SMART

Smart Automation of Rail Transport

(Project reference – 730836)

Deliverable D6.1

Architectural design of the information system for supervision and management of marshalling yards

Contractual delivery date: Month 9
Actual submission date: 30.11.2017

Start date of project: 01.10.2016  Duration: 36 months
Lead beneficiary: UNI  Responsible person: Miloš Simonović

Project co-funded by the European Commission within the HORIZON 2020 Shift2Rail

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## Abbreviations and Acronyms

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<th>Description</th>
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<tbody>
<tr>
<td>ADSS</td>
<td>Advisory Decision Support System</td>
</tr>
<tr>
<td>ARCC</td>
<td>Automated Rail Cargo Consortium</td>
</tr>
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<td>COLA</td>
<td>Collaboration Agreement between ARCC and SMART Consortium</td>
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<tr>
<td>ERTMS</td>
<td>European Rail Traffic Management System</td>
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<tr>
<td>GoA4</td>
<td>Grade of Automation</td>
</tr>
<tr>
<td>IP</td>
<td>Innovation Programme</td>
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<tr>
<td>MAAP</td>
<td>Multi Annual Action Plan</td>
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<td>RTYM</td>
<td>Real Time Yard Management</td>
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<td>RTMYM</td>
<td>Real Time Marshalling Yard Management</td>
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<tr>
<td>S2R JU</td>
<td>Shift2Rail Joint Undertaking</td>
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<td>SWL</td>
<td>Single Wagon Load</td>
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<td>SMART</td>
<td>Smart Automation of Rail Transport</td>
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<tr>
<td>TAF/TSI</td>
<td>Telematics Applications for Freight / Technical Specifications for Interoperability</td>
</tr>
<tr>
<td>TD</td>
<td>Technical Demonstrator</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
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<tr>
<td>UIC</td>
<td>International Union of Railways</td>
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<td>WP</td>
<td>Working Package</td>
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1. ABSTRACT

Deliverable D6.1 - Architectural design of the information system for supervision and management of marshalling yards is deliverable of the Work package 6 - Development of Web-based information system for supervision and management of marshalling yards. Deliverable D6.1 includes a prototype of an architectural design of the information system for supervision and management of marshalling yards. This deliverable focuses on the design of the global architecture of the web-based information system for supervision and management of marshalling yards which fulfils the requirements and specifications defined in WP4. In addition, database design is presented.

The main goal of SMART project is to increase the quality of rail freight, as well as its effectiveness and capacity, through the contribution to automation of railway cargo haul at European railways. Two SMART working streams are:

- Development of a prototype of an autonomous obstacle detection system,
- Development of a real-time marshalling yard management system.

The SMART prototype solution for obstacle detection will provide prototype hardware and software algorithms for obstacle detection, as well as standardized interfaces for integration into ATO module. The system will combine two night vision technologies, thermal camera and image intensifier, with multi stereo vision system and laser scanner in order to create fusion system for mid (up to 200 m) and long range (up to 1000 m) obstacle detection during day and night operation, as well as during operation in impaired visibility. By this planned fusion of sensors, the system will be capable, beside reliable detection of obstacles up to 1000 m, to provide short range (< 200 m) wagon recognition for shunting operations.

The SMART real-time marshalling yard management system will provide optimization of available resources and planning of marshalling operations in order to decrease overall transport time and costs associated with cargo handling. The yard management system will provide real time data about resources available over standard data formats for connection to external network systems and shared usage of marshalling yards between different service providers.

A web-based information system will be developed that will visually represent the marshalling yard configuration, provide manual and automated input of inbound and outbound train parameters, and provide planning of wagons sorting (marshalling) using the machine learning based optimization algorithm.

In order to provide web based information system with desired performances and to achieve objectives given at the beginning of the project, a prototype of architectural design of the information system for supervision and management of marshalling yards is needed. The main goal is to provide advisory system for decision making process in order to take into account dispatchers’ experience while decreasing his subjective impact on the overall management system of marshalling yard.

In line with the targets of the MAAP TD5.2 and within the scope of digitalization for future rail freight, SMART established close cooperation in project realization and information exchange with complementary S2R JU member project ARCC-Automated Rail Cargo Consortium and project stakeholders. This deliverable D6.1 is in line with established cooperation and targeting information system for decision making processes and deviations of decision making processes in marshalling yard are just in line with conclusions of joint meeting between SMART and ARCC partners for Real Time Yard Management System, which took place in Frankfurt, 12-13 June 2017.
2. EXECUTIVE SUMMARY AND REPORT SCOPE

This report is the first deliverable of the Work Package 6 within the Real Time Marshalling Yard Management working stream of the SMART project.

The purpose of the performed tasks reported in this Deliverable D6.1 was design of the architecture of the Web-based information system for supervision and management of marshalling yards based on requirements and specifications defined in WP4. A subtask is devoted to the design of the database for storing the marshalling yards models obtained in WP5, data necessary for planning marshalling process in these modelled marshalling yards and all other data used by the information system. Such data includes information about inbound and outbound trains and their cars, information needed for planning marshalling process, as well as information system user data and other auxiliary information.

An introduction is given in Chapter 3, followed by State of the art of information systems for supervision and management of marshalling yards presented in Chapter 4. This includes description of 9 different IT solutions available at the market. Each of the analysed solutions was presented within separate subchapters. At the end of Chapter 4 comparative analysis of presented IT solutions and some conclusions are given.

According to Chapter 4 and project specific goals, architectural design of SMART RTMY system is presented in Chapter 5. There are three subchapters concerning general concept of SMART RTMY, functional requirements and architecture, and conclusions. Functional requirements and architecture are given in three separate sections describing software modules for SMART RTYM system, software tools for data visualization and planning of marshalling yard, and software tools for the Optimization module.

Chapter 6 gives general concept of database and design in some details.

Chapter 7 concludes the report.
3. INTRODUCTION

In this introductory chapter we give general overview of a framework for focusing on the relevant domain knowledge prerequisites for SMART requirements regarding real time marshalling yard (RTMY) working stream. In this deliverable, a general concept of RTMY and a prototype of a software architecture and design of the database of the final RTMY system with respect to important issues and objectives of the whole project working stream are presented. Regarding the prototype of software architecture, in this deliverable, general issues are defined and presented. The use case analysis will be done at a later time point of the project and it will be the part of Deliverable D5.1.

3.1 Context and motivation

The research and innovation activities will evolve within the SMART working stream Real Time Yard Management System in line with the Shift2Rail (S2R) Multi-Annual Action Plan (MAAP) [1].

The MAAP is a long-term investment planning document, which translates the strategic research and innovation priorities for the rail sector – as described in the S2R Master Plan - into concrete actions, milestones and deliverables to be undertaken in the period 2015-2024.

As indicated in MAAP, the work conducted within the Shift2Rail framework is structured around five asset-specific Innovation Programmes (IPs), covering all the different technical and functional sub-systems of the rail system. These five IPs are supported by work in five cross-cutting areas and themes (CCA) that are of relevance to each of the projects and take into account the interactions between the IPs and the different subsystems.

The Innovative Programme 5 (IP5) named Technologies for Sustainable and Attractive Rail Freight is the programme which addresses the project working stream Real Time Yard Management System.

Shift2Rail addresses the above-mentioned IPs and CCA by funding Research and Innovation activities that will range from applied research activities (TRL 1 to 3) to demonstration activities (TRL 4 to 7), i.e. from technology developments in lab to system prototype demonstrations in operational environments.

Demonstration activities are a priority within Shift2Rail, as they enable the entire rail sector to visualize and concretely test the transformations that they are able to create. Demonstrations also enable more appropriate quantification of the impact of each new technology. Demonstration activities also help at providing a first estimate of the potential for improvement in the sector at the levels of regional, national and EU transport network, which can be expected as a result of the developed innovations.

Technology Demonstrators (TD) focus on the development or adoption of innovative technologies and models within the rail sub-systems identified in the Innovation Programmes. They enable ground-breaking progress in key areas such as traction, automatic train operation and intelligent diagnosis and maintenance systems. They seek inspiration from innovative technologies, materials and methods used or explored in other sectors. The innovations developed may consist of software and/or hardware systems.

