SMART

Smart Automation of Rail Transport

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Deliverable D4.2

Overall framework architecture and list of requirements for real-time marshalling yard management system

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Responsible person: Florian Eßer
D4.2 - Overall framework architecture and list of requirements for real-time marshalling yard management system

Document Contributions History

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Date</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florian Eßer (RWTH)</td>
<td>16/02/2017</td>
<td>Initial draft, document structure and content</td>
</tr>
<tr>
<td>Miloš Simonović (UNI)</td>
<td>01/03/2017</td>
<td>Review of document structure and content</td>
</tr>
<tr>
<td>Dušan Stamenković (TUS)</td>
<td>27/03/2017</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>Sanel Purgić (TUS)</td>
<td>22/03/2017</td>
<td>Subchapter 4.3</td>
</tr>
<tr>
<td>Lubomir Dimitrov (TUS)</td>
<td>22/03/2017</td>
<td>Subchapter 4.2</td>
</tr>
<tr>
<td>Miloš Simonović (UNI)</td>
<td>27/03/2017</td>
<td>Chapter 3, Abstract, Report Scope</td>
</tr>
<tr>
<td>Aleksandar Miltenović (UNI)</td>
<td>27/03/2017</td>
<td>Subchapters 5.2, 5.3 and 5.4</td>
</tr>
<tr>
<td>Miloš Simonović (UNI)</td>
<td>30/03/2017</td>
<td>Subchapter 4.1, 4.4, Chapter 6</td>
</tr>
<tr>
<td>Miloš Simonović (UNI)</td>
<td>30/03/2017</td>
<td>Final draft</td>
</tr>
<tr>
<td>Florian Eßer (RWTH)</td>
<td>30/03/2017</td>
<td>Reviewing</td>
</tr>
<tr>
<td>Danijela Ristić Durrant (UB)</td>
<td>30/03/2017</td>
<td>Reviewing</td>
</tr>
</tbody>
</table>
## Abbreviations and Acronyms

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<tr>
<td>ARCC</td>
<td>Automated Rail Cargo Consortium</td>
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<td>ERTMS</td>
<td>European Rail Traffic Management System</td>
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<tr>
<td>GoA4</td>
<td>Grade of Automation</td>
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<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>RTMYM</td>
<td>Real Time Marshalling Yard Management</td>
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<td>S2R JU</td>
<td>Shift2Rail Joint Undertaking</td>
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<td>SL</td>
<td>Single Wagon</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>
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<tr>
<td>TD</td>
<td>Technical Demonstrator</td>
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<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
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<td>UIC</td>
<td>International Union of Railways</td>
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<td>WP</td>
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1. ABSTRACT

Deliverable D4.2 - Overall framework architecture and list of requirements for real-time marshalling yard management system, is deliverable of Work Package 4 of SMART project, Analysis, Requirements and Specification of real-time marshalling yard management system D4.2 includes overall architecture framework of the yard management problem, based on the operational research techniques that cover simulation based rules, heuristic, dynamic programming with problem decomposition and mathematical programming. This deliverable also includes a report on list of requirements for real-time marshalling yard management, forming questionnaire form for marshalling yard operational requirements that will be used later for data collecting (task 5.2 of WP5) and forming of database (task 6.1. and 6.2 of WP6).

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 short (up to 20 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 open and TAF/TSI 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, as well as planning of wagons sorting (marshalling) using the machine learning based optimization algorithm. The information system will be able to export data to other systems.

Web-based information system will consist of two modules that cooperate:

- Visual representation module
- Module for marshalling process planning

In order to provide necessary specification and to define main processes for designing information system as start-up activities, beside analysis of real marshalling yards and analysis of marshalling yard sorting methods done in deliverable D4.1, description of overall framework architecture of the yard management problem and list of requirements for real-time marshalling yard management are needed.

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 D4.2 is in line with established cooperation.

2. EXECUTIVE SUMMARY AND REPORT SCOPE

This report is the second deliverable for Work Package 4 under Real Time Marshalling Yard Management working stream of SMART project.

The aim of this deliverable is to give overall architecture framework of the yard management problem, based on the operational research techniques that cover simulation based rules, heuristic, dynamic programming with problem decomposition and mathematical programming. This deliverable also includes a report on list of requirements for real-time marshalling yard management, forming questionnaire form for marshalling yard operational requirements further used for data collecting (task 5.2 of WP5) and forming of database (task 6.1. and 6.2 of WP6).

This report is the part of the results of activities in T4.1 (Analysis of the marshalling yard management problem), T4.2 (Analysis of train classification process in marshalling yard), T4.3 (Analysis of marshalling yard sorting methods) and T4.4 (Forming of requirements list for real-time marshalling yard management).

An introduction is given in Chapter 3, followed by Overall architecture of Real time Yard Management problem presented in Chapter 4. This includes sections about decision making processes in general and description of the crucial ones for marshalling yard management problem for designing information system. Beside information gathered in D4.1 data from literature review used to complete all variations of potential deviations important for proper design.

The analysis of the marshalling yard management problem done by analyzing Real Marshalling Yards: Nis Ranžirna – Popovac, Serbia and Karnobat, Bulgaria in D4.1 is used for defining main processes in marshalling yard and point out decision making processes as a subject of our research. In addition, data from analysis of the marshaling yard Ranzirna Beograd, Serbia are also used.

Also there are subchapters concerning technical standards and standardization processes needed to be fulfilled.

Detailed list of requirements for real time yard management systems is given in Chapter 5. This chapter involves divisions based on different criteria for needed requirements. Two main divisions are presented in separate subchapters according to dynamic criteria and according to static criteria. As a separate subchapter a questionnaire for forming database of marshalling yards is given.

Chapter 6 concludes report.

The following documents provide additional perspectives for the present work:

- D9.1 Kick-off meeting report
- D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods
3. INTRODUCTION

In this introductory chapter we give general overview of a framework for focusing on the relevant domain knowledge prerequisites of SMART requirements regarding real time marshalling yard working stream. In this deliverable a global framework for analysis is done respect to important issues and objectives of the whole project working stream. At the end, we conclude this chapter by targeting some activities that will be done in WP 5 and WP 6 as a logical continuation of WP 4.

In order to better understand goal of SMART project regarding marshalling yard working stream, observation and perspectives of rail freight transport has to be done.

3.1 Context and motivation

The research and innovation activities should evolve within working stream Real Time Yard Management System, in line with the Shift2Rail 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 collaboratively by the S2R JU 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 subsystems 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 where the project working stream Real Time Yard Management System is addressed.

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 a 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 and level of detail, where 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 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 defined in Project Call, 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 ARCC consortium, the mutual 2 way direction cooperation is developed between SMART and ARCC partners.

As it stated in 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 on Fig.3.2.
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. 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 wagons 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. 3.3. 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

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
  Visual representation 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
Module for marshalling process planning will provide process realization according to TAF/TSI standards and optimization module will provide optimal or near optimal solution in real-time.

Figure 3.3 SMART real time marshaling yard management system

3.2 Single Wagon Load (SWL) concept

As it stated in previous chapter beside optimization of available resources in marshalling yards, very important issue is to provide monitoring of wagons based on the concept of Single Wagon Load. Monitoring of each wagon on every marshalling yard is crucial for operators to provide reliable freight transportation and to be more competitive to road transport. To provide more reliable and flexible freight transportation system according New Single Wagon Load system is one of the key elements of MAAP TD5.2 Access and Operations.

Single Wagon Load (SWL) represents the transport of freight in individual railway wagons or groups of wagons where the shipment is less than a whole trainload. The SWL supply includes grouping and sorting of wagons in order to assemble full trains with different shipments, in order to take advantage of the full train size and, thus, increasing the productivity. Grouping and sorting can take place through marshalling in dedicated yards where each train is disassembled and the groups of wagons are classified to form new full load trains for the next yard, or more simplified arrangement with removal or addition of groups of wagons at intermediate stops. Any kind of wagons including the one loaded with combined transport units can be moved in SWL supply chain.

The fact that sorting and grouping wagons are crucial activities for SWL brings us to conclusion that marshalling yards are the heart of SWL concept, in general.

Recent EC study [2] estimated that SWL accounts for 27% of rail freight as it is shown on Fig.3.4. It is obvious that market share of SWL v. full trainload is decreasing. On the other hand, SWL is also a key feeder for rail freight:
- Only 20-30% of full trains are shuttles
- 70-80% of full trains use SWL to distribute wagons between marshalling yards

![Figure 3.4 Market share of SWL v. full trainload [3]](image)

This mentioned above decreasing of market share is mainly due to low quality and unfavorable cost structures which led to the cutting of the least cost-effective tracks, yards and sidings as well as the general downscaling of SWL transport networks. The almost non-existent internal competitiveness, together with the strong competition through conventional block trains, intermodal transport and road transport services, built the background of a challenging future for this production scheme. In detail, the decrease of SWL market shares is supported by the following key factors [4]:

- high fixed costs linked to infrastructure and operation of marshalling yards;
- insufficient SWL service profitability due to slow and expensive “last mile” operations and poor utilization rates of resources, e.g. trains and wagons;
- additional costs to be borne by the shippers to ensure wagon handling in their private sidings;
- insufficient SWL service quality and transport time compared to other transport modes, especially in competition with road (increasingly important in state-of-the-art logistics);
- negligible competition in the SWL segment because of heavy fixed costs, complex operations and the need for a minimum critical mass of traffic;
- loss of profitable markets/transports from SWL rail operators to intermodal competitors and production systems (wagonload block trains/intermodal services) and
- increasingly limited possibilities to cross-subsidize SWL from the profitable full trainload (FTL) business.
The second important issue is the fact that there are different levels of SWL traffic across the different European countries, as it is shown on Fig 3.5. That fact makes SWL concept and future directions of its improvement more complex from perspective of integration and standardization of rail freight services and their general market share. Regarding optimization and objectives of SMART project working stream, it becomes more complicated for collecting relevant data because of different conditions and different ambitions on national level for SWL in European countries. Also, it is necessary to take into account EU countries and non EU countries where statistical data are not available for SWL share and traffic.

