single track operation) and 2b (parallel track operation) will cover the most common operations in a double track situation. Different to the pure single track more than just one train could pass through the double track gate and locally on a different track. In case of limited space between two tracks in the railway infrastructure a double track gate could be necessary to solve the problem, otherwise separate gates on each track would be preferable to handle data.

Scenario 2a considers a double track situation running just one train on either left or right trackside. The IVG spans these two tracks and the gate components cover the suitable nearest long-side of the train. In case of track 1-operations the identifying components cover the left side for number recognition and image acquisition, the cameras on the opposite side cover the damage...
documentation as there is open field of view to focus on the passing vehicles on track 1. In case of a single track 2-operation in the same way the right side of the identifying components handle the process of data acquisition as in the way before. For this reason, an exact ID-stamp of the components is necessary to link with the data set of the relevant track correctly.

![Diagram of double track with single train operation](image)

**Figure 4-2. Scenario 2a, double track with single train operation.**

Scenario 2b considers a double track situation running two trains at the same time through the gate. The IVG spans these two tracks and the gate components cover the suitable nearest long-side of the train.

In case of parallel operation, the identifying components cover the left side for number recognition and image acquisition of the train on track 1. The identifying components on the right side cover the passing vehicles of the train 2 on track 2. For this reason, an exact ID-stamp of the components is necessary to link with the data set of the relevant track correctly.

Depending on the roof camera positions and their ability to cover and focus on the space between the two trains the quality of the images during the passage could suffer because of interference. In cases of intermodal terminals like DUSS-Terminals Hamburg-Billwerder, Cologne Eifeltor or Munich-Riem (each of them operates 3 crane runways) parallel train operation on the connection tracks is not unusual. Therefore, terminal operators should concentrate on either equip and adjust camera positions optimally for damage documentation or take care with operational measures and infrastructure managers that scenario 2a (with single train operation) is the optimal process to avoid bad images.
4.2.1 Common requirements

The installation of the IVG needs about 60-80 meter 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 sensors in relation to the “camera” is depending on the actual train speed at the site, see example in Figure 4-4.

The wayside IVG components, such as cameras and scanners, should be placed approximately 3 meters from the rail, mainly due to EMC regulations as well as optical characteristics and local regulations in each country, see example in Figure 4-5. For the physical site installation it is important to be stable and robust to avoid mechanical vibrations produced by the running trains producing blurred images.
4.2.2 Construction requirements

Recommendation from earlier installations are to use some kind of “total suppliers” for the installation, set up and fine tuning to get optimal performance of the complete IVG.

Optical fibre is recommended for communication cabling or a radio link if more convenient for installation purpose. When feasible also 5G will be tested as communication link.

The vibration sensitivity of the cameras is different depending of the train velocity when passing through the gate. At low speed < 25 km/h a stable enough pole/installation should be sufficient but in higher speed there is need for more stable construction.

Normally a minimum distance of 3 meters from the track (rail head) is enough mainly due to optics characteristics and EMC and vibration standards. This is independent from train speed. Anyway all equipment has to go through less restrictive EMC type tests and through climatic type tests depending on installation environmental zone, i.e. installations in Italy will have different climatic test parameters setup then those in Sweden.

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 better checked.

4.2.3 Maintenance and Life Cycle Support

Traditional maintenance is to be performed for this kind of installations, mainly belonging to one of the following types:

- Preventive maintenance
- On demand
- Predictive, if an Intelligent Asset Maintenance System (IAMS) is used

Preventive maintenance defines the list of activities to be periodically handled by maintenance teams to avoid IVG degrading over time up to an unacceptable level. For each preventive activity, a series of checks and actions to be performed is defined together with recommended frequency. Some specific examples are monthly (based on local needs) cleaning of the illuminators and camera lenses as well as scanner calibration every 6 months or 1 year. Checks of wayside and on track
sensors, as well as all power supply and server equipment have normally to be done once a year. This kind of activities in normally performed by terminal or line owner/maintainer.

On Demand maintenance requires interventions when something goes in a fault state in the IVG system, for example a camera is broken, a server is missing power supply, a wheel sensor breaks, etc. The definition of Least Replaceable Units is necessary as well as a certain number of spare parts to be kept in warehouse for fast replacement. The first intervention is always performed by the stakeholder in charge of the terminal maintenance, probably the terminal owner, to check if the problem is rapidly solved. Otherwise a more technical second of third level intervention is necessary for the entity in charge of IVG maintenance. There is need for a maintenance contract with the IVG supplier or another specialized entity that can take care of it.

If an Intelligent Asset Maintenance System is used for the terminal or the railway line, this could be also used for the IVG system. In this case all diagnostics and data coming from the IVG will flow through the IAMS providing to the terminal or line operator a single maintenance interface. The data could be then used for modifying normal scheduling of preventive activities to guarantee best time for intervention and to reduce the number of on demand activities and IVG downtimes.

Normally the system should be guaranteed to work for a period of 10 to 20 years, taking care from the supplier to handle configuration management and obsolescence management.