In that sense, the IP5 is structured in seven TDs with the ambition to deliver demonstrations at TRL 6-7. The seven TDs are axed around the three following work streams:
- Optimization of operational processes for infrastructure, operations and assets
- Automation of rail freight system
- New markets

Each TD is composed of different focus areas. The focus area is the framework, within the project work is described and the activities of all involved parties are bundled.

The research and innovation area for SMART working stream Real Time Marshalling Yard management System is TD5.2 Access and operations regarding [1]. There are 4 focus areas within this technological demonstrator 5.2 and one of them is Real Time Yard Management System.

As it is defined in the Project Call S2R-OC-IP5-01-2015, specific challenge of this working stream is automation of disposition processes in marshalling yards from perspective of multiple optimizations in real-time and multi-dimensional decisions needed for daily operations management in yards. It means that the main focus in research and innovation activities is to develop a real-time decision support system for optimized planning and disposition of resources in yards. Research and innovation activities regarding project call and project proposal for this working stream are gathered in SMART deliverables shown on Fig.3.1

![Figure 3.1 Project call scope/ deliverables relationship](image)

Regarding MAAP TD5.2 demands and necessities of complementary activities with the S2R JU member project ARCC-Automated Rail Cargo Consortium, the mutual 2 ways direction cooperation is developed between SMART and ARCC partners.
As it is stated in the Project Call, some expected results and expected impacts are defined for this SMART project working stream and for TD5.2 in general. There are two main expected results from SMART project working stream Real Time Yard Management System and schematic presentation of results and impacts is shown in Fig.3.2.

<table>
<thead>
<tr>
<th>Specific challenge</th>
<th>Expected Result</th>
<th>Expected impact</th>
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<tr>
<td>Automation of disposition processes in marshalling yards</td>
<td>Real-time simulation system of processes in local marshalling yards</td>
<td>To improve the quality of rail freight in terms of punctuality, reliability and flexibility</td>
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<td>The simulation system should be able to run on an IT platform available at the market and should offer open interfaces to be integrated in an IT production system for real time management of yards.</td>
<td>To reduce the operating costs maximizing energy savings and resource efficiencies</td>
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<td>To increase transport capacity on lines and hubs of the European TEN-T network</td>
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<td>To boost rail freight competitiveness in comparison to road freight according to 2011 EU White Paper Transport</td>
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<td>To make an important contribution to the vision of a fully automated rail freight system</td>
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**Figure 3.2 SMART expected results and impacts of Real Time Yard Management System**

### 3.2 The objectives of WP6

The main objective of Work Package 6 (WP6) is developing a web-based information system for supervision and management of marshalling yards.

This system will enable marshalling yards officials to view marshalling yard representation including receiving yard, hump, classification yard and departure yard. The officials will be able to manually insert information about inbound and outbound trains into the system in order to execute optimization algorithm for marshalling process planning. Depending on the railway information system and its potential for integration with the system for supervision and management of marshalling yards, the inbound and outbound train information might be collected from this system automatically, eliminating the need for manual insertion.

The database will be designed according to the specification resulting from WP4. Marshalling yard information collected in WP5 will be imported to the database. This information will be used in two system modules, visual representation module and module for marshalling process planning. Database will also be used as storage for data about inbound and outbound train traffic for particular marshalling yard, various data needed for marshalling process planning and data for identifying users accessing the information system.
Achieving the main objective of WP6 includes reaching the following specific goals:

- Designing of a database for storing information about selected European marshalling yards and marshalling processes on these yards and importing data that will be collected during activities in WP5 into this database.
- Implementing optimization algorithm so that it can be applied for specific marshalling yard model and inbound and outbound traffic information.
- The representation of the yard configuration will be enabled by the visualisation.
- Providing support for integration into railway companies’ information systems in order to achieve automated import of inbound and outbound train parameters eliminating the need for manual input from marshalling yard officials.

As it is stated in previous subchapter, specific challenge of RTYM working stream is automation of disposition processes in marshalling yards from perspective of multiple optimizations in real-time and multi-dimensional decisions needed for daily operations management in yards. It includes definition of all processes suitable for real time optimization and that was one of the key subjects of all discussions that SMART MY team had in previous period with the ARCC MY team, regarding achieving sufficient level of compatibility and advances beyond state of the art. In that sense, the main focus of research and innovation activities is directed to design efficient tool for optimization of decision making processes and their deviations in daily operations in marshalling yard.

The concluded remarks of that discussion as a result of SMART-ARCC joint meeting, hel 12-13 June 2017 in Frankfurt, are given in next subchapter. That was also the main topic in analysis of state of the art for IT solutions in next chapter.

### 3.3 Concluded remarks from joint meeting between ARCC and SMART consortium

In line with the targets of the MAAP TD5.2 and within the scope of digitalization for future rail freight, SMART established close cooperation in project realization and information exchange with complementary S2R JU member project ARCC-Automated Rail Cargo Consortium and project stakeholders. This deliverable D6.1 is in line with established cooperation and targeting information system for decision making processes and deviations in decision making processes in marshalling yard are just in line with conclusions of joint meeting that took place on 12-13 June 2017, in Frankfurt, between SMART and ARCC partners for Real Time Yard Management System.

The cooperation between two consortiums for project working stream RTMY system started immediately after the official start of both projects. All discussions and information exchange were directed to specify and narrow adequate project working stream goals regarding present IT solutions and problems which should be solved. After signing procedure for the SMART_ARCC collaboration agreement (COLA) started, all preconditions were established for defining joint conclusions for ARCC and SMART RTYM working stream.

The brief of minutes from joint meeting between representatives of ARCC and SMART MY teams, which took place in Frankfurt, on 16th of June 2017, is given below. The most important issues are underlined.
“It was stated from the ARCC perspective – as shown in the results of the analysis of marshalling yards – that work in the yards in principle is based on regular, long-term or medium-term plans. Preparation of that kind of plans is not in focus of RTMY.

In practice, a lot of disturbances as well as deviations from regular plans appear and cause ad hoc decisions and changes/adaption of planned activities at the yard. Appropriated decision-making and estimating the consequences of decisions mainly depends on the dispatcher’s individual experiences as well as on different circumstances dedicated to each individual marshalling yard. Information from existing IT-systems for supervising and control marshalling yard activities as well as from Rail control systems of rail infrastructure managers (IM) and from Production fulfilment systems of railway undertakings (RU) actually already support the dispatcher’s decision-making. Nevertheless, a system that could pro-actively warn dispatchers about the consequences of potential decisions and by this means helps to optimize operational procedures in real-time is currently not available in any of the yards.

It was agreed between the ARCC- and SMART-project partners that a focus of activities should be the development of a “RTYM Optimization Module” that would be able to support the dispatcher’s decision making in case of any deviations from regular plans. This module should create added value for improving efficiency and punctuality in marshalling yards. The module should take into account possible existing IT-solutions for yard management and from IM and RU, specific circumstances of each individual yard and the prospective availability of real-time data as well in the rail freight sector.

After discussion in the meeting following guidelines for further work in MY teams of both consortia were agreed:

• As the focus and work timeline of ARCC- and SMART work stream RTMY are in principle different, the collaboration of ARCC- and SMART RTMY teams should focus on sharing information, joint discussion of the architecture, data/modelling elements, and on requirements for a RTMY System as well as on discussions how to ensure possibility of integration of the module in existing IT-environments.

• The similar structure of selected marshalling yards analysis shall result in a joint understanding of how to define the processes, challenges and needs for optimization.

• Definition of use cases (Decision making that had to be supported, required data, used KPI – key performance index) could be the basis for a joint understanding of the needs for optimization and the requirements for modelling of assets and processes. The collaboration on the modeling and real-time decision making processes in marshalling yards shall result in a comparative analysis of selected optimization objectives and obtained optimization results.

• Draft of the SMART architecture design and the requirement list of the RTMY-System should be jointly discussed and adjusted.