As it stated above, marshalling yards represent key element for a flexible and reliable SWL concept of freight transportation. But, there are significant changes in usage and number of marshalling yards across the Europe, in general. The number of marshalling yards is decreasing rapidly in previous years. According to [2] about 35% of marshalling yards reported to be closed between 2010 and 2012. The similar situation is with freight stations also. In Fig.3.6 and 3.7 the density of existing marshalling yards and freight stations per 1000 km of rail network is shown.
Regarding SMART objectives and challenges this situation yields to the following conclusions:

- decreasing number of marshalling yards makes easier potential optimization of real time yard network (smaller number of network nodes)
- optimization of marshalling processes and other operations in individual marshalling yard becomes more complex (more inputs and outputs and more complex demands from operators)
- operations in existing marshalling yards become higher risk processes regarding punctuality and reliability for freight transportation services

One more important issue to be considered is the cost services in marshalling yards as the structural part of SWL cost. Cost structures appear to be quite different among the RUs for which data are available. In addition, specific local factors appear to have strong impacts (e.g. level of infrastructure charges, average length of the "long haul" trips, adopted production models etc.). The cost structure of SWL production chain is shown in Fig.3.9.
The analysis of this cost structure shows that services in first and last marshalling yards are 15% of total costs. If we consider also the intermediate marshalling (7%), the total marshalling costs represent 22% of the total. These costs together with distribution costs rise to 47% percent. As a conclusion, it is obvious that marshalling yard services and operations are very important for general cost of freight transportation.

Regarding SMART project working stream and expected results, cost effectiveness will be improved with real-time optimization of marshalling operations that will decrease number of needed marshalling operations.

As the conclusion of this subchapter, the following issues shall be considered from perspective of SWL improvements with Real-time yard management system:

- Real-time yard management system will provide monitoring of SWL in specified marshalling yard that yields to better reliability and flexibility
- The possibility of providing layout of present SWL in specified marshalling yard yields to better allocation and planning trip and potential SWL trip duration time

### 3.3 Further work

This is the second deliverable of WP4 and the basis for modeling required processes in marshalling yards that will be presented in the D5.1.

There are three remain deliverables as substantial part of overall process analysis and specification of requirements for Real-time yard management system as result of SMART project working stream. These three deliverables are D5.1 Identification and generation of relevant information and data flow between input and output requirements, D5.2 Integration data in unique database of EU marshalling yards and D6.1 Architectural design of the information system for supervision and management of marshalling yards. These three deliverables together with D4.1 and D4.2 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. 3.10 shows timeline of SMART deliverables regarding process analysis and providing needed information for design requested simulation system.

**Figure 3.10 Timeline of SMART deliverables for providing needed information for real-time yard management system**
4. OVERALL ARCHITECTURE FRAMEWORK FOR REAL TIME MARSHALLING YARD MANAGEMENT SYSTEM

4.1 Introduction

The scope for defining overall framework for real-time marshalling yard management system is defined in MAAP TD5.2 Access and Operations. Therefore, in addition to the various hardware developments in other TDs, this TD is focused on improved service planning and operation, which also supports a better utilization of the available capacity.

Marshalling yards and sidings with collecting and distributing function in the rail freight system are key elements for delivering last mile operation and have a decisive impact on punctuality, availability and cost efficiency of rail freight services. This MAAP TD serves to optimize access and operations of marshalling yards and sidings.

Large local hubs consist of a complex infrastructure of tracks, switches, crossings and infrastructure service facilities such as gravity humps and wagon weighbridges. For planning and steering of transit through local hubs, a complex target system exists for punctual fulfillment of operational requirements, e.g. wagon interchange and loading point operations.

There are 3 key issues to be considered according to TD 5.2:

- Optimization of operations in marshalling yards in term of optimizing overall transport time
- Improvement of rail freight operation in conjunction with passenger traffic in order to maximize utilization of existing network
- Improvement of rail freight sector in terms of information, planning and monitoring systems

The SMART project working stream directly deals with first and third issue and indirectly with second issue and expected results should provide some benefits regarding these key issues.

Regarding MAAP TD5.2, specific achievements to be delivered:

1. Improved methods for annual and ad-hoc timetable planning
2. Methods to analyze timetable efficiency and robustness in advance and in follow up process
3. Decision support and automation in timetable planning process (including the management of dangerous goods trains and their interaction with sensible targets along the route)
4. Improved methods handling larger disturbances on the line and in yards and terminals in real time
5. Slot planning/management (cross-border/cross-network)
6. ETA calculation for operation
7. Real-time monitoring of resources availability on yards, nodes and network.
8. A real-time yard management system
9. Standardized data formats / new interfaces in coordination with current TAF/TSI standards
10. Increasing speed of freight trains during day time traffic to increase line capacity
11. Systems for shared usage of marshalling yards between different service providers

The eighth achievement should be realized by SMART activities but beside that some other achievements will also be reached.

According to [1], process of reaching above mentioned achievements is based on two step approach.
In a first step operations research and accurate modeling in a scalable model for any size and type of hubs, yards and connecting sidings will result in a simulation of resources within existing infrastructure. Dynamic simulation offers the possibility to deeply analyze process flows and find the optimal process scenario through comparative evaluation of simulation runs.

In a second step, based on a stress test of the simulation, software development and testing will start, including the definition of rules, data preparation, processing and interface design, for single stream dynamic planning, disposition and knowledge management. The aim is to produce an IT prototype with HMI interface which can be validated in live demonstration for a selected large and complex hub (TRL 7).

Overall framework architecture real-time marshalling yard management system can be described from perspective of three key elements regarding the objective to have reliable and flexible rail freight service.

These are the following elements:

- Decision-making processes in marshalling yards
- Standards
- Optimization of processes in marshalling yards

Each of these elements is described separately in the following subchapters.

4.2 Decision making processes in marshalling yards

Planning the operational procedures in a railway marshalling yard is a very important and complex problem. In most cases, classification procedures in marshalling yards are planned manually by highly experienced dispatchers. The fact that marshalling process depends on experience and decisions made by one or more dispatchers put this process in group of decision making and high risk processes.

Investigation and process recording in different marshalling yards shows that there are no documented or systematic rules or guides to help operators with the planning tasks.

Analysis of two marshalling yards in Serbia and in Bulgaria, given in Deliverable D4.1, facts gathered from cooperation with ARCC and data collected from literature research show that classification procedure is the most influent procedure in marshalling yard, regarding overall time that one train or single wagon spend in marshalling yard. In addition, analysis of Belgrade marshalling yard (Ranzirna Beograd) was done and analyzed data are involved in this report.

4.2.1 Marshalling process as decision making process

The problem of marshaling yards’ operations planning not only has a complex model and intractable algorithm, but also a lot of uncertainty factors exist. Different countries, different regions and different production environments vary their description methods, in addition to optimization objectives and constraint conditions. It is very difficult for researchers from related fields to learn from each other and experimental results cannot be compared.

As it described in detail in [5], the main marshalling process by following a wagon through its life cycle in a standard marshalling yard is presented. The marshalling process is already described in D4.1 but for the purpose of defining decisions during marshalling process it is done again on similar way.

The processing of a wagon in a marshalling yard begins with the arrival of a train. This train is called inbound train. Every inbound train gets assigned to a suitable track in the receiving yard (RY), where the trains are inspected and their wagons are decoupled.
Decoupling refers to the separation of wagons that do not share the same destination. Wagons that appear sequentially on a track and share the same destination are called a block. In most cases those blocks stay together and are processed jointly throughout the process. After the separation is completed, the wagons are pushed over the hump by a shunting engine. The hump enables the wagons to enter the classification bowl without external propulsion by following a downhill system of tracks and automated switches. At this point three important decisions in respect to performance have to be made. Those are the following three decisions:

- **Roll in sequence**
  The hump can only be used for the roll-in of a single inbound train at a time. Since there is no way for a wagon to overtake a preceding wagon on a track, all wagons that have been rolled-in before other wagons are standing strictly before them. That is why the roll-in sequence is very important. In addition, the hump is operated at its capacity limit in order to process as many inbound trains as possible. This results in the need to select the next inbound train to be rolled-in from the already processed trains. This number increases and makes this decision more difficult as the yard approaches its capacity limit.