Configuration management requires that all system components, including hardware and software, have to be traced together with their models, serial numbers/versions. Software modules and libraries have to be stored in a software repository version control software, for example subversions or Rational Team Concert. For hardware components the same tools could be used, by even simpler ones, such as excel sheets, could be sufficient. Every time a system update is performed in field, software or hardware one, this has to be traced by the configuration management process, in order to be always possible to define the full system configuration at any point in time.

Obsolescence Management, similarly to Configuration Management, requires the definition of the whole system configuration. The difference is that in this case a more detailed analysis is performed aiming to define the system critical components and their presence in the market in the next 10 to 20 years. This is very important to avoid system fail due to a failing component that does not have a proper substitute in the market as well as huge expenses for whole system modifications or ad hoc component production. Common practices are the definition of alternative components from the point of view of functional, mechanical, electrical and other characteristics or the procurement of stock components.

Temperature and other environmental issues have to be considered due to local demands, cold winters in north of Europe and hot summers in south of Europe etc. Rain, snow, sunshine etc. are other aspects that can influence the functionality and has to be taken care of.

### 4.3 Real life application of the IVG concept

This section has the objective of better describing the site where the camera pre-selected components have been tested (see section 0) and of providing a commercial example of an existing Gate focused on image (and other types of sensors) acquisition capabilities. Most of the construction and maintenance requirements better described in section 4.2 have been borrowed by this system, with a special focus on best practices. Follows a short description of the TCCS system.
Hitachi Rail STS TCCS™ (Train Conformity Check System) is a system that aims to automatically detect "anomalous situations" of rolling stock in transit. In the last years several system installations have been made in Italy, but also outside of Europe. In particular, the Carbonara Scrivia site in North Italy has been used for the testing of the two camera components of the IVG.

The TCCS™ performs verification functions on the trains passing through the "Measurement Zone", where the acquisition and control devices are present, for both the tracks and in both directions. It is however possible to configure the TCCS™ to operate only partially (mono-directional / bidirectional). The TCCS™ signals any anomalous conditions to the Operators present at the "Control Centre" so that they can take the necessary actions. The system is also set up to send alarms to signalling in order to automatically stop the train.

TCCS™ proprietary core includes:

- a “tracking subsystem”,
- full 3D profile scan of rolling stock surface,
- full thermographic scan,
- high-resolution image capturing system,
- Human Machine Interface -HMI- to remotely manage in the OCC the alarms, train data and diagnostics information.

The three components highlighted above are key elements to the correct acquisition of train images according to a possible (not the only one) IVG solution provided by this work package. The wagon, ILU and dangerous goods correct recognition could build on these technologies as well as the overall Terminal IVG operation.

In particular, The TCCS™ detects high-resolution images by high-definition linear black and white cameras. The current camera model is also considered in deliverable 4.1 as one of the most recommendable components for the IVG, but due to obsolescence issues has been substituted by another one, defined and tested in section 0. The image acquisition and pre-elaboration process is composed of the following steps:

- Acquisition of vertical linear frames of the transiting train at a constant acquisition rate;
- Use position and displacement information from the appropriate functions for the correct creation of 2D images. Vertical frames are put together side by side and the image is correctly re-proportioned to compensate for over-sampling and possible variations in speed.
- Use the information related to the train decomposition in individual rolling stock to isolate the part of the image corresponding to each individual rolling stock.
- Use the information related to the type of each single rolling stock to select the reference map defining the areas of interest for each type of rolling stock.

The system operates both day and night, using a solid-state NIR (quasi-infrared) illumination, which avoids any disturbance to drivers, being almost invisible to the human eye.

The high-resolution images (Figure 4-6) are used by remote Operators to check the generated alarms, without the need to stop the trains for further verification. Images are stored for online and off-line use.

The high-resolution image production subsystem is able to generate a very high resolution image of approximately 70 MB for each wagon. Lower quality images are produced for the user interface, still being of very good quality for the human eye, to allow fast visualization.
To ensure correct functionality and measurement each camera produces a set of diagnostic data. These data are monitored by the TCCS™ in order to generate self-diagnostics and to ensure the correct functioning.

Currently, the acquired images have also been tested with the image processing capabilities of the IVG system described in chapter 2 with very good results. For examples in all cases when the UIC code was visible on the image it could be recognized by OCR software. Failure to correctly detect the code was mainly due to missing, hidden or low quality codes at vehicle sides.

4.4 Implementation Aspects for Potential Sites

In this section implementation aspects of potential sites are explored. However, as stated in the introduction of this chapter, further work is going to be developed and deployed in the future project FR8RAIL III within the Shift2Rail initiative. There the requirements for the IVG concept in an intermodal terminal will be retrieved from the FR8HUB project and compared to the requirements for an IVG in a yard, and similarities and differences will be explored and presented.