• The main data/modelling elements, interfaces and interactions of a RTMY-System as well as the standards to be considered should be agreed by SMART and ARCC RTMY teams.

• To ensure availability for testing and evaluation, interfaces of the SMART-RTMY-System should allow import/export of relevant data. Alternatively – if there is already an existing IT-solution for Yard Management/Production fulfillment, RTYM-System should use existing databases wherever possible (Yard-Infrastructure, Resource availability, train/wagon locations...).”
3.4 Further work

There are two remained deliverables as substantial part of overall process analysis and specification of the requirements for Real-time yard management system as result of the SMART project RTMY working stream. These two deliverables are D5.1 Identification and generation of relevant information and data flow between input and output requirements, and D5.2 Integration data in unique database of EU marshalling yards. These two deliverables together with D4.1, D4.2 and D6.1 will gather all needed information and encircle overall framework for design real-time decision support system for optimized planning and disposition of resources in yards according to project call requirements.

Fig.3.3 shows timeline of SMART deliverables regarding process analysis and providing needed information for design requested simulation system at the end of the project. As it is shown, deliverable D5.1 will be the last report needed as precondition for start of design an appropriate RTYM system and its testing and implementation.
4. STATE OF THE ART OF INFORMATION SYSTEMS FOR SUPERVISION AND MANAGEMENT OF MARSHALLING YARDS

In this chapter, general overview of existing information systems for supervision and management of marshalling yards is presented. Nine different solutions available at the market were selected and analysed and some common remarks are provided for each system. Comparative analysis is done in separate subchapter and recommendations for novel yard management decision support system beyond state of the art are given.

4.1 IT applications of ARCC MY

As it was stated before, SMART established close cooperation in project realization and information exchange with complementary S2R JU member project ARCC-Automated Rail Cargo Consortium and project stakeholders. According to the Project call and defined requests, providing compatibility and complementarity with ARCC results is one of the most important issues for SMART MY working stream. In that sense, state of the art of information systems for supervision and management of ARCC marshalling yards is of high importance. In addition, the fact that improving efficiency and punctuality of MY management is very important especially for ARCC members (Germany and Sweden) according to the facts stated in [D4.2] about operational marshalling yards/1000 km rail network and Single Wagon Load (SWL) usage in Europe.

In that sense, implemented IT solutions in Germany (Mannheim MY) and Sweden (Hallsberg MY) are briefly presented below.

4.1.1 DB IT applications

The first presented IT solution is the set of IT applications used at marshalling yards in Germany. Concretely, IT applications described below are used at Marshalling yard Mannheim, Germany where ARCC and SMART partners had an opportunity to see practical implementation. These IT applications are mostly developed for DB Cargo and one IT application LeiDis is developed for DB Netz. All nine IT applications are shown in Table 4.1.

Table 4.1 IT application used in DB Marshalling yards [12]

<table>
<thead>
<tr>
<th>IT application</th>
<th>Relevant Content</th>
<th>Owner</th>
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</table>
| LeiDis – Leitsystem zur Netzdisposition | - Prenotification of incoming trains  
- Monitoring of train runs  
- Causes of train delays | DB Netz       |
| TRACE – Train Control Europe       | - Overview of planned outgoing trains  
- Timetable deviations of national and international train runs  
- Overview of parked trains  
- Overview of causes for train delays | DB Cargo      |
| PVG - Produktionsverfahren Güterverkehr | - Information about trains approaching the yard  
- Administration of timetable and shipment information  
- Train decomposition and wagon transfer/interchange  
- Data interchange with the sequence control computer system of the hump  
- Support of wagon inspection activities  
- Information about wagons on tracks  
- Treatment of outgoing trains | DB Cargo      |
Some of the data in different IT applications are overlapping but these IT applications are giving total control of the most important data: train database, wagon database, timetable, yard staff and train driver usage and state of locomotives. All these solutions allow good overview of the situation at Marshalling yard and control of all important aspects in regular operation conditions. Visual representation of LeiDis and PVG is shown in Fig.4.1.

On the basis of performances and practical experience in implementation from local dispatchers, it can be said that these DB IT applications provide user friendly environment for operators and dispatchers. Beside this, it can be concluded that large number of various IT applications increase complexity of the process of control, supervision and monitoring marshalling yard and it can be defined as disadvantage.
Figure 4.1 Visual representation of LeiDis and PVG

DB does not have IT application that can give prompt advisory solutions for some of deviation that can occur on Marshalling yard in daily operations. Decision making process at the Marshalling yard is still based on the knowledge and experience of dispatchers.

LeiDIS is the network traffic-regulations control system. Primarily shown and processed are the following:

- Routes set
- Current train positions
- Actual times of current train positions

Table 4.2 shows the overview of graphical and tabular applications of LeiDis.

<table>
<thead>
<tr>
<th>Tabular applications</th>
<th>Graphical applications</th>
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<tr>
<td>Nodal table</td>
<td>Time-path diagrams</td>
</tr>
<tr>
<td>Nominal/actual variance list</td>
<td>Nodal graphs (all trains at a station on a time axis)</td>
</tr>
<tr>
<td>List of connectional conflicts</td>
<td>Station graphs (as nodal graphs plus representation of platform tracks)</td>
</tr>
<tr>
<td>Record of delays</td>
<td>Overall network records</td>
</tr>
<tr>
<td>Train running overview, analysis and status</td>
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Data for LeiDis are supplied – as a function of traffic volumes – via mirror server in the OCC or NMS that is ongoingly fed with fresh train running data and the days running schedule.
4.1.2 Swedish IT applications

The second presented IT solution is the set of IT applications used at marshalling yards in Sweden. Concretely, IT applications described below are used at Marshalling yard Hallsberg, Sweden. These IT applications are mostly developed and owned for Green Cargo AB and Trafikverket. These data are provided from Trafikverket and all eleven IT applications are shown in Table 4.3. [12]

<table>
<thead>
<tr>
<th>IT application</th>
<th>Relevant Content</th>
<th>Owner</th>
</tr>
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</table>
| BRAVO - Bättre ResursAnvändning vagnstyrning Operativt | • Client contracts and transport bookings  
• Estimated departure and arrival times for booked transports  
• Plans for all possibilities for transportation  
• Wagon routes  
• Wagon bookings on trains for each order  
• Shipment and wagon information  
• Wagon groups and ordering within trains  
• Wagon disposition and control  
• Planning of shunting activities  
• Wagon Database  
• Client alert system (delays, re-booking etc.)  
• Trip plans for each wagon | Green Cargo AB |
| Körorder | • Obtain train driving order | Trafikverket |
| Här och nu | • Report that train is ready to depart (“K-report”)  
• Monitoring train runs  
• Report train delay causes | Trafikverket |
| Opera | • Train composition  
• Locomotive type  
• Axle load | Trafikverket |
| GSM-MobiSIR and JIMO – Järnvägstjänster i mobiltelefonen | • Radio system for communication  
• Request access to train route | Trafikverket |
| Trainplan | • Timetable planning | Trafikverket |
| Trafikbilder Ebicos 9000 | • Real time traffic information | Trafikverket |
| BP | • Roster for train drivers and yard staff | Green Cargo AB |
| Loop | • Simulation, optimization and tactical schedule for locomotives | Green Cargo AB |
| Platå | • Operational schedule for locomotives and train drivers | Green Cargo AB |
| OP | • Optimization and information about train driver assignment | Green Cargo AB |
4.2 Vicos CM

Vicos CM [13] is the dispatching system for train formation yards with special operational requirements. It allows smooth and precise operations handling, thanks to early detection of conflict situations and flexible adaptation to timetable changes. As a core element of an automated train formation system, Controlguide Vicos CM communicates with station-internal facilities such as hump control or automatic composition checking systems as well as station-external facilities such as announcement and train-movement information systems.

Controlguide Vicos CM supports the continuity of the logistical transport chain and as a result offers a solution for achieving the desired goals in modern rail freight traffic.