- **Outbound train assignment**
  Every wagon has to leave the shunting yard with a suitable outbound train. All wagons have a predefined destination which allows for identification of possible outbound trains serving this destination. Usually wagons will be assigned to the next eligible outbound train, but other aspects can be taken into account which may lead to different assignments. This decision is driven by the need to reduce the number of wagons in the classification bowl (fewer outbound trains per destination) and the need to minimize marshalling effort (more outbound trains per destination).

- **Classification track assignment**
  This decision assigns a certain track in the classification bowl to a wagon. With this information the automated guidance system can lead the wagon to that track. This decision is trivial as long as there are more tracks than outbound trains. Unfortunately, this precondition is rarely met in the real world. In general, a classification track stores wagons for more than one outbound train. The idea is to keep the number of tracks per outbound train as small as possible. This decision is based on characteristics of other outbound trains at a certain track and the location of the tracks already hosting wagons of a certain outbound train.

The sum of these three decisions determines the position of every wagon in the classification bowl. This information is very important from the perspective of RU and availability of monitoring wagons by operators as one of the requested goals of the project. The actual position of each wagons on classification bowl and its place related to other wagons on classification bowl are of the highest importance either for optimization of marshalling process either for visual representation.

The classification bowl consists of a number of large, parallel tracks, each of which can be used to store wagons. The tracks can only be entered by un-propelled wagons rolling-in via the hump from one end, and by shunting engines from the other end. At some point in time before the scheduled due time of an outbound train, the train has to be prepared and cleared for exit.

Marshalling process refers to collecting wagons from their respective tracks, called source tracks, and moving them to a common track, called the building track. This building track is dynamically chosen from all suitable tracks in the Classification bowl or Departure Yard for each marshalling problem instance. When all wagons are on the building track they are joined together and become the outbound train. Outbound trains often consist of one or more blocks. A block refers to wagons that share the same destination. Most commonly the blocks correspond to the planned stops of the outbound train. This
enables the train operator to deliver the wagons at their respective destination feeder line with minimal effort by just decoupling the last block at each stop.

There are generally two ways of marshalling a train:

- The track assignment can be made in such manner that all wagons standing on a track can be pulled back on the hump and being rolled-in a number of times until the wagons of the outbound train are standing consecutively on a track in the classification bowl. Depending on the number of roll-ins, this process is referred to as single- or multi-stage sorting as it is described in D4.1.
- A shunting engine can be used to collect the wagons from their respective tracks and transfer them to the building track manually. This is sometimes referred to as flat shunting and in our case takes place between the Classification bowl and the Departure yard. This way of shunting is also described in D4.1.

The underlying planning problem of this alternative process in depth can also be discussed. The final stop of a wagon is the Departure yard. It is used to delay the exit of outbound trains until they are due.

In addition, there can be area called the Sorting bowl. This area is used to marshal outbound trains that have a large number of sequence constraints (multiple blocks), which can not be met efficiently using the main process. The sorting bowl has its own hump and operates independently from the main shunting yard.

The problem of marshalling a train is considered by using a single shunting engine. This problem is embedded in a sequence of decisions that have to be made in order to transform inbound trains into properly composed outbound trains.

In practice, these decisions are made in a just - in - time decisions and are not subject to overall optimization because of the fact that important information becomes available in time and decision are generally time-critical and irrevocable.

Those decisions are the following [5]:

1. Track assignment in receiving yard for inbound train.
2. Roll-in sequence of inbound trains.
3. Marshalling by humping
   (a) Assignment of individual wagons to actual outbound trains.
   (b) Assignment of individual wagons to tracks in the classification bowl.
4. Marshalling by shunting engine
   (a) Selection of building track.
   (b) Assembling outbound train by a sequence of pull-out operations.
5. Track assignment in departure yard.
6. Exiting sequence.

Many marshalling yards in Europe use more than one sorting mechanism. There are a number of reasons that prevent typical European marshalling yards to utilize the very efficient shunting based upon repeated roll-ins.

The main reasons are highly uncertain arrival times of inbound trains and the unfavorable ratio of number of blocks to number of classification tracks due to certain characteristics of the European railway system. These uncertain arrival times in combination with limited track capacity in the Receiving yard force shunting yard operators to utilize the hump at its capacity limit in order to guarantee the availability of receiving tracks for incoming trains. Trains can not wait in front of a yard for a receiving track to
become available, because they would block other freight or passenger trains. As a result, repeated roll-ins that would consume both track capacity in the Receiving yard as well as time of the hump are rarely executed. Furthermore, heterogeneous marshalling yard designs result in a high number of block sequence constraints due to operational or commercial requirements that further complicate the track assignment problem, hence creating the need for a second marshalling mechanism that does not consume scarce resources (Receiving yard and Hump). This second mechanism is called Flat Shunting or Marshalling by Shunting Engine. The number of blocks per track and the number of tracks, used to store blocks assigned to the same outbound train, can be very high, making the second marshalling step based on flat shunting more complicated and worthy of optimization.

As a conclusion of this marshalling process description from the perspective of decision making processes, the following issues can be marked:

- there are different types of marshalling yards and it is very difficult to make generalization for potential scenarios
- marshalling process is very complex process from decision making aspect
- there are many constraints related to decision making
- there are lot of variants of marshalling process that lead to different decisions

To conduct the analysis it is very important to use proper and sufficient information. This information should be relevant to the problem solution and should help to make criteria to evaluate different options.

4.2.2 Deviations in decision making process in marshalling yards

Deviations in decision making process could be objective and subjective.

Objective deviations could be a result from:

- Lack of information;
- Large number of data that have to be considered;
- A need of conducting many repeated observations, surveys, etc.
- Real time deviations in information flow
- Priorities that must be considered

Subjective factors could be:

- Incorrect information processing,
- Incompetence in solving problems;

Real time deviations in information flow.

- Deviation of the incoming trains from the plan (delay or arriving earlier).

The composition of freight trains is prescribed by timetable ie. annual traffic plan of trains. However, the real composition of the train may deviate from the plan. Each station from which the train is arriving have to send the analysis of the train to the next station after the train left the station. In this way, the marshalling yard during the day collect information about trains and wagons that come to the station as well as their final destination. Marshaling yard, on this way, has data on the composition of the train before the train arrives at the station. In case of train delays and limited yard resources, static user-defined rules and decision-making - based only on the experiences of the yard dispatcher - cannot ensure that yard operations are performed according to the priorities of punctuality and cost-efficiency.
• **Deviations in individual wagons modification.**

In carrying out the planned tasks, in the marshalling yard can arise unplanned situations such as found commercial or technical malfunction of individual wagons in train. The decision on the actions to be taken on that occasion (extraction of wagon, etc.) brings the train dispatcher in agreement with an operator who is represented in marshaling yard.

• **Unexpected repair or breakage of sections of rail line.**

Sometimes unexpected repair or interruption on sections of rail line can occur. In this case the train must stay at the marshaling yard and occupy extra space.

• **Unexpected repair or breakage of wagons.**

Sometimes the inspection shows that a certain wagon has problems and could not be used. In this case the wagon must be removed from the marshaling yard somehow and repaired later.

• **Deviations or incorrect weight of incoming trains or wagons.**

Many times the weight of the wagon does not correspond to the weight in the documents. The load must not exceed the permissible gross weight per axle, weight per meter and load profile of the respective tracks. Higher gross vehicle weight shall be placed, in principle, to the front of the train.

• **Priorities in cases of congested infrastructure or other priority policies.**

Priorities that must be considered in marshalling yards’ schedule. While each rail company has different wagon priority policies, normally a wagon's priority value is expressed in EUR/wagon-hour and is usually determined according to one or more of the following conditions:

- The type of goods (merchandise) loaded in the wagon.
- The wagon's consignor (some shippers receive preferential treatment with regards to rate and/or guaranteed arrival date).
- Whether or not the wagon has been designated as "special" (e.g., a refrigerator car, a tank car, or a double-stack wagon).
- Whether or not the wagon is "foreign"; i.e., the wagon is owned by another railway company.

There must be criteria for organization of marshalling yard functioning in case of “priority”. Usually the first criterion is extra payment. The following priority criteria recognize the importance to society of a service. In determining priority criteria, a special attention is to the importance of services for freight, and in particular of international services for freight. The procedures to be followed and the criteria to be used in case of priorities have to be determined in reference to the particular marshalling yard.

Where infrastructure has been declared to be congested, the infrastructure manager performed a capacity analysis and then follows the criteria policy for this particular marshalling yard.

**Extraordinary requests.** The marshalling yard manager meets the extraordinary requests by preparing an individual plan as quickly as possible.