4.4.1 Port of Gothenburg

4.4.1.1 Current situation

During the past 15 years, the Port of Gothenburg has built up an effective system for daily transport of cargo carriers and wagons between the port and inland terminals in Sweden and Norway, as illustrated by Figure 4-7. Approximately 20 inland terminals are connected to the Gothenburg port system. The terminals offer a wide range of services, such as customs, storage and landfill, adapted to customer needs. There are also routes for conventional freight wagons as shown in Figure 4-7, where tailor-made railway services are offered for e.g. timber, paper, steel and other products. (Railport, 2018)
At present, there are several terminals inside the harbor area; where the Port of Gothenburg is the infrastructure owner who interacts with the terminal operators. As can be seen, there are currently six railway-connected terminal operators inside the port area if one disregards Volvo’s area just north of the harbor area. Several of these operators have already acquired or will soon acquire cameras at the gates of their respective area, in order to use for damage claim purposes. The operators’ gates are constructed in line with scenario 1 (see chapter 4.2) thus covering the single track connections to the terminal.

Figure 4-7. Intermodal nodes that are connected to intermodal terminals from Gothenburg (left) and nodes for conventional cargo loading traffic (right). (Railport, 2018)

Figure 4-8. Terminal operators in the Port of Gothenburg (Railport, 2018)
Figure 4-9 shows the Port of Gothenburg and adjacent railway lines. Figure 4-10 shows speed limits there.

Figure 4-9. The Port of Gothenburg and adjacent railway lines (OpenRailwayMap, 2019)

Figure 4-10. Speed limits in the Port of Gothenburg and adjacent railway lines (OpenRailwayMap, 2019)

4.4.1.2 Proposal

During interviews with representatives from the Port of Gothenburg and terminal operators there, it has emerged that two operators have installed their own cameras at their respective borders and more are about to acquire this. An alternative that then emerged is that the intelligent video gate could be located on the harbor track at Kville freight yard which is shown in Figure 4-11. The gate’s location would then enable identification of freight trains adjacent to the yard in Kville but avoid the passenger trains on the Bohusbanan (yellow line in Figure 4-11).
Figure 4-11. Suggestion for placement of an "Intelligent video gate". (OpenRailwayMap, 2019)

Figure 4-12. Suggestion for placement of an "Intelligent video gate". (OpenRailwayMap, 2019)
As illustrated by Figure 4-13 the proposed gate should be constructed in line with scenario 1 (see chapter 4.3) thus covering a single track connection to the terminal.

An IVG at Kville would have limited usage for handling damage claims since the distance to the port area corresponds to a transport time of about 30 minutes. On the other hand, benefits related to deviation handling and better conditions for operational processes can be achieved. In the case of advance information of about 30 minutes before arrival at the terminal area, operators can begin their work in advance and be better prepared when wagons and cargo carriers arrive.

However, regarding handling damage claims it would be ideal if the IVG is located in direct connection with the terminal operator’s area, where the responsibility for goods and vehicles change. The terminal operator APM has its own VG at its terminal limit. For operators in the port that do not have their own cameras, a facility at Kville would be an asset to some extent also for damage claim purposes.

An IVG at Kville can also streamline the information management for the port’s intermodal rail shuttles (Figure 4-7) the best effect is achieved if an IVG is available at each end. This efficiency improvement can also be achieved for the information interface against maritime flows.

Regarding the business model and the cost distribution of a gate, a possible solution may be that Gothenburg’s port as infrastructure owner for the port area pays for the service to the Swedish Transport Administration, if the Swedish Transport Administration accounts for the investment cost, and the port in turn pays for the service and charges the operators who use the street. Further investigation is required to investigate further alternatives and to determine the legal and business aspects of a suitable business model.

4.4.2 Malmö Intermodal Terminal

Figure 4-14 shows the design of the Malmö intermodal terminal and proposals for where IVGs for trains and trucks can be installed. Installation of the IVG for trains is possible and a suitable location...
is available at the connection track to the terminal. The IVGs should be constructed in line with scenario 1 (see chapter 4.2) thus covering the single track connections to the terminal. One aspect that on the other hand requires further research is whether an IVG for trucks is a possible solution, this is because of the very short road up to the present gate (Containergatan). If an IVG for trucks was installed, the concern of the terminal operator is that queuing can be generated due to the check-in routines they have for the terminal. The queue formation would then have a very poor effect on surrounding traffic if it spread to the adjacent connection path (Västkustvägen).

![Figure 4-14. Possible placements of IVGs at Malmö intermodal terminal.](image)

### 4.4.2.1 Selection of site

Malmö intermodal terminal has been chosen for the site selection evaluation and is also the basis for a Master thesis at KTH Royal Institute of Technology produced by Branko Mitrovic, from where most of the analysis of the terminal in this section is retrieved. The reason behind the selection of this intermodal terminal is that it has a large amount of operations within Sweden and continental Europe as well. Malmö intermodal terminal is stationed in southern part of Sweden, in the city of Malmö. The terminal is positioned next to the Malmö marshalling yard, which provides them a big advantage in shunting operations. It has been renovated in 2018 and equipped with two Rail-mounted Gantry cranes. Before renovation, transshipment was done by reach stackers. Improvement in transshipment technology allowed terminal to increase operations by 75%. The terminal is operated by company Mertz Transport AB, which operates the terminal since 2013. It is considered as one of the most modern terminals in Sweden. The owner of the terminal is the state
own company Jernhusen AB. Shunting operations in terminal are performed by Mertz Transport AB as well, since this company acquired license and became rail operator in 2017.