Vicos CM 100 uses standard components widely available on the world IT market:

- a client-server architecture with – clients (standard PCs with the Microsoft Windows XP operating system) – servers (scalable from a standard PC to a high-availability multiprocessor system with the Microsoft Windows Server operating system)
- a relational database system (Microsoft SQL Server 2005)

![Figure 4.2 Visualisation of Vicos CM](image)

4.3 Trapeze

TrainPlan [14] is Trapeze Groups Windows based train scheduling system which provides complete support to the railway operations planning process:

- Quick and reliable train service scheduling using a geographical database and sectional running times for all train types in operation.
- Validation of plans, including conflict detection and resolution and timetable robustness analysis
- Short and long-term planning, taking into account track possessions and blockages.
- Preparation and publication of the operating plans to staff and customers
The Trapeze features can be summarized as following:

- Advanced train timetable management and update
- Powerful graphic and tabular displays with complete display of service schedule information
- Advanced customization to fit with existing business processes
- Comprehensive reporting, printing, publishing and data export to downstream systems
- Bid/offer support for infrastructure providers and train operating companies
- Multi-user, multi-site system, using an Oracle® database
- Access per mission controls
- Automated network conflict resolution (optional)
• Integrated resource planning module – Resource Plan (optional)
• Advanced timetable robustness analysis module (optional)

4.4 GE transportation’s digital solutions

The RailConnect Rail Yard Management [15] interface is integrated with Google Maps, and provides a bird’s-eye or map-based view of the rail cars currently in the yard. Rail Yard Management System has integrated business rules that allow users to select and colour code rail cars on its various views based on type, commodity, and load-empty status.

Figure 4.5 Visual representation of RailConnect

An advanced software solution designed to help for making better decisions around asset use and resource working sequences, Yard Planner allows visualization and monitor yard state and plan yard activities, so that it can get trains connected and out of the yard faster, and avoid trains sitting idle.

Summarized GE transportation’s digital solutions features are the following:

Core capabilities
• Generate a yard-level car processing plan with a detailed schedule for the movement and processing of each car
• Visualize current car inventory, activities, inbound and outbound schedule
• Predict yard capacity/performance in the planning horizon

Differentiating Features
• Comprehensive yard planning suite
• Provides inbound train termination, car humping, car sorting and outbound train building
Intuitive way to view yard status, yard plan and KPIs

Optimized Outcomes

- Improves car connection performance
- Improves on-time departure performance
- Improves efficiency in daily operations—Reduces overall railcar hiring costs

ShipperConnect Yard Management is used for synchronization of entire industrial yard operation. With greater inbound and outbound railcar and inventory visibility, and the option to fully integrate with GE’s Transportation Management System to interface directly with the serving railroad system—it can maximize throughput and productivity, and reduce the risk of delay, loss or contamination.

Summarized Shipperconnect features are the following:

Core capabilities

- Yard asset visibility
- Railcar inspection status
- Inbound/outbound workflow
- Order-to-railcar matching
- Yard inventory moves

Differentiating Features

- Manage multiple yards
- Built-in rail expertise
- Seamless integration (AEI, EDI, ERP)
- Quick to deploy (cloud-based)

Optimized Outcomes

- Increase yard throughput
- Control product loss in the yard
- Minimize demurrage and detention

4.5 HCL technologies

Some features of HCL IT [16] solutions are the following:

- Every car’s movement within the yard is recorded and accurately sequenced within the yard tracks
- Real-time update of car movements within the yard is automatically reported to the Track & Trace legacy system
- Provides visibility throughout the switching operation
- Complete control on every movement of cars within the yard using AEI technology
- No misplacement of hazardous materials in close proximity to other restricted commodities
HCL’S PLEDGE
The basic features can be summarized as following:

- Create IT solutions that help improve business performance
- Better visibility into movement of freight
- Enable enterprise discovery for better visibility and control on the application landscape
- Single version of truth of the organization data

![HCL solution diagram](image)

**Figure 4.6 HCL solution**

HCL differentiators

- HCL has been engaged with North America’s Class 1 railroads. Committed to meet today’s railroads challenges, HCL has proven case studies to demonstrate its experiences and subject matter expertise
- HCL’s culture of thought leadership and value centricity is a key ingredient for a successful partnership in an environment of systemic problems like aging workforce, challenges around system scalability and modernization
- HCL’s culture of creating trusted relationships through transparency and flexibility is essential for success within the rail industry
- HCL is ranked as a leader in technology areas relevant to the railroads, including legacy apps and next generation technologies
- HCL is ranked #1 in customer reference score and is amongst the leadership quadrant in application management services
4.6 GEOMETRIX RAIL Logistics

The GeoMetrix 16 Performance Suite offers an exceptionally versatile Yard Management platform that is both powerful and user-friendly. For rail yards of all sizes, GeoMetrix’s Yard Management [17] provides complete visibility on every aspect of rail yard operations at a glance. With automated data transfer capabilities, dispatchers and yard workers can coordinate with greater accuracy for more efficient operations.

Like the rest of the GeoMetrix Performance Suite, the Yard Management module offers the same user interface and the ability to quickly scan user-specified priority items as well as a detailed list of all railcars. Beyond this however, the yard mapping capability presents a Yard Layout View of entire yard with the ability to view the type, contents, location and status of every railcar.

For yards with as few as 16 spots or those with over 5,000 spots GeoMetrix 16 is completely scalable. Users can colour code any product and easily configure all tracks, racks and individual spots to align with any existing yard references.

Regardless of size or configuration, the Yard Management module can be quickly set-up to perfectly mirror any rail yard. Yard Layouts can be filtered to display Racks Only, Storage Only or Inbound/Outbound Only.

Along with three Zoom levels and a handy Search capability for individual or multiple railcars, GeoMetrix 16 lets operators quickly visualize specific yard operations. Using the Icon Display Mode, individual railcars will indicate scanner verification, BOL information, notes (including Bad Orders) and Service requirements.

Other Display modes include Spot (car ID and location), Assignment (fleets, sub-fleets, etc.) and Ghost which shows actual car locations as well as prior locations for monitoring crew performance.

The versatility of GeoMetrix’s Yard Layout View delivers complete information on available capacity, car sequencing, location, loading and departure status and yard storage capacity at a glance.
Scanning and Mobility

Regardless the method of data entry, GeoMetrix streamlines this process to reduce time and error. With GeoMetrix’s YardScan, yard workers can electronically scan The GeoMetrix 16 Performance Suite offers an exceptionally versatile Yard Management platform that is both powerful and user-friendly.

For rail yards of all sizes, GeoMetrix’s Yard Management provides complete visibility on every aspect of rail yard operations at a glance. With automated data transfer capabilities, dispatchers and yard workers can coordinate with greater accuracy for more efficient operations.

With trackside scanners, dispatchers can continuously monitor all inbound and outbound trips for optimal sequencing, location and storage capacity management. Precise date / time information also takes the guesswork out of storage calculations and provides detailed report capabilities for railroads and other transporters.

GeoMetrix 16 Yard Management module is process oriented and fully aligned with key operational considerations:

- Inbound: Handles ‘Order-In’ or ‘Spot On Arrival’ traffic.
- Arrivals: Accepts Manual, RR Inbound Consist, Track or Handheld Scanner data.
- In-Yard: Offers complete railcar data including detailed profile, location, status, history, etc.
- Load/Unload: Provides precise load monitoring and calculations based on products, temperatures and weights.
- Bill of Lading: Automatically populates bills of lading.

4.7 RAILROAD software

Rail Yard [18] and Terminal Management are developed specifically for the operators.

The dashboard provides the ability for operators and customers of the operator to quickly see the state of the rail terminal facility

- Quickly view railcars by status & type
- Always live ageing report to support the management of Demurrage charges
- Comments specific to current condition of railyard
- Summary table by status and pool id, commodity, or destination

Intuitive track map interface allow quickly drag and drop railcars in order to assign a new position or create a switch request. Here are features the Live Track Map offers:

- Drag & Drop multiple railcars to create switch requests
- Color coded railcar status, type, and switch request
- Quick locate railcars based on car status, type, number, or other fields
- Quickly manage railcar specifics
- Automatically updates the RailTab used by the switch crew

Reports are how terminals are able to track the movement of goods within their facility or their customer. Program idea is that customer should have the ability to generate almost any type of report necessary for operating a rail facility.
- Ad-hoc report builder
- Historical reporting of railcars based on status changes
- Automated email reporting
- Direct access to the reports as a view-only user
- All reports can be viewed, printed, and downloaded as an excel file with a single click.