Intelligent decision making on a real-time basis will be required and become a strategic element of automation and optimization in marshalling yards.
4.3 Standards

In order to provide rail freight transport with the technological means to achieve the business objectives and to address new needs and customer demands, the innovative IT solutions will be specified, designed and developed for improving freight transport stakeholder’s coordination with real time data exchange capabilities and enhanced planning tools. This should take advantage of existing cutting-edge technological solutions already successfully applied in other transport areas and business sectors (maritime, roads, smart cities, telecom etc.). [1]

System integration based on standardized electronic interfaces is therefore envisaged as one of the most relevant topics to be developed under this R&I area, and therefore, within TD5.2. In a multimodal freight transport environment, the need to integrate and manage a wide variety of different data, from different origins and natures, requires the use of high performance and distributed IT architectures which will be developed in this TD. The central objective is to bring in TD5.2 all relevant and added-value initiatives and ideas related to system integration and interoperability issues coming from related topics especially on IP2 and IP4. [1]

A real-time yard management system must have information and communication system that consist of one or more optimization algorithms coupled with information and communication system, where the important role is played by navigation (RFID, DGPS).

In order to efficiently use several different applications for planning improvements to rail freight operations together, data must be exported from one program and imported into another for further processing. This can be done by copying data between applications (a long and tedious process for programs with any significant amount of data) or by using an automatic data transfer program (transparent for the user). Several specialized interfaces between programs currently exist, but as the number of railway applications grows this solution becomes less efficient.

Transferring data between two particular programs requires that two different interfaces be developed (one for each direction of transfer). As the number of programs increases the number of possible data transfers increases significantly.

Clearly, the number of new interfaces to be developed for these new applications represents a great challenge to the railroad industry.

There are different European and international standards related to marshalling yards. However, most of them are dealing with purely infrastructural aspects of marshalling yards or with equipment requirements.

Some of standards regarding infrastructure in MY and indirectly related to MY processes are:

- prEN 50239:2016 - Railway applications - Radio remote control system of traction vehicle for shunting traffic;
- Other European standards dealing with technical requirements for different railway track elements like plain lines, switches, crossings etc.
Also some of standards are related to safety aspects of marshalling yards, concerning mostly the safety, the transport of dangerous goods or environmental aspects. These standards are:

- UIC Leaflet 201:2003 - Carriage of dangerous goods – Emergency planning guidance for rail marshalling yards;
- prEN 16860:2015 - Railway Applications - Requirements and general principles for securing payload in rail freight transport;
- Regulation VDI 2720-1:1997- Noise control by barriers outdoors etc.

All standards and regulations listed above have only indirect relation to marshalling yard processes and communication between marshalling yards.

Some of standards related directly to communication between marshalling yards and other railway stakeholders are described in text below.

Regarding implementation and fulfillment of standards, SMART Real-Time Marshalling Yard Management System for project purposes, has to provide two most important issues:

- data exchange in standard format – RailML is selected
- standardized business process in marshalling yards – TAF/TSI is mandatory

Figure 4.1 shows the standards relevant for SMART Real Time Marshalling Yard Management system for project purposes.

![Figure 4.1 The standards relevant for SMART Real-Time Yard Management System](image)

### 4.3.1 RailML

There is a growing need for efficient data exchange in railways. Today these types of data incompatibility problems are being addressed using "open and universally usable data formats". Such formats are generally developed using the eXtensible mark-up language (XML) as a basis (e.g. MathML for mathematical expressions and GML for geographical data).

XML was developed by the World Wide Web consortium. XML is not an application language, but rather a set of rules that can be used to define other “mark-up” languages and therefore functions as a meta language. The major advantage of XML based documents is that they describe both data as well as the data’s structure. Therefore, XML was an ideal solution for transfer and storage of railroad data.
The data transfer problem created as the number of applications increases can be solved by means of EAI (Enterprise Application Integration). EAI enables the collaboration of different programs by creating standard interfaces, which are independent of any given application, but focus on the objects to be exchanged.

The corresponding object descriptions are based on XML syntax.

Effective data exchange between two applications requires that each program include a function for generating XML data (export) and a function for reading in and interpreting XML files (import). Due to both the widespread use of XML and the standardization caused by the World Wide Web, most computer application development platforms include pre-defined libraries and functions for the processing of XML based data, which substantially reduces the time needed to develop import and export functions for creating specialized applications such as for railroads.

RailML is a simple and efficient way to transfer data between computer programs used to model different aspects of railroad operations. Programs using the RailML language produce export files with the RailML structure; these files can then be used directly by other programs. The receiving program parses the incoming file to obtain only the data it needs, which allows many different programs to use the same data file.

The railML.org initiative was founded in early 2002 against the background of the chronic difficulty of connecting different railway IT applications. Its main objective is to enable heterogeneous railway applications to communicate with each other. Today, the connection of various railway software packages is beset with problems. The purpose of the railML.org initiative has been to find, discuss and present systematic, XML-based solutions for simplified data exchange between railway applications.

Since 2002, on the basis of information on the railML.org website, our project partners have been working on the simplification of data links for information exchange between different computer applications. The result has been the development of the Railway Markup Language - railML® - which delivers a universally applicable data exchange format and is thus making a substantial contribution to this simplification.

RailML is a joint, evolutionary project of railway companies, software and consulting firms and academic institutions located in a number of countries.

The RailML specification contains subschemas for four main areas: infrastructure, timetable, rolling stock and interlocking. These topics are themselves further divided into additional subschemas that address more specific areas. Additional RailML-subschemas like for crew rostering, asset management or real-time data are being planned and discussed.

One RailML file can contain several subschemas. The division into subschemas allows each individual RailML-compatible application to apply the parts of the full schema - e.g. the subschemas - in various combinations.

All needed information RailML can be provided in [6] and according to project proposal SMART Real-Time Management System will be able to exchange data via RailML as standardized format.

On the other hand, variety of marshalling yards in operational environment and their IT status necessities SMART Real-Time Management System to provide possibility for flexible transfer to some other channels for exchange data.
4.3.2 Technical Specifications for Interoperability for Telematics Applications for Freight – TAF TSI

In order to make the rail freight transport process easier, different customers, Infrastructure Managers (IMs), Railway Undertakings (RUs), etc. started to develop different IT systems for exchange of data related to the rail freight transport chain.

Tens of such systems can be find across the European railway stakeholders (RUs, IMs, keepers, customers, etc.). Unfortunately, these systems have been developed without close international cooperation, which has caused the non-standardized situation [7]:

- Most IT systems are able to exchange data domestically but not internationally.
- The data/messages are mostly generated with different formats and are not therefore readable by other systems which do not support those formats.
- Each system was built with different aims, some focused on operations and management of wagons, while others are with the focus on business processes.

This situation implies that nowadays we have a lot of different systems for data exchange in rail freight traffic, but generally they are not able to communicate with each other and there is no standardized environment for data exchange.

This situation is incompatible with the objectives of EU rail policy, because the EU is creating interoperability between the different national legacy systems through technical harmonization [7].

The concept of interoperability and how to achieve it is set out in European Directive 2008/57/EC [8] on the interoperability of the rail system within the EU. These conditions are specified in the respective TSI (technical specification for interoperability) for each of the followings subsystems [9]: infrastructure, energy, control-command and signaling, rolling stock (structural subsystems) and traffic operation and management, maintenance, telematics applications for passenger and freight services (functional subsystems).

This means that the TAF TSI is part of a comprehensive legal framework to facilitate interoperability at technical and operational levels.

It includes in particular [10]:
- applications for freight services, including information systems (real-time monitoring of freight and trains),
- marshalling and allocation systems, whereby under allocation systems is understood train composition,
- reservation systems, whereby here is understood the train path reservation,
- management of connections with other modes of transport and production of electronic accompanying documents.

The „Technical Specifications for Interoperability for Telematics Applications for Freight” - TAF TSI was issued as Commission Regulation No 62/2006. This Regulation has been replaced by Regulation no 1305/2014, known as the revised TAF TSI.

TAF TSI was developed with aim to facilitate the international exchange of information on rail-freight services [7], [10]. It sets the functional and technical standards (mainly content and format of data) for exchanging information between IMs, RUs and other stakeholders. The goal of such a uniform exchange of information should be in increasing efficiency, service quality, reducing freight handling costs and providing better customer information. There is no direct data transmission from the subsystem Telematics Applications for Freight Services into the train, to the driver or to parts of the Control Command and Signaling subsystem and the physical transmission network is a completely different one from the network used by the Command Control and Signaling subsystem.
TAF TSI takes into account the present service providers and the various possible service providers of the future involved in freight transport such as (this list is not exhaustive) [10]:

- Wagons
- Locomotives
- Drivers
- Switching and Hump shunting
- Slot selling
- Shipment management
- Train composition
- Train Operation
- Train monitoring
- Train controlling
- Shipment monitoring
- Inspections & Repair of Wagon and/or Locomotive
- Customs clearance
- Operating Intermodal Terminals
- Haulage management.

The TAF TSI is structured into the following 7 chapters:
1) Introduction – defines technical and geographical scope as well as content of the TSI.
2) Definition of subsystem/scope – specifies functions within the TSI/outside the TSI and gives an overview of the subsystem description.
3) Essential requirements – specifies which essential requirements the TAF system must meet (safety, reliability and availability etc.).
4) Characterization of the subsystem – describes the TAF subsystem, especially the functional and technical specifications.
5) Interoperability constituents – this chapter is not relevant to TAF subsystem as there are no interoperability constituents determined as far as the subsystem TAF is concerned.
6) Assessment of conformity and/or suitability for use of the constituents and verification of the subsystem – this chapter is also not relevant for TAF subsystem.
7) Implementation – sets out the practical steps for implementation of TAF TSI.