### 4.4.2.2 Data collection

Data collection has been performed on the site, during the visit to the Malmö intermodal terminal. This kind of a data is not very easy to get access to and is obtained by the interview with the Mertz AB Terminal Manager. The interview has included information about terminal history, design and operations. Some data collection is collected in the interview with one of the terminal crane operators as well. Technical specification of Malmö intermodal terminal is given in Table 4-1:

<table>
<thead>
<tr>
<th>Table 4-1. Technical specification of Malmö Intermodal terminal</th>
</tr>
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<tbody>
<tr>
<td>1. 4 rail transshipment tracks</td>
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<tr>
<td>2. 2 RMG cranes</td>
</tr>
<tr>
<td>3. 1 cross-dock facility</td>
</tr>
<tr>
<td>4. 2 truck transshipment lanes</td>
</tr>
<tr>
<td>5. Connection to the main rail line from both sides</td>
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<tr>
<td>6. One connection to the main road for trucks</td>
</tr>
<tr>
<td>7. Inspection and registration area available upon arrival to the terminal for the trucks</td>
</tr>
<tr>
<td>8. Truck parking area available next to the rail transshipment trucks</td>
</tr>
</tbody>
</table>

Figure 4-15 below shows how Malmö Intermodal terminal transshipment area is designed.
The longest rail transshipment track is 800 meters. However, not all 800 meters are used for transshipment operations. RMG crane longitudinal serving area is 660 meters, while lateral serving area is around 30 meters, which means that crane can serve all transshipment tracks and truck lanes, but also parking for semi-trailers. Terminal is operated by 2 cranes, which are both RMG cranes, produces by Kuenz GmbH (Figure 4-16).

Both RMG cranes are operated by crane operators, which are positioned in the crane cabin. Crane operators are assisted by the cameras, which allow them to have a better view of ITUs in transshipment process. Beside cameras, crane cabin is equipped by Hogia Terminal Mobile software, which helps drivers to know more information about ITUs. This software gives the information about LU number, type of operation, LU state (loaded or empty), tonnage, owner, etc. Figure 4-17 below shows cameras and software installed inside of crane cabin. Figure 4-17 also illustrates the task of the crane operator, who has a list of LU’s and their sequence on the train that they have to check for deviation manually by observing the registration numbers of the units. 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 transhipment as the crane operator do not have to carry out the deviation control.
4.4.2.3 Simulation and simulation results

Simulation of Malmö Intermodal terminal is performed in Planimate software, developed by InterDynamics. This software is chosen because its features suits well the purpose of case study. Addition to this, this is a freeware software, which made it much easier to develop the simulation model. It enables the creation of highly interactive and animated tools for a wide range of dynamic systems, including transportation and logistics networks. Planimate® allows the simulation of a process as a set of discrete events, in series or in parallel, by means of hierarchical networks (Baldassarra et al., 2010). Moreover, the model permits to quantify the effects of possible implementations of new technologies or operational measures (Ricci et al., 2016). The programme principle is based on graphical programming where different object (e.g. terminal entrance, transshipment tracks, parking area) are connected along the network. Different items are sent from one object to another, by connecting them. These items could be ITUs, trains, trucks etc.

Simulation model is built based on intermodal terminal operations and data provided for Malmö Intermodal terminal and from some previous research to the similar topic as well. Model is built based on following assumptions:

1. Operations that are simulated are in situation where loaded train arrives to the intermodal terminal,

2. Check-in procedures including all inspections are set to be 50 minutes

3. Transshipment operations are only in-direct (from train to parking), as there was no information or any specific rule about percentage of direct and in-direct transshipments. This could be solved by applying some of statistical distributions as well,

4. Transshipment operations are set to be 3 minutes per one transshipment operation

5. Truck check-in procedure is set to be 10 minutes, with the inter-arrival time between trucks normally distributed,

6. Simulation is performed for track length of 660 meters, as that is maximum crane serving area in Malmö Intermodal terminal. Assumption is that no split-up activities occur in simulation, even if this happens sometimes in the terminal.

Two scenarios are compared to show how the system changes when certain processes are automated. First scenario is without IVG considered in terminal operations, while another scenario is with IVG included in terminal operation. Three different times are measured to show how different parts of system reacts on IVG implementation.

Figure 4-18 shows the total transit time that ITU spend from arriving to the terminal with the train until leaving the terminal with the truck. Results have shown that total transit time with IVG implemented in terminal is shorter than the total transit time without IVG in the system. In fact, results have shown that total transit time with IVG is almost 2 hours shorter than the operation without IVG. Results could be different if the truck arrival is differently distributed, but in ideal situation (where IVG project stream for), this would be the case. What needs to be considered here is that operations are performed on single train arrival.
Figure 4-19 shows the results of total transshipment time of ITU from train to parking area, in case where loaded semi-trailers are transhipped from the train to the parking with the cranes. This figure shows also that there are time savings with the IVG implemented. In this case, only crane operations are considered as an improvement in processes. As here is not the case of crane optimization processes, but improvements in regular operations, time saving are not much higher, but are still considered as valuable. This situation is also considered as an ideal process, where crane operations are simultaneous, with no any obstacles during the work.