Some feature of interface for easier manage of railcars in facility:

- Inline editing of all values
- Quick view of railcars on Track Map
- Robust search and sorting options
- Multiple methods for adding railcars
- Scheduled status change of railcars

![Figure 4.8 Interface of Railcar](image)

Every railcar, every trip in rail yard, every movement, and every status change tracked for consistency, accuracy, and accountability.

- User based record to hold employee’s accountable for actions within the system
- Tracking of status changes can be used to generate historical reports
- Productivity of a railcar movements can be tracked and enhanced
- Visibility into process and operation management of the rail yard
4.8 Rail Manager® and Logger

Data Capture is using stationary AEI reader, handheld reader or electronic records (CLMs) imported from rail carrier

- Reduce labour costs for acquiring railcar arrival, departure and location data
- Eliminate labour costs for manual data entry
- Reduce labour costs currently spent searching for cars

Accurate and timely collection of railcar info

- Improve railcar utilization and decrease fleet costs
- Reduce switching costs caused by inaccurate car location and status records
- Eliminate shipping & inventory errors caused by manual entry of railcar data
- Accelerate shipping process with timely electronic records
- Maximize labour utilization by eliminating wait time for manually collecting car arrival & departure information

Effective tools for yard management

- Reduce labour costs for creating & communicating switching and shipping requests
- Reduce time and costs for data analysis and investigations by storing all historical records in easily searchable electronic format
- Utilize built-in tools for measuring, monitoring and improving performance
- Optimize yard capacity with high visibility of yard utilization and car status

Designed for integration with existing systems

- Automate weight capture with integration of Rail Scale™
- Designed for integration with existing financial, manufacturing, process control, shipping and 3PL car tracking systems.

All railcars in North America are equipped with an Automatic Equipment Identification (AEI) tag on each side of the car. A stationary reader can be installed trackside to read these tags and record every car that passes by, collecting data such as car number, date, time, direction and speed. Many companies manufacture stationary railcar readers and each generates data in a proprietary format. Rail Logger® [19] collects this raw data and translates it into useable information. The sophisticated programs within Rail Logger® enable it to translate data from all makes of readers, and to provide output in multiple user-friendly formats.

Some features of Rail Logger are:

- Real time tracking of rail car arrivals, departures, and movements.
- Error-free data collection.
- Provides accurate list of all car arrivals and departures.
- Fully automated process that reduces labour cost and speeds reporting.
- Most robust Front End processor for AEI readers on the market.
- Easy integration of AEI data to core business process.
- Eliminates wasted time dealing with inaccurate info from railroads and searching for cars.
- Effective and easy to use reporting.
- Sophisticated error checking processes with automated alerts.
- Can operate as a standalone system or can be linked to Rail Manager® to provide a comprehensive automated yard management solution.
4.9 Villon

Villon [20] is a software simulation tool for creation and application of universal and detailed simulation models of transportation logistic terminals and their technological processes. Villon supports microscopic modelling of various types of transportation logistic terminals containing railway and road infrastructures (e.g. marshalling yards, railway passenger stations, factories, container terminals, depots, airports, etc.).

Using Villon, users (professionals in the field of logistics) are able to create detailed simulation models of terminal operation, define simulation scenarios, make experiments with the model and evaluate results of simulation runs in one integrated user-friendly environment. Villon aids tactical (middle-term) and strategic (long-term) planning related usually to infrastructural or operational proposals, which are supposed to guarantee optimal (or at least effective) behaviour of modelled terminal.

Villon’s features like its flexibility, detailed microscopic modelling of operation of various types of terminals, flowchart driven definition of operational procedures, user interaction, selection of decision strategies, 3D animation output, extensive result evaluation possibilities underscore its uniqueness throughout the world.

Villon is based on state of the art methods and techniques of computer simulation (agent based simulation) and visualisation (3D accelerated utilising MS DirectX).

The tool has been in development since 1994 (the development of the tool, formerly known as VirtuOS, has started at the University of Žilina and was taken over by the Simcon company in 1997).

Villon features are:

- Precise infrastructure modelling
- Individual Modelling of Resources
- Detailed and Flexible Modelling of Operation
- Microscopic Modelling of Transport processes
- Modelling of Multi-modal Systems
- Extensive Evaluation Possibilities
- 3D Animation of Simulated Processes
- Modelling of Storage Systems and Passenger Transportation
Figure 4.9 Visual representation of Villon
4.10 Comparative analysis

In this chapter, nine IT applications for rail yard management were analysed. Information for analysed software was obtained mostly from internet web sites and public available data and directly from ARCC partners concerning their applications (DB and Trafikverket applications).

Software have mostly standard features that can be found in almost all analysed IT solutions like timetable and database of trains; database and trip plan for cars; overview of planned outgoing trains as well as monitoring of parked trains, real time tracking of car arrivals, departures and movements; inspection status and treatment of trains; monitoring of cancellation and delays of trains; roster for yard staff and use of resources etc.

Some software are monitoring and giving support in short-term planning by taking into account track possessions, blockages and raising effectiveness of marshalling yards. Some software has some modules for optimisation of operations in marshalling yards.

Some software has advanced visualisation solutions which makes easier doing operations. Here, we should have in mind that this software need to be made for dispatchers with specialised education and used working methods. Also, visualisation performances have to be adjusted to their needs.

In general, there are no IT applications that can give prompt advisory solutions for some of deviation that can occur on marshalling yard in daily operations. Decision making processes at marshalling yard are still based on the knowledge and experience of dispatchers.

In that sense, the development of decision support advisory system for operational procedures in marshalling yards will be beyond state of the art and will provide improvements for management processes in marshalling yards, in general.

On the other hand, SMART MY management system shall be adjustable enough in the manner to be integrated in existing IT applications. It comes out the fact that all major marshalling yards in Europe already use some set of IT applications for their purposes.

Potential improvements that can be provided by SMART MY management system implementation can be summarized as following:

- SMART MY management solution would help improving business performances of operational processes in MY
- SMART advisory system would give list of prompt solutions for deviations that are occurring in every day work at marshalling yard
- SMART would provide automation and simplification of decision making process in MY in real time
- SMART would provide optimisation of operations in special cases that need to be defined
- SMART would provide some visualization improvements according to new possibilities and trends in that field that can make more user friendly environment for operators and system users
5. ARCHITECTURAL DESIGN OF SMART RTMY SYSTEM

Design of the architecture of the Web-based information system for supervision and management of marshalling yards based on requirements and specifications defined in WP4 is presented in this Chapter.

5.1 General concept of SMART RTYM System

General concept of SMART solution is presented. Some data flow and process flow from general view should be given from software aspect beside the fact that there is separate deliverable D5.1 for that purposes.

SMART is developing a real-time marshalling yard management system which will enable the optimization of available resources and planning of marshalling operations in order to decrease overall transport time and costs associated with cargo handling in existing infrastructure. Optimization of the processes will be performed by a machine learning decision system which will be trained to give the optimal, or near-optimal solution of marshalling operations in real time, based on data of optimization from heuristic or meta-heuristics optimization algorithm. A web-based information system will be developed that will visually represent the marshalling yard configuration, provide manual or automated input of inbound and outbound train parameters, as well as planning of cars sorting (marshalling) using the machine learning based optimization algorithm. The information system will be able to export data to other systems.

The diagram of SMART real time marshalling yard management system is shown in Fig. 5.1.