The TAF TSI includes several technical annexes, which describe the provisions from Chapter 4 [11]:
- ERA-TD-100: TAF TSI - Annex A.5: Figures and Sequence Diagrams of the TAF TSI Messages
- ERA-TD-102: TAF TSI - Annex D.2 : Appendix B - Wagon and intermodal unit operating database (WIMO)

The TAF TSI concentrates on operational interoperability in rail freight transport. The interoperability of telematics applications is intended to support transport processes. The concept of creating the uniform data exchange platform for rail freight traffic within the EU in accordance with TAF TSI is summarized in Chapter 4 and consists of the followings points [10]:

TAF TSI prescribes processes and protocols for data exchange for the following functionalities:
- Consignment note data
- Path request
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- Train preparation
- Train running forecast
- Service disruption information
- Train location
- Shipment Estimated Time of Interchange/Arrival
- Wagon movement
- Interchange reporting
- Data Exchange for Quality Improvement.

The TAF TSI processes are shown in Fig. 4.2.

![Figure 4.2 TAF/TSI processes [12]](image)

The TAF TSI also prescribes the creation of various databases, which serve different purposes in the overall concept of TAF TSI. The databases which must be implemented by different entities involved in TAF TSI are [10]:

- **Infrastructure Restriction Notice Database** - specifies all the restrictions on the network. This database has been removed from the revised TAF TSI.
- **Reference files** – contains unique location ID, company ID, etc. across the EU to identify uniquely the actors and locations within the TAF TSI.
- **Rolling Stock Reference Database** - contains administrative and technical data about the wagons.
- **Wagon and Intermodal Unit Operational Database (WIMO)** - used for the storage and provision of the data needed for operational purposes and for the tracking of wagons.
- **Trip plan for wagon/intermodal unit** – used for dynamic trip planning.

In subchapter 4.2.11.3. of TAF TSI 22 requirements on the Databases are listed.

**Common interface** [7], [10]

In rail freight operation there are different IT systems generating messages with different formats. TAF TSI therefore prescribes the mandatory use of a so-called common interface. Using this should
ensure that all systems which are needed to implement TAF TSI (RUs, IMs internal legacy systems, databases, etc., see figure 2) can communicate with each other through a standardized message format. As a common interface is used, the non-standardized legacy systems can continue to be used. The common interfaces transform the legacy system’s output to a standardized TAF message format in which it can be understood as input to other, previously incompatible, legacy systems. The common interface should ensure:
- the appropriate formatting, conformity checking, encrypting, signing, addressing and decrypting of the exchanged messages
- the appropriate access to all the data required according the TSI within each RU, IM, etc., whether the relevant Databases are central or individual.

![Figure 4.3 Common interface of TAF TSI [11]](image)

**Implementation of TAF TSI [7], [10]**

The implementation of TAF TSI is a very complex process and it requires the cooperation and involvement of many different stakeholders from the railway area across the EU. The implementation according to the initial master plan did not go well, as the railway stakeholders were not able to meet the implementation dates. The European Commission therefore accepted a new consolidated Master Plan to replace the old one (from 2007). The plan was published in May 2013 and sets final dates when each functionality within TAF TSI should be implemented. According to it, full implementation of TAF TSI is expected by 2021, although without the TID (Train Identification) most of the functionalities should be implemented by 2018. Some projects have already been finished.

Many legacy IT systems at RUs and IMs are now being updated in order to comply with TAF TSI requirements. Implementation is generally achieved in the following steps:

1. Adjusting the national IMs’ and RUs’ IT systems to TAF TSI
2. Installation of the common interface
3. Implementation of the prescribed supporting databases.

There are many actors involved in the implementation of TAF TSI, who have different roles, such as: monitoring TAF TSI implementation, development of products in accordance with TAF TSI, financing the development, development of the product on their own initiative, etc.
Besides the monitoring of implementation, the European Commission now co-finances some of the products which are being developed in accordance with TAF TSI.

The UIC was tasked with developing the common interface and reference files. These essential parts of TAF TSI are developed inside the so-called Common Component Group by UIC.

There is also RailNet Europe (RNE), which is a system for cooperation between European IMs. They joined forces in order to develop platforms for the international exchange of information. Their products, such as the Train information system (TIS RNE) and Path coordination system (PCS RNE), are now a vital part of the practical implementation of TAF TSI.

An association of European RUs called RAILDATA maintains the applications such as ORFEUS and USE-IT. Those platforms also became standard tools for the practical implementation of TAF TSI among the European RUs.

The UIP has initiated the development of RSRD, which not only complies with TAF TSI, but also provides some additional data.

**Scope of the TAF TSI**

Chapter 1.2 (Geographical scope) of the TAF TSI states that [10]: “The geographical scope of this TSI is the trans-European conventional rail system as described in Annex I to the Directive 2001/16/EC. But this TSI may also be applied to the complete freight transport rail network of the Member States of the EU, with the restriction that the requirements of this TSI are not mandatory for freight transport arriving from or going to a non EU country.”

**Revised TAF TSI Regulation No 1305/2014**

On January 1\(^{st}\) 2015 new regulation No 1305/2014 entered into force, known as revised TAF TSI. The main changes introduced in the revised TAF TSI (Regulation No 1305/2014) in comparison to the 1\(^{st}\) TAF TSI (Regulation No 62/2006) could be summarized in following points [7]:

- Broadening the Geographical and technical scope: TEN network + Off-TEN network
- Removal of detailed definition of messages within the legal text
- Introducing the new TAF/TAP national contact points
- Reinforcement of the role of Freight customer within the regulation
- Deletion of some messages, functionalities withdrawn (Infrastructure restriction notice database)
- Extraction of the sequence definition for train running forecast and shipment ETI/ETA
- Better alignment with TAP TSI and OPE TSI.

**Benefits of TAF TSI**

More specifiable the benefits of TAF TSI are:

- Simplifying the train/cargo handover processes. Simplified, seamless data exchange, i.e. simplified data handover, implies also an easier train or cargo handover. Through its unique representation and interpretation, the receiving side instantly recognizes the data, and therefore also the train or cargo may be accepted without unnecessary delay.
- Opening competition among Information and Communications Technology (ICT) vendors means also pushing down the prices of ICT. As the data exchange is not driven by proprietary, closed standards anymore (which are often hard to get documented from the original vendor), the new ICT systems and components may be purchased from an arbitrary vendor, only on the condition of the standards implementation.
- Shortening the handover and/or dwell times of the trains means less idle times and lower losses on dwell for the Railway Undertakings (RU) or operator (more efficient usage of train paths, vehicles, staff etc., and therefore increasing capacity and reducing costs).
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- That way a better utilization of the vehicles and other resources is achieved, which leads again to increased capacity and higher cost efficiency and pushing the prices for the end customer down.

For a long time, the aspect of real-time data within the TAF TSI was limited on real-time monitoring of freight and trains. Nevertheless, the TAF TSI is a living concept and will be further developed.

**Messages of TAF TSI [10]**

The messages are structured into two data sets:

- Control data: defined through the mandatory message header of the messages of the data catalogue.
- Information data: defined by the mandatory/optional content of each message and mandatory/optional data set in the data catalogue.

**4.3.3 Marshalling yard related processes of TAF TSI**

Listed below are almost all functionalities and related messages of TAF TSI, which have direct or indirect relation to marshalling yard processes. Those of them, which have higher importance for marshalling yard processes, are described more detailed.

**Consignment note data.**

- Customer Consignment Note
  
  Selected data of the consignment note data must also be accessible for all partners (e.g. IM, Keeper, etc.) in the transport chain including customers. These are especially per wagon:
  - Load weight (Gross weight of the load),
  - CN/HS Number,
  - Dangerous goods information,
  - Transportation unit.

  Exceptionally a paper version can be used only if this information cannot be sent using the messages defined above.

- Consignment orders

**Path request. It comprises following messages:**

- Path Request (RU -> IM)
- Path Details (IM -> RU)
- Path Confirmed (RU -> IM)
- Path Details Refused (RU -> IM)
- Path Cancelled from (RU -> IM)

**Train preparation.**

This basic parameter describes the messages which must be exchanged during the train preparation phase until the start of the train. Train preparation includes compatibility check between the train and the route. This check is done by the RU on basis of information provided by concerned IMs on infrastructure description and infrastructure restrictions.

During train preparation the RU must send the train composition to the next RUs. According to contractual agreements this message must also be sent from the RU to the IM(s) with whom it has contracted a path section.
If the train composition is changed at a location, this message must be exchanged once more with information updated by the RU responsible. For the preparation of the train, the RU must have access to the infrastructure restriction notices, to the technical wagon data from The Rolling Stock Reference Databases, to the information on dangerous goods and to the current, updated information status on the wagons. This applies to all wagons on the train. At the end the RU must send the train composition to the next RUs.

This message must also be sent from the RU to the IM(s) with whom it has booked a path section, when requested by the Conventional Rail TSI Operation and Traffic Management or by the contract(s) between RU and IM(s).