Figure 4-20 shows the comparison of truck pick-up time in case of technology improvement and current situation. This figure shows considerably high time saving with IVG implemented, due to lower time for truck check-in procedures. This result shows the time from truck check-in until truck leave the terminal. In this case it has been also considered that both cranes are working simultaneously on lifting operation, but after they have finished transshipment operations from train to the parking area.
Train check-in activities are not included in comparison, as their time is already known. Different times are used for simulation without and with IVG. However, reducing train check-in activities is one of the main goals of IVG project. The results have shown that implementing IVG would give considerably time savings. This means that terminal can increase its own productivity. For instance, reduced total transit time for one ITU could lead to increase in productivity up to 30%, based on given results. Also, implementing IVG technology could lead to reducing staff, better terminal operation etc.

4.4.3 Eskilstuna Intermodal Terminal

Eskilstuna intermodal terminal has four 750 meters electric train tracks for transhipment. The terminal is operated by Eskilstuna Logistik & Etablering AB, which is a municipal-owned company. The terminal has a capacity of 300,000 TEU/year and a terminal area of 83,000 square meters.

Each week, a total of 10 trains arrive to Eskilstuna intermodal terminal. In total, the terminal handles 75,000 TEU per year. The terminal handles both trailers and containers. Two reach stackers are used for handling the load units. The terminal is open Monday to Friday 05.30 - 21.00 and is open on weekends if required (if a train arrives).

Today the terminal has an automated gate for entry and exit by road. The gate photographs and records the entry and exit of each truck and container/trailer. For load units arriving or leaving the terminal on train only an ocular inspection is made. The automated gate reads the vehicle registration plate. Only pre-announced vehicles may enter the terminal.

Two rail gates in line with the concept of the IVG could be installed at each entrance to terminal and they should be constructed in line with scenario 1 (see chapter 4.3) thus covering a single track connection to the terminal.

![Eskilstuna intermodal terminal with four tracks for transhipment.](image)
4.4.4 Katrineholm’s Logistics Centre

The Katrineholm’s logistics centre is located approximately 140 km southwest of Stockholm, at the intersection between the west and the south mainline. It contains a multimodal terminal for rail and road transport, the north terminal, which offers a total of 65,000 square meters of available loading area and four electric train tracks for trains up to 750 meters long. The south terminal handles wagons and piece and has 20,000 square meters of available loading area and electric track for trains up to 650 meters.

The terminals opened in 2010-2011 and managed by Katrineholm Rail Point AB. Catena Fastigheter AB and the municipality of Katrineholm own the logistics centre. Van Dieren operates on the North terminal daily Monday-Saturday with train from Duisburg in Germany. Reach stackers are used for handling the load units.

A rail gate in line with the concept of the IVG could be installed at proposed location illustrated by Figure 4-22 at the entrance to terminal and it should be constructed in line with scenario 1 (see chapter 4.3) thus covering a single track connection to the terminal.

Figure 4-22. Katrineholm’s logistics centre with potential gate location (Google Earth, 2019, OpenRailwayMap, 2019)
4.4.5 DUSS-Terminal Cologne Eifeltor

The terminal is located in the center of North Rhein Westphalia and belongs to the biggest intermodal terminals in Europe. It is one of the terminals located at the freight corridor 3 connecting Scandinavia and Italy and would provide direct intermodal traffic from and to Sweden. The terminal consists of 3 crane modules and has several connection tracks from and to the terminal. The terminal itself has 12 transshipment tracks. The main connecting tracks between the shunting yard Eifeltor and the intermodal terminal run under the bridge of the motorway A4. The terminal is operated 24 hours per day and parallel track operation is necessary to exchange full trains and wagon groups.
Not considered the space that is needed to install an IVG with the requirements of this FR8HUB-Project a full coverage of the connecting tracks just from this side – even if reduced local space of the gate was conceivable - requires more than just one IVG. Basically, the minimum of two IVGs would be necessary. The first IVG in the layout of scenario 2b (see 4.3) would cover the inner tracks connecting Module 1 + Module 2/3 and the second IVG in the layout of scenario 1 (see 4.3) would cover the additional tracks for Module 1. Not in the scope is an IVG spanning 3 tracks. All tracks are electrified which means that electric wires need to be considered in detailed planning of the height and gauge.

4.5 Business Impacts

Implementation of the IVGs at rail terminals has a potential to improve the transferring of cargo within intermodal supply chains, with regards to efficiency in economics, sustainability and operations.

4.5.1 Expected changes on terminal operations

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. 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, see Figure 4-26. 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/ioL 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 changes 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.