The concept solution of SMART Real Time Yard Management System consists of five important modules:

- Data input module
- Data output module
- Visual representation module
- Module for marshalling process planning
- Optimization module for intelligent decision making processes

During analysis of processes in marshalling yards, this concept solution is slightly modified. It is defined that Visual and planning module and Optimization module are the core of the system and Data input and Data output module can be considered as sub modules. The modified concept solution is shown in Fig.5.2.

These modules should give a solution to three main issues generated in MAAP and previous EU projects regarding marshalling yard infrastructure and processes. The issues are as following:

- Data standardization
  Data input and data output module will provide exchange data in standard formats

- Real-time monitoring of Single Wagon Load (SWL) on marshalling yard
  Visualization and planning module will enable yard officials and operators to follow each wagon movement on marshalling yard and state on marshalling yard in real-time

- Efficiency and standardization of decision making processes
Visualization and planning module will provide process realization according to adopted and implemented standards and optimization module will provide optimal or near optimal solution in real-time.

**Figure 5.1 Initial SMART real time marshalling yard management system concept solution**

**Figure 5.2 Modified SMART Real time marshalling yard management system concept solution**
5.1.1 Data input module

Data input module, as a sub module, would enable users (marshalling yards officials) to enter data about inbound and outbound train traffic which will be stored in the database. This data will also be displayed in the visual representation module to show the status of the marshalling yard.

The support for integration with railway information systems will be developed in order to provide the opportunity to obtain inbound and outbound traffic data automatically. It means that standard data format for import and export data should be implemented.

As it stated in Minutes of ARCC-SMART Meeting, integration of SMART system with existing IT applications on local marshalling yards is mandatory. The present state of all important data on marshalling yard has to be provided in every moment because of adequate analysis and response to potential deviations and difficulties that can occurred. Without reliable information about actual state, it is not possible to obtain optimal solution (advice) as the answer on deviations in decision making processes.

In Fig. 5.3 the functionalities of Data input module are presented.

![Figure 5.3 Functionalities of Data input module](image)

5.1.2 Visualization and planning module

Visualization and planning module would display current potential status of the marshalling yard to the user, based on data entered manually by the user or acquired automatically from a railway information system. This module will also be able to display the future state (advisory proposition) of the marshalling yard based on input data and the outputs of the optimization module for specific occurred deviation.

The methods used for modelling marshalling yards and inbound and outbound traffic information, as well as methods implementing the algorithm for optimal marshalling process planning will be extracted and encapsulated into a publicly available software library. This library will enable users to model their own marshalling simulation scenarios and perform marshalling process planning using the developed optimization algorithm outside of the information system for supervision and management of marshalling yards.

Visual representation will be able to be seen for different kind of users – dispatchers, cargo operators, infrastructure managers, etc.
Figure 5.4 shows process and data flow for Visualization and planning module.

5.1.3 Optimization module

As it was agreed in Minutes of Joint ARCC-SMART meeting, the main goal of the project should be the development of a “RTYM Optimization Module” that would be able to support the dispatcher’s decision making in case of any deviations from regular plans. It is stated that this module should create added value for improving efficiency and punctuality in marshalling yards. In addition, the module should take in account where possible existing IT-solutions for yard management and from IM and RU, specific circumstances of each individual yard and the prospective availability of real-time data as well in the rail freight sector. The functional relationship of Optimization module is shown in Fig.5.5.

Within the complexity of the infrastructure and the target system, the vision of the TD 5.2 Access and Operations is to master the challenging task to develop an overall optimization tool for yard management in order to adequately steer resources in rail freight yards, hubs and connecting sidings by introduction of real-time data based decision support systems.

As it stated in the project proposal and according to project scope SMART will develop a real-time marshalling yard management system which will enable the optimization of available resources and planning of marshalling operations in order to decrease overall transport time and costs associated with cargo handling in existing infrastructure.

It means that crucial part of Real-time marshalling yard management system is decision support system. The core of all research and innovation activities of SMART project working stream is directed to design and implement algorithm for real-time optimization. It means that the heart and advances beyond the state of the art will be the part of information system for optimization named Optimization module.

The optimal strategy for the development of solutions required to assess any possible decision on the proposed development alternatives or solution to a problem, and also to make a comparative
assessment of the proposed alternatives. This management strategy requires sufficient information for a large range of conditions in order to seek for the optimal solution.

**Figure 5.5 Functional relationship of Optimization module**

On this level of conceptuality, it should point out importance of communication between Optimization module and other modules. Communication has to be prompt enough to support getting optimal solution in real time.

Optimization module deals with variety of data. Beside data for the present state of marshalling yard infrastructure parameters, historical data and data for potential scenarios have to be provided in special part of central application database.

Process and data flow for Optimization module is shown in Fig.5.6.

In Deliverable D4.1, Chapter 8 describes sorting methods for marshalling yards and gives their comparative analysis. These sorting methods will be used for defining simulation scenarios for different cases addressed to different marshalling yards and as theoretical background for optimal sorting.

Working Package 5 deals with process modelling and optimization of marshalling process in scope. Deliverable D5.3 Algorithms for modelling and real time optimization of marshalling process is the report on developed mathematical models and optimization algorithms for marshalling process. Optimizing of marshalling processes and deployment of wagon paths will be performed with heuristic and meta heuristics algorithms with real data acquired in T5.2. The report will include intelligent real-time optimization algorithm for marshalling yard management.
5.2 Functional requirements and architecture

Detailed overview of functional requirements and architecture for SMART solution is given. Analysis is given divided into 2 subchapters below. Software modules for data integration, export and import will be done later, regarding special requests.

General diagram structure is shown in Fig. 5.7.
5.2.1 Software modules of the SMART RTYM System

Two main software modules will be developed. Both modules will be merged into one complete application for the SMART ADSS (Advisory Decision Support System) for management of the marshalling yard and they are shown in Fig. 5.8.

First software module is Visualization and planning of marshalling yard. This module will enable complete visual representation of marshalling yard layout: sidings, wagons positions, locomotives, etc. It will enable, complete insight into the current and possible (suggested) layouts of the freight trains in yard. Connection with second module of the application will be enabled. Suggestions/Propositions from second module (optimization module) will be displayed as possible solutions of marshaling yard layouts. Vector graphics will be used, in order to create scalable graphical representations of marshalling yard. Everything on the drawing canvas will be movable, so that operators can manually move wagons, or even complete trains if suggested solutions do not comply with the real situation.

Second software module is a tool for the optimization of deviations in decision making processes. This module will enable real time optimization of deviations in decision making processes. It will include optimization and AI techniques, in order to respond to the disturbances in timetable, infrastructure resources, yard staff and other reasons for different deviations described in previous reports. In Deliverable D5.1, detailed use case analysis of all scenarios for deviations in defined decision making processes will be described.

Both modules are very important for the realization of the software application. In this stage of the research, potential features of the application are defined:

- Application will be created in such manner that it can work as online web application and in offline mode, as standard desktop application. The main reason for this is security: protection of the data and structure of the system.
- Both modules will have Front End part oriented to the user, and Back End part which contains business logic of the application. Of course, some of the business logic can be implemented in Front End section as well.
- Marshalling yard data will be inserted and organized in relation manner, through RDBMS (Relation Database Management System) – MySQL database is chosen as preferable storage system.
- Front End will be realized in JavaScript (JS) and supporting libraries. Back End will be based on Java or Python programming languages, or on combination of both, Fig. 5.9 and Fig. 5.10.
D6.1 - Architectural design of the information system for supervision and management of marshalling yards

Figure 5.8 Modules of the application for real time marshalling yard management system

Figure 5.9 Prototype scheme of the application structure for the real time marshalling yard management system (Python based)
5.2.2 Software tools used for Data visualization and planning of marshalling yard management system (Java based)