If the train composition is changed at a location, this message must be exchanged once more with information updated by the RU responsible. At each point, e.g. origin and interchange point, where the responsibility changes on the RU side, the start procedure dialogue between IM and RU ‘Train ready — Train Running Information’ is obligatory.

Figure 4.4 Train preparation I

Figures 4.3 and 4.4 illustrate the Train preparation process and related messages send between RU and IM.
Train Composition message

This message must be sent from the RU to the next RU, defining the composition of the train. According to network statement this message is also to be sent from the RU to the IM(s). Whenever there is a change in the composition during the journey of a train, the RU that makes the change has to update this message to LRU, which informs all parties involved.

The definition of the mandatory structure of Train Composition message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ and illustrated in Fig. 4.5.

Minimum elements to be delivered for the message exchange between RU and IM for the purpose Train Composition are defined in Chapter 4.2.2.7.2 of Decision 2012/757/EU, OPE TSI.
Train Ready message

The railway undertaking shall send a ‘train ready’ message to the infrastructure manager every time a train is ready to start after train preparation, unless under national rules the infrastructure manager accepts the timetable as a ‘train ready’ message. The definition of the mandatory structure of Train Ready message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ listed in Appendix I. In addition, other existing standards may be used for the same purpose if the parties involved have concluded a specific agreement allowing these standards to be used.

To deliver the Train Composition of a train RU needs:
- the infrastructure restriction notices
- the technical wagon data (Rolling Stock Reference Database -RSRD)
- the dangerous goods reference file
- the updated information status of the wagons (Wagon and Intermodal Unit Operational Database –WIMO)

Train running

- Train Running Information Message

Figure 4.6 illustrates the communication links between IM and RU running the train. The “Train Running Information Message” includes information concerning departure from departure point and arrival at destination as well as arrival and departure at handover points, interchange points and at agreed reporting points based on contract (e.g. handling points). In case of delay, its cause (first assumption) must be sent in a separate “Train Delay Cause Message” as soon as it is identified.

![Communication links between IM and RU running the train](image)

Service disruption information

- Delay Cause Message

Wagon/Intermodal unit ETI/ETA, Shipment Estimated Time of Interchange/Arrival (ETI/ETA)

ETA for the shipment is the most important information for a customer. The ETA for the Wagon must be sent by RU to the LRU. The ETA must be electronically stored along with wagon movement. For each wagon the Lead RU must establish/update a wagon trip plan:
- Trip plan for wagon / Intermodal unit
Wagon Trip Plan Databases
- Wagon Exception Reason ETI/ETA_Request
- Wagon ETA/ETI Message

For the reporting of the movement of a wagon, the following data must be stored, sent and received by the WIMO:

- **Wagon Release Notice message**
  The Lead RU is not necessarily the first RU in the transport chain. In this case the LRU must tell the RU in charge that the wagon is ready for pull at the customer sidings (Place of departure according to the LRU commitment) at the given release time (date and time of departure). These events must be stored in the Wagon and Intermodal Unit Operational Database. The definition of the mandatory structure of Wagon Release Notice message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ listed in Appendix I.

- **Wagon Departure Notice message**
  The RU must inform the LRU of the actual Date and Time that the wagon has been pulled from the place of departure. These events must be stored in the Wagon and Intermodal Unit Operational Database. With this message exchange the responsibility for the wagon changes from customer to the RU. The definition of the mandatory structure of Wagon Departure Notice message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ listed in Appendix I.

- **Wagon Yard Arrival message**
  The RU must inform the LRU, that the wagon has arrived at its yard. This message can be based on a ‘Train running information’ message from Chapter 4.2.4 (Train Running Forecast). This event must be stored in the Wagon and Intermodal Unit Operational Database. The definition of the mandatory structure of Wagon Yard Arrival message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ listed in Appendix I.

- **Wagon Yard Departure message**
  The RU must inform the LRU, that the wagon has left its yard. This message can be based on a ‘Train running information’ message from Chapter 4.2.4 (Train Running Forecast). This event must be stored in the Wagon and Intermodal Unit Operational Database. The definition of the mandatory structure of Wagon Yard Departure message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ listed in Appendix I.

- **Wagon Exception message**
  The RU must inform the LRU if something unexpected occurs to the wagon, which might have an impact for the ETI/ETA, or requires any additional action. This message requires in most of the cases also a new ETI/ETA calculation. If the LRU decides to have a new ETI/ETA, it sends a message back to the RU, which has sent this message together with the indication ‘ETI/ETA requested’ (message: Wagon Exception message New ETI/ETA Request). The new ETI/ETA calculation must follow the procedure of Chapter 4.2.6 (Shipment ETI/ETA). This information must be stored in the Wagon and Intermodal Unit Operational Database. The definition of the mandatory structure of Wagon Exception message and the elements to be followed are described in the document ‘TAF TSI — Annex D.2: Appendix F — TAF TSI Data and Message Model’ listed in Appendix I.

- WagonArrivalNotice
- WagonDeliveryNotice
Interchange reporting.
The interchange reporting describes the messages attached to the transfer of responsibility for a wagon between two railway undertakings, which occurs at interchange points. It also commands the new RU to make an ETI calculation and to follow the process as described in Shipment ETI/ETA. The following messages must be exchanged:
— Wagon Interchange Notice,
— Wagon Interchange Sub Notice,
— Wagon Received At Interchange,
— Wagon Refused At Interchange.

4.3.4 Other standards related to marshalling yard management

Other standards not directly related to marshalling yard management as TAF TSI, but with possible application, e.g. timetable exchange, are described below. On one side these are:

- EN 12986: 2006 “Road transport and traffic telematics – Public transport – Reference data model (Transmodel V5.1)” and

Based on these two European standards, the European Committee for Standardization (CEN) published in 2014 the specification “Public transport - Network and Timetable Exchange (NeTEx)” for the harmonization of various standards that support public transport data exchange between interested parties.

NeTEx should facilitate interoperability between IT systems of involved parties by [12]:
- Introducing common architectures for message exchange;
- Introducing a modular set of compatible services for real-time vehicle information;
- Using common data models and schemas for the messages exchanged for each service;
- Introducing a consistent approach to data management.

On the other side, it complements and therefore may be used in combination with “CEN/TS 15531-1 to 5: 2011 Public transport – Service interface for real-time information relating to public transport operations (SIRI)”.

SIRI was first published in 2006 in 3 parts as the Technical Specification and became a CEN Technical Standard in 2007. Two further parts extended it in 2011. Since 2013, part 1 to 3 are published as draft European Standard (prEN 15531) that are intended to supersede the CEN/TS 15531 documents of 2007.

SIRI provides a framework for specifying communications and data exchange protocols in order to exchange real-time information related to public transport operations. SIRI is designed as a modular and expandable standard that uses XSD schemas [12].
4.4 Optimization of processes in marshalling yards

Regarding MAAP, the overall concept of real-time yard management focuses on the simulation of interdependencies to understand capacity-relevant links on developing a tool that allows orchestrating disposition processes in hubs in real-time. The aim is to improve customer quality and reduce operating costs. For planning and disposition in yards, current IT systems in use administer the relevant resources required to steer trains through these important hubs of the system. In the focus are “Real-time Yard Management” processes in the marshalling yard will be optimized, allocating the existing resources in the yard optimally in real-time. The development of the overall optimization tool and simulation model for yard management, in order to adequately steer resources in rail freight yards, will take into account the new available automated handling systems and the possible different levels of automation. This is the consequent further development of the IT-supported processes using the existing data.

In the status quo, yards are a black box for operators and transport customers, due to stand-alone systems for yard planning only. On top of this, rolling stock, personnel and track infrastructure are planned completely separately within historical legacy systems. There is little transparency of planned resources: Neither integrated resource disposition, nor a real-time view, nor overall optimization of resource allocation is possible. Disposition of assets and personnel is being based exclusively on experience of planners and dispatchers who are still regarding each other as separate functions and not using the same information system.

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. In order to design and implementation of Optimization module some preconditions are needed. It is shown in Fig. 4.8.

![Figure 4.8 Preconditions for designing Optimization module](image-url)
Advance beyond state of the art is machine-learning based decision system that can give optimal or near-optimal solution for marshalling yard operations in real time. According to sorting methods detailed described in D4.1 characteristics of each individual marshalling yard adequate model will be assigned to each yard. In order to choose the optimal marshalling yard model with a maximum savings of time sorting, selected models will be firstly tested using Monte Carlo simulation method. Using Monte Carlo experiments will enable us to choose the mathematical model. Using the most appropriate yard model will allow maximal sorting time reduction as well as the sorting costs.

Developed models can then be used for marshalling yard operations optimization. In our research we suggest determination of the best heuristic or meta-heuristics optimization algorithm (regardless the time of optimization), based on pre-defined criteria and one of the multi-criteria decision methods. This optimization cannot give real-time solution for marshalling yard management, so in our work we suggest using the optimization results as a training data for machine learning decision system. The trained machine learning system will then give the optimal or near-optimal solution of marshalling operations in real time. The concept solution for Optimization module is shown in Fig. 4.9.