In the next stage, after implementation of IVG and setup of data register, the terminal operator can start to use the information generated for planning smoother distribution flows of goods along supply chains. This is expected to enable more possibilities to collaborate with other actors and includes possibilities to start transshipment planning in advance. It is an important contribution to the development of Internet of Logistics (ioL). The access to ioL is through common (Internet-) infrastructure and it allows all stakeholders to plan activities globally.

The use of IVG, especially connected with ioL, can facilitate the development of harmonized regulations at international level, thus reduce the problems due to different or complicated (national and international) rules of transportation and admission requirements for load units that demand more than just checking the existence and correctness of an ILU- or BIC-Code. Problems related to
differences in transport and customer policies of train operators can also be reduced when using more similar data sets, especially in IoL.

**Improved information exchange along the supply chain**

![Diagram of Improved information exchange along the supply chain](image)

**Figure 4-26.** Improved information exchange along the supply chain by implementing IVGs. Data (orange box) that can be identified and benefits (pink box) that this can lead to.

Suggested measurable values for comparison before and after IVG implementation:

- lead time needed for the identification/verification process of train-sets (manually: a standard freight train-set, full length freight train, can take around 45 minutes to complete. IVG target: processing time down to 15 minutes per train)
- number of people at tracks/trains
- error rate during reading (example: on May 2018, after an initial learning phase, the accuracy of the OCR-recognition is about 96% of all cases. Cologne Eifeltor, Road gate)
- a 75% reduction of complaints and disputes for damages/losses with customers (example: for Cologne this would mean reducing from 12% of the total shipment volume that on average leads to the documentation of irregularities of load units, most of them on demand of the truck drivers when they take over the load unit and want to leave the terminal, down to 3%)
- reduction of the cost of compensation for terminal operators, such as DUSS
- increase terminal capacity/throughput by faster workflow and reduced dwell time for trains, trucks and ILU up to 15%
- accurate and appropriate maintenance inputs through IVG/IoL info, which leads to fewer infrastructure-related errors in the yard, which reduces errors by 10%.
4.5.2 Optimization potential of terminal and inter-terminal operations

Optimization potentials due to a considerable amount of digital information available to administration procedures and container handling operations at the terminal are related to activities within the own terminal, e.g. allow optimized scheduling of inbound trucks, as well as inter-terminal operations related to the delivery and pick-up of intermodal containers, thanks to increased visibility of container/train information to third parties. Examples of optimization potentials are:

- Suggest picking order/crane orders for truck drivers and crane drivers (see chapter 3.2 about scheduling crane movements)
- Sorting (fast, slow, dangerous) to different zones, handling
- Minimizing time at terminal, e.g. dangerous cargo, Time Sensitive Low Density High Value goods (TSLDHV)
- Minimizing drivers time at terminal
- Match with drivers schedule, i.e. report ETA and the load will be ready to load by then
- Offering possible time windows to drivers for loading and unloading (with possibility to book/change time in case of delays)
- Adjustment of departure time from terminal due to early finalizing of loading and if suitable with the traffic situation on tracks.

4.5.3 Expected changes in costs

Costs related to the implementation of an IVG are mainly focused to the initial costs for the gate’s physical construction and the IT-system needed. The terminal management system should be prepared for the communication with an IVG and will include updates in hardware (e.g. exchange server) and software (e.g. data exchange converter) as well as training for staff, software licenses, support costs and potential fees for using a common information-exchange platform.

- Purchasing of new hardware
- Estimation of cost for installation (can be based on installation of RFID readers or Cameras at Årsta)

Expected reduction in costs are initially related to less hours of manually inspections along trains during arrivals, and later on new opportunities for businesses and planning due to increased level of automatization and possibility for optimization. The business cost for an intermodal rail terminal can be describes as fixed and variable costs and a summary of expected changes in costs are shown in Table 4-2.

IVG-installation costs are connected to the administrative preparation, the equipment, the building of the gate, electric installation and connection to IT systems. Administrative costs are related to planning and potential permissions. Costs for IT-system are related to purchasing of new software and hardware, support during the installation and preparations of the local terminal management systems, in order to be able to communicate with IVG. The building and setting up of the IVG include costs for components related to the construction, the electrical installation and the data connection, cameras and RFID-readers and costs for workers.

Expected changes in fixed costs are mainly related to the IT systems are expected to increase due to licenses and fees for using a common information-exchange platform, or backbone, etc. Other fixed costs are not expected to change such as the costs for cranes and/or reachstackers, land area, fence, lighting poles, rail track(s), office/buildings, rail connection to the network and realisation costs (total infrastructure and pavement).
Variable costs expected to change include costs related to administration, employees, energy, insurances, maintenance, support for IT-systems and management/manager(s). There are no expected changes in variable costs regarding guards, interest, network fee for rail access, terminal licenses or taxes.

Table 4-2. Expected changes in costs for intermodal rail freight terminal connected to IVG implementation. Categorization of fixed and variable costs is based on terminal characteristics presented by Wiegmans and Behdani (2018).