- Front End – JQuery (standard, generally known JavaScript library) and D3.js (Data-Driven Documents) is a JavaScript library for manipulating documents based on data. The example for one of analysed marshalling yard, Popovac, Serbia is shown in Fig.5.11. D3 helps you bring data to life using HTML, SVG, and CSS. D3’s emphasis on web standards gives you the full capabilities of modern browsers without tying yourself to a proprietary framework, combining powerful visualization components and a data-driven approach to DOM manipulation. D3 allows you to bind arbitrary data to a Document Object Model (DOM), and then apply data-driven transformations to the document. For example, you can use D3 to generate an HTML table from an array of numbers. Or, use the same data to create an interactive SVG bar chart with smooth transitions and interaction. D3 is not a monolithic framework that seeks to provide every conceivable feature. Instead, D3 solves the crux of the problem: efficient manipulation of documents based on data. This avoids proprietary representation and affords extraordinary flexibility, exposing the full capabilities of web standards such as HTML, SVG, and CSS. With minimal overhead, D3 is extremely fast, supporting large datasets and dynamic behaviors for interaction and animation. D3’s functional style allows code reuse through a diverse collection of official and community-developed modules.
• Back End (Two possible approaches, or combination of both):
  o First approach is based on Java programming language - Java is a general-purpose computer programming language that is concurrent, class-based, object-oriented, and specifically designed to have as few implementation dependencies as possible. It is intended to let application developers "write once, run anywhere” (WORA), meaning that compiled Java code can run on all platforms that support Java without the need for recompilation.
    ▪ The Spring Framework provides a comprehensive programming and configuration model for modern Java-based enterprise applications (including Web applications) - on any kind of deployment platform. A key element of Spring is infrastructural support at the application level: Spring focuses on the "plumbing” of enterprise applications so that teams can focus on application-level business logic, without unnecessary ties to specific deployment environments.
    ▪ JavaFX is a set of graphics and media packages that enables developers to design, create, test, debug, and deploy rich client applications that operate consistently across diverse platforms.
  o Second approach is based on Python programming language which is very popular among scientists. Python is a powerful high-level, object-oriented programming language. It has simple easy-to-use syntax, and great number of libraries for different fields. Excellent graphic libraries for visualization (Cairo, PyGame, etc.), enable creation of applications with lots of vector and raster drawings. Also, it has a great Django web application framework which enables creation of rich business web applications.

Figure 5.11 Layout of Marshalling yard- Popovac, Serbia – SVG example

5.2.3 Software tools used for Optimization of marshalling Yard module

This module follows up with previous module. Both modules are integrated, so both Java and Python can be used.

• Front End – Same tools as for the previous module
• Back End (Two possible approaches, or combination of both):
  o Java has a great number of statistics, optimization and Artificial Intelligence (AI) libraries.
  o Python has of great number of libraries for scientific calculations, statistics, machine learning, deep learning, etc.
6. DATABASE DESIGN

Database design of SMART ADSS is presented in this Chapter. Database consists of two main parts. The first part provides all necessary static data for the SMART ADSS system. Logic data model of static data is given below.

The second part provides all necessary data (mainly dynamic) for selection of optimal solution when deviations in decision making processes occur. Detailed design of this part of database will be presented in line with developed and selected algorithms for optimization. It will be described in details in Deliverable D5.3.

6.1 Logic data model (Prototype)

6.1.1 E/R model of TIMETABLE, TRAINS and WAGONS

<table>
<thead>
<tr>
<th>TIMETABLE ENTITY</th>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IDTimeTable</td>
<td>Unique attribute (Primary key in database) for Timetable Entity [INT]</td>
</tr>
<tr>
<td></td>
<td>IDTrain</td>
<td>Foreign Key which connects TRAIN Entity with TIMETABLE entity [INT]</td>
</tr>
<tr>
<td></td>
<td>DispatchTimeTable</td>
<td>This parameter is giving information about possible deviation in regard to Timetable [DATE/TIME]</td>
</tr>
<tr>
<td></td>
<td>Attributes i..k</td>
<td>Possible additional attributes which will be add during development.</td>
</tr>
<tr>
<td>Definition</td>
<td>Attributes</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>IDTrain</td>
<td>Unique attribute (Primary Key in database) [INT]</td>
<td></td>
</tr>
<tr>
<td>TrainType</td>
<td>D4.1: 7.1 Train classification: According the type of transported goods and transportation speed, freight trains are divided into express freight train, direct freight trains, pick-up trains, military freight trains, breakdown freight trains, service freight trains etc. [INT] This parameter is important for determination of priority activities in Marshalling yard.</td>
<td></td>
</tr>
<tr>
<td>TrainNumber</td>
<td>This parameter is giving general information about the train (D4.1 7.1 Train classification) [VARCHAR]</td>
<td></td>
</tr>
<tr>
<td>DispatchTimeStarting</td>
<td>This parameter is giving information about possible deviation regarding to Timetable [DATETIME]</td>
<td></td>
</tr>
<tr>
<td>TrainWeightPerAxle</td>
<td>This parameter is required for calculating the maximal possible vehicle axle load and the maximum load. (Limitations of railway traffic direction) [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>TrainMassInTones</td>
<td>This parameter is required for calculating the maximal possible vehicle axle load and the maximum load. (Limitations of railway traffic direction) Ability of locomotive and loading sidings. [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>TrainLengthInMeters</td>
<td>This parameter is required for estimating the maximal possible train length. (Limitations of railway traffic direction) [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>TrainComposition</td>
<td>Load type (full/empty) [VARCHAR]</td>
<td></td>
</tr>
<tr>
<td>Attributes i..k</td>
<td>Possible additional attributes which will be add during development.</td>
<td></td>
</tr>
<tr>
<td>Definition</td>
<td>Attributes</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>IDWagon</td>
<td>Unique attribute (Primary Key in database) [INT]</td>
<td></td>
</tr>
<tr>
<td>WagonSeries</td>
<td>This parameter defines wagon type - technical-exploitation characteristic [VARCHAR]</td>
<td></td>
</tr>
<tr>
<td>NumberWagonAxles</td>
<td>This parameter is required for calculating the maximal possible vehicle axle load and the maximum load. (Limitations of railway traffic direction) [INT]</td>
<td></td>
</tr>
<tr>
<td>WagonLength</td>
<td>This parameter is used in calculation of train length [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>WagonMass</td>
<td>This parameter is used in calculation of train mass [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>NetMassCargo</td>
<td>This parameter is used in calculation of train mass [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>BrakedWeight</td>
<td>This parameter is important for calculation of train braking Characteristics [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>TypeOfCargo</td>
<td>Load type (is there special type of load that needs special treatment) [VARCHAR]</td>
<td></td>
</tr>
<tr>
<td>Attributes i..k</td>
<td>Possible additional attributes which will be add during development.</td>
<td></td>
</tr>
</tbody>
</table>
Defined Relationships

- Train and Wagon are connected by N – M relationship. One train can have multiple (N) Wagons, and one Wagon can in some context belong to multiple (M) Trains.
- Timetable and Train – This relationship is defined as 1 – N because, for one year, one train is shown once in the timetable. Also, train is composition of different wagons, so it is always possible to create new Train by the composition of different wagons.
- Wagons are connected to the Timetable by the Train Entity.

Applying this kind of connections between basic entities, dynamic change of train composition is enabled. The cause for this can be some disturbance in the plan. Of course, it should be noted that this is prototype version of the data model, so additional changes can be done.
E/R Logical Model of TIMETABLE, TRAIN and WAGON entities

Relations between Entities re defined

TIMETABLE

- IDTimeTable
- IDTrain
- DispatchTime

WAGON

- IDWagon
- WagonSeries
- NumberWagonAxles
- NetMassCargo
- Attributes i..k
- TypeOfCargo

TRAIN

- IDTrain
- IDTRain
- DispatchTimeStarting
- TrainNumber
- TrainType
- TrainMassInTones
- TrainLengthInMeters
- TrainComposition

- TrainWeightPerAxle
- Attributes i.k
- NetMassCargo
- BrakedWeight
- WagonMass
- WagonLength
- Type

Relations:
- 1:1 IDTimeTable to IDTrain
- N:1 Wagon to Train
- 1:1 Train to IDTrain
- ST M:1 Train to Wagon
### 6.1.2 E/R model of SIDING, SIDINGS GROUP and WAGON