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 4.9 Concept solution of Optimization module

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.

Figure 4.10 Risk analysis of optimization
The good design of optimization module faces with many risks. In Fig. 4.10 short risk analysis is presented.

Working Package 5 deals with modeling processes and optimization of marshalling process in scope. Deliverable D5.3 Algorithms for modeling 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. LIST OF REQUIREMENTS FOR REAL TIME MARSHALLING YARD MANAGEMENT SYSTEM

5.1 Introduction

Timetable of freight trains i.e. the freight train formation plan aims to ensure a speedy delivery of the goods, and better use of the wagons, most appropriate distribution of marshalling work, reducing the manoeuvring work and the achievement of economically viable shipping routes of wagon flows.

The optimum plan of forming trains in freight yard is calculated for single-group, multigroup, express, fast, trains made up of empty trains etc. Ordering in determining the plan of formation of trains is:

- Preparation of the planned flows of loaded and empty wagons and determine their correspondence between the freight yards;
- Determining the train mass for certain routes;
- Developing a plan of forming block trains for loading places;
- Developing a plan for forming the trains on the freight yards;
- Harmonization of the plan of formation with capacity of freight yards and the railway sections;
- Harmonization of plan formation trains with graph of total traffic;
- Development of measures to ensure the execution of the plan of train formation.

The final version of the plan of train formation shall be determined by taking into account the throughput and the processing capacity of the freight yard. In doing so, wagon should be taken to keep a certain reserve in the throughput and the processing capacity of the yard in case of increasing wagon flows, or to mitigate the uneven traffic.

Considering the possibility of increasing the volume of wagon flows it is possible to foresee the use of so-called additional freight yards at certain periods of time. These yards take up part of the marshalling work of the Marshalling yard when they occur congestion. At the time of decreasing the intensity of wagon flows, it is purposeful instead single-group to form multigroup trains. Organizing multigroup trains can significantly reduce the retention of wagons in station for accumulation of wagons in train, which increases the speed of transport of goods, but also increase expenses due to increased shunting work on the formation of the train.

It is necessary to periodically perform analyses of the execution plan for forming trains and making correction for improvements.

Basic indicators of work in Marshalling yard are quantities of freight and number of loaded / unloaded the wagons, the retention time of transit wagon at the yard, wagon traffic, the number of arrived and departured trains and wagons, the percentage of execution of train traffic charts, costs, productivity and so on.

During the development of the daily work plan of marshalling yard, i.e. chart of work of yard are taken into account technological times for the execution of the basic technological operations. Considering the available technical resources and facilities in the yard, the level of automation of work processes and the available human resources are determining the technological time for each specific marshalling yard.
Basic technological parameters that are characterizing compliance of work in Marshalling yard are [13]:

- Intensity of basic operations in Marshalling yards (intensity of trains in arrive, intensity of trains in departure, intensity of disassembling/assembling trains, intensity of accumulation of wagons, etc.)
- Intervals between basic operations (intervals between trains that are arriving in yard and that are departing from the yard; intervals between operations for disassembling and forming the trains; intervals of accumulations of wagons etc.)
- Technological norms of basic operations (technological norms of times for disassembling-assembling trains, technological norms of times for forming the trains, technological norms of times for processing trains in receiving/departure park, etc.)
- Times of occupancy of sidings with train that have arrived/departure or some other trains.
- Intervals between technological operations (retentions due to waiting period of following operations like train waiting in arrive or departure park, waiting for disassembling and forming trains, etc.)

In order to perform optimal marshalling yard management data that should be considered are as following:

- Timetable of incoming and outgoing trains
- Trip planes of wagons
- Roster of the required staff categories at marshalling yards
- Regular schedule of marshalling, shunting and check activities at marshalling yards
- Lack of assets against the regular schedules
- Any significant actual and/or proposed deviations of the scheduled operations
- Layout (infrastructure) of the marshalling yard and available equipment
- Relevant characteristics of technical assets and qualifications of the staff
- Relevant load characteristics (weight, dangerous goods)
- Rules and restrictions for the operation’s performance.

Essentially, for real-time marshalling yard management system are required two parameter types (Fig. 5.1):

- Dynamic parameters: freight transport that is going through marshalling yard and temporary restrictions in work
- Static parameters: marshalling yard infrastructure – all parameters that are making up capacity of a marshalling yard as well as all limitations that are restricting the use freight transport in the marshalling yard
5.2 Dynamic parameters

Dynamic parameters consist all the information that considers the use of yard on daily base. This is defined by freight train timetable which is defined on country level and on yearly base. Here belongs also temporary restriction in work of marshalling yard. Temporary restrictions are reality in work of marshalling yard and they cannot be predicted. Operator on real-time marshalling yard software has to have options to disable some function as it is happening in reality. For example, it can be malfunction of the single siding or reduction in capacity of railway traffic direction.

There are number of rules defined in Traffic regulations that are used in work of marshalling yard management. In the composition of the train, it is necessary that wagon should be: valid and capable for traffic (technically correct, properly loaded, capable for appropriate speed, type of braking, etc.). The vehicles must not exceed the permissible gross vehicle weight per axle, load per unit of length and load profile of the respective tracks (Table 5.1). Higher gross vehicle weight shall be placed, in principle, to the front of the train.

Table 5.1 Mass per axle according to UIC CODE 700

<table>
<thead>
<tr>
<th>mass per m=p</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>16t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.5t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 t/m</td>
<td>A</td>
<td>B1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4 t/m</td>
<td></td>
<td>B2</td>
<td>C2</td>
<td>D2</td>
<td></td>
</tr>
<tr>
<td>7.2 t/m</td>
<td></td>
<td>C3</td>
<td>D3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 t/m</td>
<td></td>
<td>C4</td>
<td>D4</td>
<td>E4</td>
<td></td>
</tr>
<tr>
<td>8.8 t/m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E5</td>
</tr>
</tbody>
</table>

Heavyweight vehicles, individual or in a group, are still placed in the front of the train in front of the other wagons. Lightweight vehicles are placed at the end of the train.

Wagons are placed in order of the intermediate stations for pick-up goods, station and circuit-working freight trains. If with these trains are dispatched and heavy vehicles, then it is incorporated into
the front of the train in front of the other wagons. If with these trains are dispatched and light vehicles, then it is for the relevant station placed at the end of the train.

5.2.1 Flow Data

Flow data parameters are directly connected to freight transport that is realized on the marshalling yard. It is also defined by traffic planning - timetable and scheduling on year level. Flow data is determined by the timetable of freight trains. The schedule of freight trains is established on year base in the whole railway network on national level and it is harmonized with the international timetable. In the timetable of freight trains are regular and optional train lines. Exact composition of regular trains as well as arrival and exact composition of optional trains is known on the day when trains are expected to arrive at marshalling yard. Also, a number of trains are formed in the marshalling yard according to timetable. In the year work plan of marshalling yard are provided marshalling yard capacities for execution of shunting activities. If necessary, the introduction of new trains into traffic is done in accordance with established routes of optional trains that do not run or on new route within the available capacity of railway lines. Optional trains have determined the route of movement that are reserved for them.

Table 5.2 Flow data parameters

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Train type</strong></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. This parameter is important for determination of priority activities in Marshalling yard.</td>
</tr>
<tr>
<td><strong>Train number</strong></td>
<td>This parameter is giving general information about the train (D4.1 7.1 Train classification)</td>
</tr>
<tr>
<td><strong>Dispatch time of starting station</strong></td>
<td>This parameter is giving information about possible deviation in regard to Timetable</td>
</tr>
<tr>
<td><strong>Train weight per axle</strong></td>
<td>This parameter is required for calculating the maximal possible vehicle axle load and the maximum load. (Limitations of railway traffic direction)</td>
</tr>
<tr>
<td><strong>Train mass in tones</strong></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.</td>
</tr>
<tr>
<td><strong>Train length in meter</strong></td>
<td>This parameter is required for estimating the maximal possible train length. (Limitations of railway traffic direction)</td>
</tr>
<tr>
<td><strong>Train composition</strong></td>
<td>Load type (full/empty)</td>
</tr>
<tr>
<td><strong>Wagon series and subseries</strong></td>
<td>This parameter defines wagon type - technical-exploitation characteristic</td>
</tr>
<tr>
<td><strong>Number of wagon axles</strong></td>
<td>This parameter is required for calculating the maximal possible vehicle axle load and the maximum load. (Limitations of railway traffic direction)</td>
</tr>
<tr>
<td><strong>Wagon length</strong></td>
<td>This parameter is used in calculation of train length</td>
</tr>
<tr>
<td>Wagon mass</td>
<td>This parameter is used in calculation of train mass</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Net mass of cargo in wagon</td>
<td>This parameter is used in calculation of train mass</td>
</tr>
<tr>
<td>Braked weight</td>
<td>This parameter is important for calculation of train braking characteristics</td>
</tr>
<tr>
<td>Type of cargo</td>
<td>Load type (is there special type of load that needs special treatment)</td>
</tr>
</tbody>
</table>

5.2.2 Restrictions and deviations

Restrictions and deviations are happening at Marshalling yard and they are problematic for parameterization while every marshalling yard has their own specifics.