<table>
<thead>
<tr>
<th>Costs</th>
<th>Expected changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVG-installation costs</td>
<td></td>
</tr>
<tr>
<td>Administration</td>
<td>- New costs related to administrative preparation: planning and potential permissions</td>
</tr>
<tr>
<td>Building and connection of the IVG</td>
<td>- New costs due to structural, technical and logical components related to the construction, electrical installation and data connection</td>
</tr>
<tr>
<td></td>
<td>- New costs due to the building and installation labour</td>
</tr>
<tr>
<td>Cameras</td>
<td>- New costs for purchasing and installing cameras</td>
</tr>
<tr>
<td>IT systems</td>
<td>- New costs for preparations of local terminal management systems, in order to be able to communicate with IVG. Due to protection against “data sniffer” there is a need of secured interfaces in terminal management systems, especially when handling dangerous cargo.</td>
</tr>
<tr>
<td></td>
<td>- New costs for purchasing new hardware and software</td>
</tr>
<tr>
<td></td>
<td>- New costs due to support during installation</td>
</tr>
<tr>
<td>RFID-readers</td>
<td>- New costs for purchasing and installing RFID-readers</td>
</tr>
<tr>
<td>Fixed costs</td>
<td>- Increased costs for new software (licenses, potential fees for using a common information-exchange platform, or backbone, etc.)</td>
</tr>
<tr>
<td>Variable costs</td>
<td></td>
</tr>
<tr>
<td>Administration and organizational costs</td>
<td>- Reduced costs associated with paper handling, fax or email messaging</td>
</tr>
<tr>
<td></td>
<td>- Reduced administrative cost of compliance and cost of dispute resolution with customers, as stakeholders would be able to handle all administrative tasks online instead of filling in paper documents.</td>
</tr>
<tr>
<td></td>
<td>- Increased costs due to training/reorganization of staff</td>
</tr>
<tr>
<td>Energy (mainly electricity and diesel)</td>
<td>- Decrease costs due to decreased amounts of energy needed per ton cargo.</td>
</tr>
<tr>
<td>Employees</td>
<td>- Reduced costs due to increased automatization</td>
</tr>
<tr>
<td></td>
<td>- Increased costs due to training/reorganization of staff are however expected.</td>
</tr>
<tr>
<td>Insurance (staff + cargo)</td>
<td>- Reduced costs due to decreased insurances due to safer work environment and more surveillance of incoming cargo</td>
</tr>
<tr>
<td>Maintenance</td>
<td>- Increased support costs related for IT-systems, cameras, RFID-readers</td>
</tr>
<tr>
<td>Management/manager(s)</td>
<td>- Reduced costs due to increased automatization</td>
</tr>
<tr>
<td></td>
<td>- Initially increased costs related to the determination of appropriate staff for the operation of the IVG.</td>
</tr>
</tbody>
</table>

Example for reduction of variable costs, increasing quality and higher environmental benefits:

Between 2018 and 2019 DUSS had implemented a complete digital workflow for the road-side check-in-procedure for 17 (out of 24) terminals, that had been carried out so far by manual paper documentation. By reducing these paper prints (1 page per load unit original + 1 copy page for the customer) for check-in, about 500.000 check protocols (thereof 30.000 for dangerous cargo) within 1,5 years have been saved in a short time (at the moment 2.500 protocols per day). This caused a saving of 1.000.000 printed pages. Each printed page had internal costs of at least 0,15 EUR, so the overall saving was about 150.000 EUR which enables a rather short amortization of the investment, led to a significant environmental contribution (no print, no paper), less administrative costs for archives, local search efforts in case of claims, higher employee and customer satisfaction, etc.
If this result is transferred to large terminals like Cologne Eifeltor, Munich or Malmö the impacts for the train operations will also be significant.

This example shows that a useful and effective digitalization of processes also on the railway side will lead to a measurable contribution to all focus areas.

4.6 Stakeholders and their responsibilities

To create a credible success story around the IVG the relevant partners (infrastructure managers, railway undertakings, terminal operators, but also Federal authorities) need to make clear and need to be reminded from time to time, what was/is the main goal to achieve.

The technological advantage of the IVG is to identify automatically, to use and to share the common visible (and therefore public) information on wagons and load units in an appropriate way. Therefore, the IVG-operation should be kept on an affordable level, in a well-balanced and co-operative way. The relevant use-cases focus on the main goal to enable existing and potential new customers to get easier access to the railway system in competition to the road market. It should not be used to produce an overkill demand or supply for information depth, data protection and a permanent pressure for finger-pointing and for shifting responsibilities and liabilities between the partners back and forth. This is worth mentioning, since digitalization as well as transparency issues have led to a lot of discussions and decisions of Highest Court of Justice that could be quoted for requirements of data protection, commercial protection of train compositions, used rolling stock, copy right for the use of brand logos on images, etc. but also to poke at good or bad conditions of wagons or load units of some certain (unruly) customers, etc.

For sure there are reasons enough to do so, but the more requirements have to be taken into account the more sophisticated, complex, inflexible and risky to be maintained become these IT systems. The IVG should simply help to make processes in the transport chain easier and more fluent and more reliable than today – this in direct cost competition to the road transport.