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IDSiding</strong></td>
<td>Unique attribute (Primary Key in database)</td>
</tr>
<tr>
<td></td>
<td>[INT]</td>
</tr>
<tr>
<td><strong>SidingPurpose</strong></td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td></td>
<td>[VARCHAR]</td>
</tr>
<tr>
<td><strong>IDSGroup</strong></td>
<td>Foreign Key which defines Sidings and Group</td>
</tr>
<tr>
<td></td>
<td>[INT]</td>
</tr>
<tr>
<td><strong>SidingLength</strong></td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td></td>
<td>[DOUBLE]</td>
</tr>
<tr>
<td><strong>SidingType</strong></td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td></td>
<td>[INT]</td>
</tr>
<tr>
<td><strong>MasPerAxle</strong></td>
<td>This parameter is required for calculating the allowable vehicle axle load and the maximum load</td>
</tr>
<tr>
<td></td>
<td>[DOUBLE]</td>
</tr>
<tr>
<td><strong>Attributes i..k</strong></td>
<td>Possible additional attributes which will be add during development.</td>
</tr>
</tbody>
</table>
## SIDINGGROUP Entity

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDSGroup</td>
<td>Unique attribute (Primary Key in database) [INT]</td>
</tr>
<tr>
<td>NumberSidingGroup</td>
<td>This parameter is required for calculating the capacity of the yard. [INT]</td>
</tr>
<tr>
<td>Attributes i..k</td>
<td>Possible additional attributes which will be add during development.</td>
</tr>
</tbody>
</table>

### Defined Relationships
- Siding and Group – This relationship is defined as 1 – N because, it is presumed that one siding can belong to only one group.
- Wagons an Siding are connected many to many, because one wagon can move between sidings.

Of course, is should be noted that this is prototype version of the data model, so additional changes can be done.
E/R Logical Model of SIDING, SIDINGGROUPD and WAGON entities

Relations between Entities are defined
### 6.1.3 General time properties of the marshaling Yard added as entity OperativeTimes

<table>
<thead>
<tr>
<th>OPERATIVETIMES Entity</th>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDOP</td>
<td>Unique attribute (Primary Key in database) [INT]</td>
<td></td>
</tr>
<tr>
<td>MeanTimePrepWagonRec</td>
<td>It is the operative time for wagons uncoupling. [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>MeanTimeLostWagonRec</td>
<td>It is the waiting time for documents exchange and train identification. [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>MeanTimePrepWagonDir</td>
<td>It is the operative time for wagons coupling. [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>MeanTimeCommInspecWagon</td>
<td>This parameter is required for calculating the capacity of the yard [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>MeanTimeTechnicalInspecWagon</td>
<td>This parameter is required for calculating the capacity of the yard [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>MeanTimeUncouplingDepTrainLoc</td>
<td>It is the operative time for train locomotive uncoupling. [DOUBLE]</td>
<td></td>
</tr>
<tr>
<td>MeanTimeCreatinShuntingLists</td>
<td>This parameter is required for calculating the waiting time before the shunting activities. [DOUBLE]</td>
<td></td>
</tr>
</tbody>
</table>
### MeanTimeOrdersMarshallingOffice
This parameter is required for calculating the waiting time before the manoeuvres. [DOUBLE]

### MeanTimeUncouplingPreparationWagons
This parameter is required for calculating the capacity of the yard. [DOUBLE]

### MeanTimeBetweenThrowing
This parameter is required for calculating the maximum potential of the hump or shunting locomotive. [DOUBLE]

### MeanTimeShuntingGroupWagons
It is the average operative time for shunting the group of wagons. [DOUBLE]

### MeanTimeFormingSingleGroupTrain
It is the average operative time for forming one single train. [DOUBLE]

### MeanTimeFormingGroupTrains
It is the average operative time for forming two group train. [DOUBLE]

### Attributes i..k
Possible additional attributes which will be added during development.

---

#### General equipment properties of the Marshalling Yard added as entity Equipment

<table>
<thead>
<tr>
<th>EQUIPMENT Entity</th>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDOP</td>
<td>Unique attribute (Primary Key in database)</td>
<td>[INT]</td>
</tr>
</tbody>
</table>
### E/R Logical Model of EQUIPMENT and OPERATIVETIMES entities

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NumShuntingLocomotives</td>
<td>This parameter is required for calculating the shunting process. [INT]</td>
</tr>
<tr>
<td>TypeShuntingLocomotive</td>
<td>This parameter is required for estimation the shunting and marshalling yard processes. [VARCHAR]</td>
</tr>
<tr>
<td>OperativeLengthShunting</td>
<td>This parameter is required for calculating the shunting process. [VARCHAR]</td>
</tr>
<tr>
<td>NumberHumpRetarders</td>
<td>This parameter is required for calculating the shunting process. [INT]</td>
</tr>
<tr>
<td>LevelOfAutomation</td>
<td>This parameter is required for calculating the shunting process. [VARCHAR]</td>
</tr>
<tr>
<td>Attributes i..k</td>
<td>Possible additional attributes which will be add during development.</td>
</tr>
</tbody>
</table>
D6.1 - Architectural design of the information system for supervision and management of marshalling yards

Attributes i-k

NumShuntingLocomotives

OperativeLengthShunting

TypeShuntingLocomotive

TypeShuntingRetarders

NumberHumpRetarders

LevelOfAutomation

IDEQ

OperativeTimes

Mean_Times_Technological...

Attributes i-k

IDOP
6.1.4 E/R model of TRAFICDIRECTION and TRAFICDIRECTIONPARAMETERS

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDTD</td>
<td>Unique attribute (Primary Key in database) [INT]</td>
</tr>
<tr>
<td>TrafficDirection</td>
<td>Number of origins and destinations of the traffic through the yard. [INT]</td>
</tr>
<tr>
<td>Attributes i-k</td>
<td>Possible additional attributes which will be add during development.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDTDP</td>
<td>Unique attribute (Primary Key in database) [INT]</td>
</tr>
<tr>
<td>LocomotiveType</td>
<td>Number of origins and destinations of the traffic through the yard. [INT]</td>
</tr>
<tr>
<td>MaximumTrainLength</td>
<td>Total train length [DOUBLE]</td>
</tr>
<tr>
<td>Limitations</td>
<td>This parameter is required for calculating the allowable vehicle axle load and the maximum load; use of electrical or diesel locomotive; maximal train length etc. [LIMITATIONS]</td>
</tr>
<tr>
<td>Attributes i-k</td>
<td>Possible additional attributes which will be add during development.</td>
</tr>
</tbody>
</table>
Defined Relationships

- TrafficDirection and Siding – This relationship is defined as M – N because, it is presumed that many directions can happen on many siding.
- TrafficDirectionParameters – This relationship is currently defined as M – N, but it will be put under revision.

Of course, it should be noted that this is prototype version of the data model, so additional changes can be done
E/R Logical Model of TRAFFICDIRECTIONS and TRAFFICDIRECTIONSPARAMETERS entities
6.1.5  E/R Logical Model of Marshalling Yard (Merged diagram)
7. CONCLUSION

In this document, overall framework of real-time marshalling yard management problem is presented. This report Deliverable D6.1 is the first result of activities from WP 6 and presents the background for further activities on WP6 - Development of web-based information system for supervision and management of marshalling yards.

In the document three important issues are presented. The first one is the state of the art of existing IT applications regarding marshalling yard management systems. At the end of that part, comparative analysis is presented and directions for novelties and beyond state of the art performances of SMART ADSS system.

The second issue is architectural design of SMART ADSS system where concept solution is presented and description of main software modules. Two software modules are pointed out as the most important: Visual and planning module and Optimization module.

The third issue is database design. It is noted that there are two main parts of database. One is for static data and the second for storing information and selection of optimal solutions in case of deviations in decision making processes in marshalling yards. The logic data model for the first part of database is presented.
8. REFERENCES


[11] SMART Deliverable D4.2- Overall framework architecture and list of requirements for real-time marshalling yard management system, 2017

[12] ARCC Deliverable D2.1 - Description of automation/optimization requirements and capabilities of decision making process in Marshalling yards and Terminals, 2017