Marshalling yard management system has to have possibility to limit some parameters (static parameters) as possible restriction of Marshalling yard. These parameters directly decrease the capacity of marshalling yard.

One the other hand, the deviations are the part of everyday life at marshalling yard. These deviations are related to the Timetable - flow data parameters (dynamic parameters). Real-time marshalling yard system has to include:

- Changes of the planned sequence of incoming trains
- Acceptance of delay from outgoing trains in order to ensure wagon transit according the trip plans of wagons
- Changing the sequences of planned shunting operations (Manoeuvring, use of sidings, sorting methods…)
- Change assignment of staff to trains/processes

5.3 Static parameters

Static parameters are considering capacity of marshalling yard and it depends from geographical location within the railway network, building infrastructure – layout data (number of sidings, siding length, yard connections etc.), equipment (hump, retarders, shunting locomotives) and operative times. These parameters are changed very rarely, and for them are needed big investments and for real-time marshalling yard management can be considered as static parameters.

5.3.1 Yard connections – Railway routes

Yard connections – railway routes parameters are considering geographical location within the railway network (Table 3). Railway routes can limit the trains in one railway traffic direction with infrastructure limitations like maximal allowable mass per axle (Table 1); maximal allowable train length and mass, etc.

### Table 5.3 Yard connections – Railway routes parameters

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway traffic directions</td>
<td>Number of origins and destinations of the traffic through the yard.</td>
</tr>
<tr>
<td>Limitations of railway traffic direction</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.</td>
</tr>
</tbody>
</table>
5.3.2 Operative Times

Main operations that are performed in marshalling yards are:

- Arriving and checking incoming trains
- Disassembling/assembling trains
- Wagon shunting within the yard
- Throwing wagon using the hump and/or the locomotive
- Checking and departure outgoing trains.

In addition there are a number of partial activity of these main operations. Necessary time for each activity is need to know in order to determine the marshaling yard capacity [13].

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean time for the preparation of a wagon in the reception sidings</td>
<td>It is the operative time for wagons uncoupling.</td>
</tr>
<tr>
<td>Mean time lost in the reception sidings</td>
<td>It is the waiting time for documents exchange and train identification.</td>
</tr>
<tr>
<td>Mean time for preparation of a wagon in the direction sidings</td>
<td>It is the operative time for wagons coupling.</td>
</tr>
<tr>
<td>Mean time for commercial inspection of wagon</td>
<td>This parameter is required for calculating the capacity of the yard</td>
</tr>
<tr>
<td>Mean time for technical inspection of wagon</td>
<td>This parameter is required for calculating the capacity of the yard</td>
</tr>
<tr>
<td>Mean time for uncoupling and departure of train locomotive</td>
<td>It is the operative time for train locomotive uncoupling.</td>
</tr>
<tr>
<td>Mean time for creating shunting lists</td>
<td>This parameter is required for calculating the waiting time before the shunting activities.</td>
</tr>
<tr>
<td>Mean time to receive orders from the marshalling yard control office</td>
<td>This parameter is required for calculating the waiting time before the manoeuvres.</td>
</tr>
<tr>
<td>Mean time for uncoupling the wagons and preparation composition for maneuver</td>
<td>This parameter is required for calculating the capacity of the yard</td>
</tr>
<tr>
<td>Mean time between throwing</td>
<td>This parameter is required for calculating the maximum potential of the hump or shunting locomotive.</td>
</tr>
<tr>
<td>Mean time for shunting the group of wagons</td>
<td>It is the average operative time for shunting the group of wagons.</td>
</tr>
<tr>
<td>Mean time for forming the single group train</td>
<td>It is the average operative time for forming one single train.</td>
</tr>
<tr>
<td>Mean time for forming the two groups train</td>
<td>It is the average operative time for forming two group train.</td>
</tr>
</tbody>
</table>
In process of forming the time table of freight trains it is necessary to know the capacity of shunting yards in railway node. In accordance with that analysis of marshalling yard capacity shall be conducted and useful information are: mean number of trains daily treated, mean mass towed of incoming/outgoing trains, mean number of shunted wagons.

Operating times parameters are all mean time. This means that in some processes can be done in real-time with delays and cause deviations in operations. This all has to be taken into account as possible deviations as it is explained in 5.2.2.

5.3.3 Layout data

Layout data consists of infrastructural parameters regarding sidings that are defining capacity of a Marshalling yard.

Table 5.5 Layout data

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups of sidings on the marshalling yard</td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td>Number of sidings per group</td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td>Siding purpose</td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td>Length of sidings</td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td>Siding type (one-sided or both-sided)</td>
<td>This parameter is required for calculating the capacity of the yard.</td>
</tr>
<tr>
<td>Mass limit per axle</td>
<td>This parameter is required for calculating the allowable vehicle axle load and the maximum load.</td>
</tr>
</tbody>
</table>

5.3.4 Equipment and others parameters

Shunting locomotives are mobile elements of a Marshalling yard. Shunting locomotives, their type and power, are limitation of the single shunting process. Important parameter for shunting is the length of operative shunting siding.
Table 5.6 Equipment and others parameters

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number and type of shunting locomotives</td>
<td>This parameter is required for calculating the shunting process.</td>
</tr>
<tr>
<td>Operative length of shunting siding</td>
<td>This parameter is required for calculating the shunting process.</td>
</tr>
<tr>
<td>Number and type of hump retarders</td>
<td>This parameter is required for calculating the shunting process.</td>
</tr>
<tr>
<td>Number of operators per function</td>
<td>This parameter is required for calculating the shunting process.</td>
</tr>
<tr>
<td>Level of automation of switches and communication</td>
<td>This parameter is required for estimation the shunting and marshalling yard processes.</td>
</tr>
</tbody>
</table>
5.4 Questionnaire form

In this subchapter, the questionnaire form for marshalling yards is presented. This form is the basis for forming database of EU marshalling yards. Defined data in Questionnaire form provide enough potential information for following project activities. Questionnaire form is substantial part of WP5 - Task 5.2 Collecting the data from EU marshalling yards.

Collecting and gathering data from different marshalling yards is the process of high importance for validation real-time optimization algorithms. On the other hand, regarding the risk analysis, it is one of the high risk process marked as milestone of the whole project.

That is forming Questionnaire form just first step in creating relevant information database that can be usable for testing different scenarios and different algorithms in WP5.

Yard connections – Railway routes parameters

<table>
<thead>
<tr>
<th>Railway traffic direction 1</th>
<th>Direction</th>
<th>Limitations of railway traffic direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway traffic direction 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railway traffic direction 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Operative time

<table>
<thead>
<tr>
<th>Mean time for the preparation of a wagon in the reception sidings [min]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean time lost in the reception sidings [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for preparation of a wagon in the direction sidings [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for commercial inspection of wagon [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for technical inspection of wagon [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for uncoupling and departure of train locomotive [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for creating shunting lists [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time to receive orders from the marshalling yard control office [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for uncoupling the wagons and preparation composition for maneuver [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time between throwing [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for shunting the group of wagons [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for forming the single group train [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for forming the two groups train [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for forming the three groups train [min]</td>
<td></td>
</tr>
<tr>
<td>Working hours of the yard [h]</td>
<td></td>
</tr>
<tr>
<td>Mean time for arrival and coupling of train locomotives [min]</td>
<td></td>
</tr>
<tr>
<td>Mean time for forming a journey report that are submitted to the train staff [min]</td>
<td></td>
</tr>
</tbody>
</table>

**Layout data**

| Groups of sidings on the marshalling yard |  |
| Number of sidings per group |  |

<table>
<thead>
<tr>
<th>Siding</th>
<th>Operative length [m]</th>
<th>Siding group</th>
<th>Siding purpose</th>
<th>Siding type (one-sided or both-sided)</th>
<th>Mass limit per axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siding 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siding 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siding 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Equipment and others parameters**

| Number and type of shunting locomotives |  |
| Operative length of shunting siding |  |
| Number and type of hump retarders |  |
| Number of operators per function |  |
| Level of automatization of switches and communication |  |
6. CONCLUSION

In this document, overall framework of real-time marshalling yard management problem is presented. This report Deliverable D4.2 is the second result of activities from WP 4 and presents the background for further activities on WP5 - Modeling and real time simulation of marshalling process and WP6 - Development of web-based information system for supervision and management of marshalling yards. Also, detailed list of needed requirements for real time marshalling yard management system is given.

In addition, questionnaire form for marshalling yard operational requirements further used for data collecting planned in task 5.2 of WP5 is presented.

In the document, three important issues are presented and analyzed. One is marshalling process as decision making process. The second issue is standards to be fulfilled for real-time marshalling yard management system. The third issue is short review of marshalling yard operations optimization. All three issues are inevitable for good optimization of planning operations and managing of local marshalling yard.

As the result of analysis of real marshalling yard, literature review and project demands the list of requirements for real-time marshalling yard management system is presented. Parameters are basically divided on static and dynamic, both very important for providing enough information for establish sustainable and efficient real-time optimization during further SMART activities.
REFERENCES