Therefore, infrastructure managers need to provide organizational support for IVG-installation and access to maintenance as far as relevant to avoid delays in operational availability of the IVG.

Terminal operators, RUs, intermodal train operators and infrastructure managers should ensure a reasonable data sharing and service level agreement to run rail traffic more efficiently.

Federal authorities should focus on welcoming and embracing of new technologies in the market.
5 Conclusion and Recommendations

Chapter 2 describes in detail the developments that have been carried out to produce a proof of concept for the IVG. To test the functionalities of the logical modules, software and algorithms, the approach followed was to use a train model as the physical input to the system in a laboratory environment. For this phase, specific technical components were selected to acquire the images and RFID signals of the train model. To detect the ILU, UIC codes, algorithms were developed using licensed OCR engines; to detect the dangerous cargo signs, a computer vision method was followed. Twelve cases were carried out to test the system, demonstrating its capabilities to detect, classify, show and compare the information of the train models passing through the IVG, as well as the correct performance of all the interfaces, software and algorithms developed. The image processing functionalities developed were also tested with real images obtained on-site with two different cameras, which also provided successful results in the detection and identification of ILU and UIC codes, as well as different dangerous cargo signs. An early comparison of the two cameras used revealed that the one selected in D4.1 to be tested showed a lower sensibility than the previously installed camera. The images produced in the test environment however are of such good quality and therefore useful for unprioritized damage research and claim support.

As we have shown in Section 3.2, it is possible to use optimization methods and rolling planning to schedule crane movements at a terminal, achieving high-quality schedules within reasonable time. We created crane schedules for periods that were 90 minutes long, and could generally produce optimal or close to optimal schedules by running the optimization process for 15 minutes. This indicates that it is possible to implement a practically useful decision support system that can do crane scheduling for terminals. Such a system would base its schedules on information from both IVGs (at the terminal for which planning is done, at other terminals and along the routes of the trains) and the terminal operating system used at the terminal.

Chapter 4 has introduced an implementation plan for potential sites in Sweden and Germany. The main aspects considered are categorized as administrative preparation, construction requirements and stakeholders involved. After the presentation of the potential sites in chapter 4.4, overall business impacts; costs and expected changes on terminal operations are presented in chapter 4.5. The sites considered in Sweden are Malmö intermodal terminal, Port of Gothenburg, Eskilstuna intermodal terminal and Katrineholm intermodal terminal. The most likely site for a pilot seems to be Malmö intermodal terminal. At the site there is plenty of space for the installation and there is already an RFID reader installed. A thorough analysis of the impact of the IVG concept on the terminal is presented in 4.4.1. The results of the simulation in the analysis of Malmö shows that implementing IVG would give considerably time savings, enabling the terminal to improve their processes and thus increasing their productivity. The potential site considered in Germany is DUSS-Terminal Cologne Eifeltor.

The complexity of software algorithms for identification and classification of dangerous cargo could be reduced if common rules of marking and signs could be implemented for all types of loading units. As described in chapter 2.1.2.5. At the moment (analysed in an internal DUSS-pre-study) too many legal exemptions are made for the different modes of transport by road, rail and ship which increases the number of different use and test cases. International harmonization of the different legal frameworks of requirements seems to be necessary and is highly recommended to enable more automatic processing on an easier and also cost-efficient level. The development of deep learning models would be obsolete, if only high quality and standardized markings in same positions are accepted.
5.1 Further studies

The functionalities of the IVG system developed could only be tested partially in a real scenario, feeding the system with images previously captured. Therefore, only the image processing module could be tested, limiting the system abilities to the identification of the ILU, UIC codes and dangerous cargo signs of real images. Further work is needed to integrate and deploy the complete system in a real scenario, with all the modules and interfaces working together at the same time. Additionally, the identification of dangerous cargo signs and placards was done using a Computer Vision solution; however, an alternative Deep Learning method was also considered for this task. Further work would be required in order to develop a Deep Learning solution capable of identifying and classifying dangerous cargo signs and placards in order to compare both methods. Out of the scope of this proof of concept was the recognition of damages and defects on wagons and containers, a functionality identified in D4.1 to be of great value to the different stakeholders of the IVG. This functionality needs to be developed and included in future versions of this IVG. Still remaining functionality to investigate is the automatic detection of damages.

The crane schedules created in Section 3.2 are based on synthetic and historical data. When one or several IVGs have been installed, it will be possible to create schedules based on a large amount of real-time data from the IVGs and thus further investigate both the time needed for the optimization process and the quality of the produced schedules. We also believe that IVGs will make it easier to synchronize data from sending and receiving terminals, something which turned out to be hard (due to differing principles for how to register data in the terminal operating system) when historical data were used. Furthermore, there is a need to investigate if the terminal model should be made more detailed to make the results more reliable. For example, it might be necessary to take the varying sizes of the units into account, to assign containers to temporary storage locations before each planning period instead of just before the first one, and to make it possible to move delayed units to a later planning period.

Regarding the roll-out and implementation plan implementation plan presented in chapter 4, further studies are required in all categories of evaluation parameters prior to full scale installation and a pilot of the concept.
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